

Quantitative Spectrophotometric Analysis of Metoclopramide Hydrochloride in Pharmaceutical Tablets via Bromination Reaction

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Abstract

This study aimed to suggest and validate a simple and sensitive visible spectrophotometric method for the quantification of metoclopramide hydrochloride (MCPH) in its pure form and pharmaceutical tablets. The method uses bromine generated *in situ* by the action of an acid on a mixture of bromate and bromide, which acts as an environmentally friendly brominating agent for the bromination of MCPH. It enables a cost-effective analysis while eliminating the handling of hazardous liquid bromine. The method is based on adding a carefully measured excess of bromate-bromide reagent to MCPH solution in an acidic medium. Upon completion of the reaction, the residual bromine is quantified by reacting it with a fixed amount of methylene blue dye, followed by measuring the absorbance at 665 nm. Under optimal conditions, MCPH can be quantified over a concentration range of 1.25–25.0 µg/mL, with a molar absorptivity of 1.032×10^4 L/mol.cm and a Sandell's sensitivity of 0.0326 µg/cm². Experimental *t*- and *F*-values were calculated and compared with critical tabulated values using Student *t*-test and *F*-ratio at a 95% confidence level, confirming no significant difference between the official and suggested methods in terms of accuracy and precision. The suggested method was successfully applied for the analysis of MCPH in raw material and tablets, and its reliability was confirmed using a standard addition method.

Keywords: Metoclopramide hydrochloride, bromate-bromide mixture, methylene blue, spectrophotometry, pharmaceutical tablets.

التحليل الطيفي الكمي لهيدروكلوريد الميتوكلوبراميد في الأقراص الصيدلانية عبر تفاعل البرومة

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الملخص

هدفت هذه الدراسة إلى اقتراح طريقة طيفية مرئية بسيطة وحساسة والتحقق من صحتها لتقدير كمية هيدروكلوريد الميتوكلوبراميد (MCPH) في شكله النقي وفي الأقراص الصيدلانية. تستخدم هذه الطريقة البروم المُنتَج في الموقع (*in situ*) بتأثير الحامض على خليط من البرومات والبروميد، والذي يعمل كعامل برومة صديق للبيئة لبرومة هيدروكلوريد الميتوكلوبراميد. تتيح هذه الطريقة تحليلاً منخفض التكلفة مع إلغاء الحاجة إلى التعامل مع البروم السائل الخطير والسام. اعتمدت الطريقة على إضافة زيادة مُقاسة بدقة من كاشف البرومات والبروميد إلى محلول الميتوكلوبراميد في وسط حامضي. وبعد اكتمال التفاعل، تم تقدير البروم المتبقي من خلال تفاعله مع كمية ثابتة من صبغة أزرق الميثيلين، ثم قياس الامتصاص عند طول موجي قدره 665 نانومتر. وفي الظروف المثل، يمكن تقدير الميتوكلوبراميد ضمن نطاق تركيز يتراوح بين 1.25 و 25.0 ميكروغرام/مل، بمعامل امتصاص مولاري قدره 1.032×10^4 لتر/مول. سم وحساسية ساندل قدرها 0.0326 ميكروغرام/سم². وتم حساب قيم *t* و *F* العملية ومقارنتها بالقيم الجدولية الحرجة باستخدام اختبار الطالب *t* ونسبة *F* عند مستوى ثقة 95٪، مما أكد عدم وجود فروق جوهرية بين الطريقة المقترحة والطريقة المعتمدة من حيث الدقة والمصادقية. طُبِّقَت الطريقة المقترحة بنجاح لتحليل الميتوكلوبراميد في المادة الخام وفي الأقراص، وتأكدت موثوقيتها باستخدام طريقة الإضافة القياسية.

الكلمات المفتاحية: هيدروكلوريد الميتوكلوبراميد، خليط البرومات والبروميد، أزرق الميثيلين، التحليل الطيفي، الأقراص الصيدلانية

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1. Introduction

Metoclopramide hydrochloride (MCPH), chemically known as 4-amino-5-chloro-N-[2-(diethylamino)ethyl]-o-anisamide monohydrochloride monohydrate, has the chemical structure shown in Figure 1. Its molecular formula is $C_{14}H_{23}Cl_2N_3O_2$ while its molecular weight is 336.26 g/mol. The drug appears as a white or almost white crystalline powder, and it has been reported to be freely soluble in alcohol, very soluble in water, and sparingly soluble in methylene chloride [1].

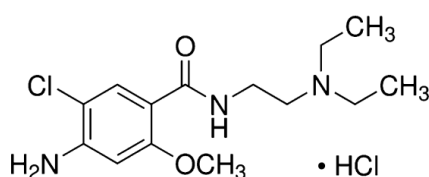


Figure 1. Chemical structure of metoclopramide hydrochloride.

Metoclopramide acts as a dopamine receptor antagonist. It is used to treat and prevent nausea and vomiting. It also influences 5-HT₃ receptors in the gastrointestinal tract, though at concentrations higher than those typically achieved in standard therapy. Although metoclopramide has been partly supplanted by newer related compounds, it remains the most extensively used antiemetic drug of neuroleptic type. Consequently, the most comprehensive understanding of its adverse effects, particularly neuroleptic and endocrine reactions, has emerged from its long-term use. These effects are generally short-lived upon treatment discontinuation; however, the duration of their adverse profile cannot always be fully explained by straightforward pharmacokinetic principles. A review of the evidence for using metoclopramide to treat gastroesophageal reflux in infants led to an inconclusive recommendation for this indication [2].

Literature on the quantitative analysis of MCPH reveals that extensive research has been carried out for the determination of MCPH alone in pharmaceutical products. These investigations include techniques such as high-performance liquid chromatography, ultra-performance liquid chromatography, potentiometry, voltammetry, spectrofluorimetry, chemiluminescence, flow injection analysis, titrimetry, atomic absorption spectrometry, UV spectrophotometry [3-8], and visible spectrophotometry [9-44].

Despite their availability, many of these methods suffer from certain limitations, including the use of expensive instrumentation, complex and time-consuming procedures, extensive sample preparation steps, or the use of toxic organic solvents. Furthermore, several reported visible spectrophotometric methods lack sufficient sensitivity or require critical experimental conditions, which limit their applicability in routine quality control laboratories. To the best of the researchers' knowledge, no previous studies have employed a bromate-bromide (BB) mixture as an environmentally friendly brominating agent for the determination of MCPH in pharmaceutical dosage forms. The present study introduces a simple, sensitive, and environmentally friendly visible spectrophotometric method for the quantification of MCPH in pharmaceutical tablets.

The suggested method is based on the *in situ* generation of bromine from a BB mixture in an acidic medium, which serves as a safe alternative to hazardous elemental bromine. Following the bromination of MCPH, the residual bromine reacts with methylene blue (MB) dye, and the increase in absorbance is measured at 665 nm. This approach offers several distinct advantages over many of the previously reported methods, including simplicity, cost-effectiveness, high sensitivity, elimination of toxic organic solvents, and absence of heating or extraction steps, making

it particularly suitable for routine quality control analysis.

2. Materials and Methods

2.1. Instrument

All absorbance readings were carried out using a V-1000 visible spectrophotometer (AOE Instruments, Shanghai, China) fitted with matched quartz cells of 1 cm path length.

2.2. Reagents and Chemicals

All chemicals and reagents used in this investigation were analytical grade, and only distilled water was utilized.

Bromate-bromide (BB) mixture: 50 mg of potassium bromate (HiMedia Laboratories Pvt. Ltd., Mumbai, India) and 500 mg of potassium bromide (HiMedia Laboratories Pvt. Ltd., Mumbai, India) were precisely weighed, dissolved in distilled water, and diluted to the appropriate volume in a 100 mL volumetric flask to obtain a standard stock solution equivalent to 500 $\mu\text{g/mL}$ KBrO_3 . After diluting this stock solution with water, a working BB mixture solution with a KBrO_3 concentration of 35 $\mu\text{g/mL}$ was obtained for use in the suggested method. The BB stock solution was found to be stable for up to 4 weeks when protected from light and stored in a tightly closed amber glass bottle at room temperature ($25 \pm 2^\circ\text{C}$). The working solution was prepared freshly on the day of analysis to ensure optimal brominating activity, as the *in situ* generation of bromine in acidic medium is more reliable with freshly prepared dilute solutions.

Methylene blue (MB): A standard solution equivalent to 485 $\mu\text{g/mL}$ MB was prepared by dissolving 50 mg of MB (High Purity Laboratory Chemicals PVT. LTD., Mumbai, India, 97% dye content) in water and diluting to the mark in a 100 mL volumetric flask. This solution was then diluted with distilled water to obtain a 60 $\mu\text{g/mL}$ MB solution. The MB stock solution was stored in an amber glass bottle in a dark place at room

temperature. Under these conditions, the solution remained stable for at least 1 week.

Hydrochloric acid (HCl): A 5 M HCl aqueous solution was prepared by diluting the appropriate volume of concentrated acid with distilled water.

Pharmaceutical-grade metoclopramide hydrochloride (MCPH) was kindly provided as a gift by Shaphaco Pharmaceutical Industries, Sana'a, Yemen, and was used without further purification. The commercial tablets selected for estimating MCPH content using the suggested method were Metoclopramide 10 mg (manufactured by Biopharmaceutical Industries, Sana'a, Yemen) and Plemazol 10 mg (manufactured by Chemical Industries Development, Giza, Egypt).

A standard stock solution containing 500 $\mu\text{g/mL}$ of MCPH was prepared by accurately weighing 50 mg of the pure drug, dissolving it in distilled water, and diluting to the mark in a 100 mL volumetric flask using the same solvent. This stock solution was then diluted with distilled water to obtain a working solution with a concentration of 50 $\mu\text{g/mL}$ MCPH.

2.3. Methods

2.3.1. Assay Procedures of MCPH Using MB

A series of 10 mL volumetric flasks were filled with precisely measured volumes (0.25, 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 mL) of a standard MCPH solution (50 $\mu\text{g/mL}$). The required amount of distilled water was added to each flask to make the total volume 5.0 mL. Then, 1.5 mL of 5 M HCl and 1.0 mL of the BB mixture solution, which is equal to 35 $\mu\text{g/mL}$ KBrO_3 was added to each flask. After the flasks were sealed, their contents were combined, and they were allowed to stand for 10 minutes with occasional swirling. Following that, 1.0 mL of MB solution (60 $\mu\text{g/mL}$) was transferred to each flask. Five minutes later, the contents were completely mixed after being diluted to the mark with

water. At 665 nm, the absorbance of every solution was measured versus the corresponding reagent blank.

2.3.2. Assay Procedures for MCPH in Tablets

Five tablets with 10 mg of MCPH each were precisely weighed and pulverized into a fine powder. After carefully weighing a portion of the powder equal to 2.5 mg of pure MCPH, it was put into a 50 mL volumetric flask with around 35 mL of acetone. The mixture was shaken for approximately 15 minutes and filtered through Whatman No. 42 filter paper. The filtrate was collected in another 50 mL volumetric flask, and the solvent was evaporated to dryness using a water bath. The resulting residue was then dissolved in approximately 20 mL of distilled water, and the solution was diluted to volume with distilled water. The final solution was utilized for the assay in accordance with the previously mentioned procedure, where it had a concentration of 50 µg/mL MCPH.

2.3.3. Method Validation Procedures

The suggested method is validated following the latest International Conference on Harmonization (ICH) guidelines [45]. The validation parameters included limit of detection (LOD), limit of quantification (LOQ), linear concentration range, precision, accuracy, and selectivity.

Seven standard MCPH solutions were analyzed to assess linearity. Plotting absorbance (Y-axis) versus MCPH concentration (µg/mL, X-axis) allowed for the construction of a calibration curve. The linear range was determined and the regression equation was derived.

Three solutions containing 10, 15, and 20 µg/mL MCPH were prepared. For intra-day precision and accuracy, each solution was analyzed three times on the same day. However, each solution was analyzed once per day on three different days for inter-day evaluation. Precision was expressed as percentage relative standard deviation (RSD%)

and accuracy as percentage relative error (RE%).

Sensitivity of the suggested method was expressed as molar absorptivity (ϵ) and Sandell's sensitivity.

In order to evaluate the suggested method's selectivity, a placebo blank was created by combining common excipients (talc 100 mg, starch 100 mg, acacia 30 mg, gelatin 50 mg, calcium gluconate 40 mg, sodium alginate 40 mg) and then processed exactly as described for the tablet assay. A 2 mL aliquot of the resulting solution was analyzed three times. To further confirm selectivity, 2.5 mg of pure MCPH was added to the same placebo mixture. This synthetic mixture was processed following the tablet assay procedure to obtain a 50 µg/mL MCPH solution. Aliquots of 3 mL were analyzed in triplicate using the suggested method.

3. Results and Discussion

3.1. Chemistry of the Suggested Method

This study represents the first account of employing a BB mixture for the visible spectrophotometric estimation of MCPH in pharmaceutical tablets. The suggested method relies on the bromination of MCPH using bromine generated *in situ* through the reaction of acid with the BB mixture, which serves as an environmentally friendly brominating agent, thereby eliminating the need for highly toxic and hazardous liquid bromine.

The suggested method is indirect and involves adding a known excess of the BB mixture to MCPH in an acidic medium. After the reaction between MCPH and bromine came to completion, the residual bromine is quantified indirectly by measuring the residual absorbance of the unbleached MB dye at 665 nm (Figure 2), which increases proportionally with the MCPH concentration due to the competitive consumption of the brominating agent.

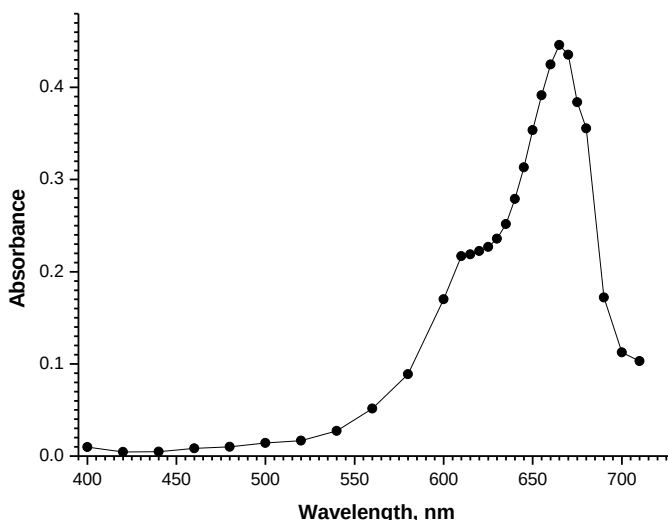


Figure 2. Absorption spectrum of acidic solution of MB (4 µg/mL MB).

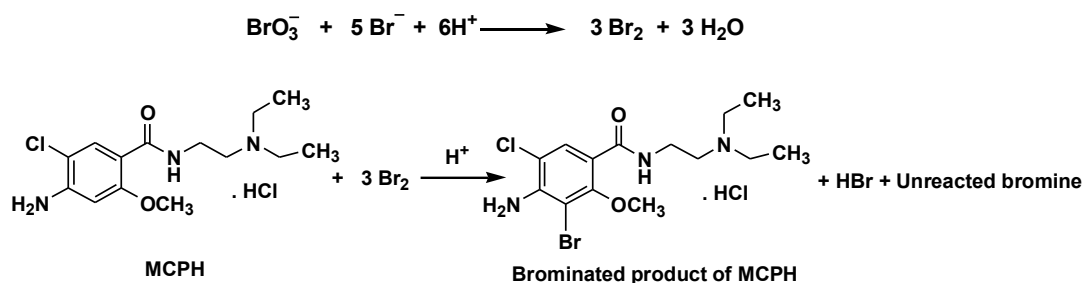
An electrophilic substitution mechanism drives the reaction between MCPH and bromine, which is produced *in situ* when the acid reacts with a BB mixture. The amino group attached to the benzene ring, being the strongest directing group among those present on the ring, directs bromination to the ortho and para positions. However, bromination occurs exclusively at the ortho position relative to the amino group, because the para position and the other ortho position are already occupied by other substituents, as illustrated in Scheme 1.

Once the reaction between MCPH and bromine reaches completion, the remaining bromine reacts with MB dye, leading to a substantial reduction in molar absorptivity at 665 nm. This decrease results from the oxidative destruction of the dye due to the bleaching effect of bromine. In this process, the sulfur atom in MB is oxidized to an S-oxide (Scheme 2), and electrophilic bromination occurs on the carbon atom adjacent to the dimethyl amino group [46].

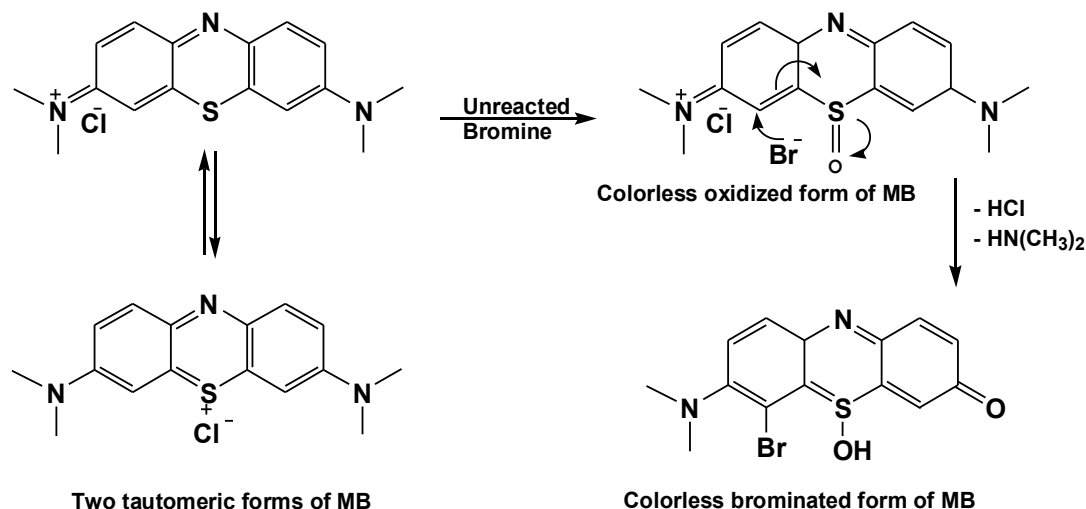
3.2. Method Development

The reaction parameters and the diverse experimental conditions that influence the color development of the measured species in the suggested method and ensure its accurate and precise outcomes were optimized systematically.

The suggested method relied on the bromination of MCPH using a precisely measured excess of a BB mixture in a hydrochloric acid medium. After a fixed reaction time, the residual bromine reacted with a certain amount of MB, and the absorbance of unbleached dye is measured at 665 nm. It was observed that the absorbance varies linearly with the concentration of MCPH. When increasing concentrations of MCPH are added to a constant amount of *in situ* generated bromine, the bromine is consumed proportionally, leading to a corresponding decrease in its concentration. Subsequently, adding a fixed quantity of MB dye to these decreasing bromine concentrations results in a proportional increase in the absorbance of the blue color of MB in acidic medium at 665 nm, which forms the basis of the assay.



Scheme 1. The proposed reaction pathway for bromine formation and its subsequent reaction with MCPH.



Scheme 2. Proposed structures of different forms of MB before and after bromination [46].

3.2.1. Effect of Reagents Concentrations

Optimization was carried out for various parameters influencing the MCPH bromination as well as the subsequent decolorization of MB dye by the residual bromine. Preliminary experiments were conducted to determine the maximum concentration of the dye that could be measured spectrophotometrically at 665 nm in an acidic medium, which was established as 6 µg/mL of MB. A bromate concentration of 3.5 µg/mL, together with a large excess of bromide, was found to be optimal for bleaching the blue color of 6 µg/mL MB in the acid medium. Consequently, varying concentrations of MCPH were allowed to react with 1.0 mL of a 35 µg/mL BB mixture in acidic medium in the presence of a large excess of bromide. The residual bromine was

then determined following the procedure described for that purpose.

3.2.2. Effect of Acid Concentration and Reaction Time

With the dye absorbance remaining constant in a 0.5–1.0 M HCl, hydrochloric acid was found to be an appropriate medium for both steps of the suggested method. It was found that the best acid concentration to complete the bromination process within a reasonable time–10 minutes–was 0.75 M, which was prepared by adding 1.5 mL of 5 M HCl to a total volume of 10 mL. When determining residual bromine using MB dye, the same acid concentration was maintained, and it was found that the reaction time for this step is not critical. To ensure the complete decolorization

of the MB by the remaining bromine, it was necessary to wait for five minutes.

3.3. Method Validation

3.3.1. Quantitative Data

Beer's law was followed by the suggested procedure within an MCPH concentration range of 1.25–25.0 $\mu\text{g/mL}$. The regression equation obtained from the linear calibration plot (Figure 3) is $Y = 0.0307 X - 0.0012$, where X is the concentration expressed in $\mu\text{g/mL}$ and Y is the absorbance.

The calibration curve's correlation coefficient (r) of 0.99996 and coefficient of determination (R^2) of 0.99992 confirmed a linear relationship between the drug concentration and absorbance. The Sandell's sensitivity value was $0.0326 \mu\text{g/cm}^2$, and the calculated molar absorptivity was $1.032 \times 10^4 \text{ L/mol.cm}$. The suggested method was found to

have a LOD of $0.40 \mu\text{g/mL}$ and a LOQ of $1.20 \mu\text{g/mL}$.

3.3.2. Accuracy and Precision

Solutions containing three different concentrations of MCPH were prepared and examined in triplicate in order to evaluate the suggested method's accuracy and precision. Table 1 displays the collected results. The excellent precision and satisfactory accuracy of the suggested method are confirmed by the low percentage relative standard deviation ($\text{RSD}\% \leq 2.49$) and low percentage relative error ($\text{RE}\%$) values, which ranged from -3.00% to -0.80% , indicating a slight consistent underestimation. To evaluate repeatability (intra-day precision) and intermediate precision (inter-day precision), the $\text{RSD}\%$ and $\text{RE}\%$ values were calculated on the same day and over three different days.

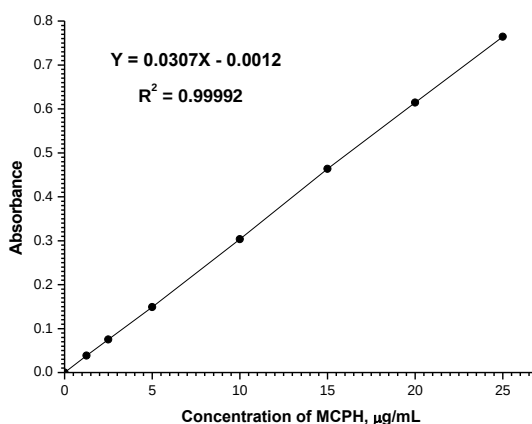


Figure 3. Calibration curve.

Table 1. Results of intra-day and inter-day precision and accuracy evaluations

MCPH taken $\mu\text{g/mL}$	Precision and accuracy assessed on a single day (n=3)			Precision and accuracy evaluated on three different days (n=3)		
	MCPH found* $\mu\text{g/mL}$	RSD%	RE%	MCPH found* $\mu\text{g/mL}$	RSD%	RE%
10	9.92	1.53	-0.80	9.89	1.87	-1.10
15	14.8	1.94	-1.33	14.6	2.08	-2.67
20	19.6	2.01	-2.00	19.4	2.49	-3.00

* Average of three measurements

3.3.3. Selectivity

Using a placebo blank, any interference from common excipients listed under Method Validation Procedures was investigated to evaluate the selectivity of the suggested method for pharmaceutical formulation analysis. It was verified that the absorbance measurements in relation to the water blank resulted exclusively from the analyte. A different experiment was carried out using the suggested method to estimate MCPH in a synthetic mixture; the recovery percentage of MCPH was calculated and found to be 98.72 ± 1.41 ($n=3$), indicating that no significant interference from the excipients occurs in the MCPH assay under the optimized conditions specified.

3.4. Comparison of Suggested Method with Some Literature Spectrophotometric Methods

The analytical performance of the suggested method was compared with some previously reported visible spectrophotometric methods for the determination of MCPH in terms of linear range, molar absorptivity, LOD, and other practical features.

The suggested method offers a linear dynamic range of 1.25–25.0 $\mu\text{g/mL}$, which is comparable to or broader than those of many reported methods [11, 13, 15, 28, 32, 33]. The LOD of the suggested method was of 0.40 $\mu\text{g/mL}$, demonstrating superior sensitivity compared to several previously reported visible spectrophotometric methods. For example, methods using diazotization reaction with 1-naphthol [23] reported an LOD of 0.5448 $\mu\text{g/mL}$, while condensation reaction with vanillin [15] gave an LOD of 0.51 $\mu\text{g/mL}$. The molar absorptivity of the suggested method (1.032×10^4 L/mol.cm) is higher than those reported in many visible spectrophotometric methods, including those based on an azo coupling reaction with 2-tert-Butyl-4-

methoxyphenol [33] (0.26×10^4 L/mol.cm), an oxidative coupling reaction of pyrocatechol with MCPH using ammonium ceric sulphate as the oxidizing agent [38] (3.01×10^3 L/mol.cm), and an oxidative coupling reaction of metoclopramide with 2,5-dihydroxybenzoic acid using potassium periodate as an oxidizing agent [40] (2.196×10^3 L/mol.cm). This indicates that the suggested method offers good sensitivity for the determination of MCPH.

Unlike many diazotization-based methods [13, 16, 28, 30, 32] that require low temperatures (0–5°C), the suggested method is carried out at room temperature. Similarly, compared to many reported methods [14, 19, 29, 32, 43] that often require organic solvent extraction or heating steps, the suggested method is simpler and faster. Furthermore, several reported visible spectrophotometric methods involve the use of toxic organic solvents such as methanol [13, 28]. The suggested method avoids such solvents, making it environmentally friendly and safer for laboratory personnel. The suggested method also eliminates the need for heating or lengthy extraction procedures, which are common in some reported methods, thereby reducing analysis time and energy consumption. From a green chemistry perspective, the suggested method employs a bromate-bromide mixture to generate bromine *in situ*, safely replacing the use of hazardous elemental bromine. This represents a significant advantage over methods that use toxic reagents.

Based on the comparisons above, the suggested method offers a simple, sensitive, cost-effective, and environmentally friendly alternative for the routine quality control analysis of MCPH in pharmaceutical tablets, with performance characteristics that are comparable to or better than those of many previously reported methods.

3.5. Analytical Applications

3.5.1. Determination of MCPH in Pharmaceutical Tablets

The suggested method was used to estimate MCPH in two tablet brands having the same concentration. The results of this study displayed in Table 2 were statistically compared using Student's *t*-test and the variance ratio *F*-test, with those obtained using the official British Pharmacopoeia method [47] in terms of accuracy and precision. The official

method involves an aqueous titration of the MCPH drug solution with 0.1 M sodium hydroxide, with the end point determined potentiometrically. At a 95% confidence level, the calculated *t*-values and *F*-values were compared to the tabulated values. No significant difference was observed between the suggested method and the official method in terms of accuracy and precision, as indicated by the calculated *t*- and *F*-values (shown in Table 2) which do not exceed the tabulated values.

Table 2. Comparison of assay outcomes using suggested and official methods

Commercial Tablets	Nominal quantity, mg	Found % (of nominal quantity $\pm$ SD) *	
		Official method	Suggested method
Metoclopramide	10	99.58 $\pm$ 1.14	98.36 $\pm$ 2.16 <i>t</i> = 1.17 <i>F</i> = 3.59
Plemazol	10	99.42 $\pm$ 1.09	98.22 $\pm$ 1.84 <i>t</i> = 1.29 <i>F</i> = 2.85

*Mean of five replicate measurements.

The 95% confidence level tabulated *t*-value is 2.776.

The 95% confidence level tabulated *F*-value is 6.39.

3.5.2. Recovery Study

A standard addition technique was used to confirm the accuracy of the method. Three levels of pure MCPH (50, 100, and 150% of the current quantity) were added to pre-analyzed tablet powder (10 mg each of metoclopramide and plemazol). Three

measurements were performed for each level. The recovery values in Table 3 ranged from 97.75 to 99.12%, with a standard deviation (SD) of 1.76 to 2.40%, suggesting that common excipients had no effect on the assay.

Table 3. Outcomes of a recovery investigation based on the standard addition technique

Tablet Used	MCPH in tablet, $\mu\text{g/mL}$	Pure MCPH added, $\mu\text{g/mL}$	Total found, $\mu\text{g/mL}$	Pure MCPH recovered, (Percent $\pm$ SD)
Metoclopramide 10	7.87	4.00	11.82	98.75 $\pm$ 1.83
	7.87	8.00	15.80	99.12 $\pm$ 1.91
	7.87	12.0	19.64	98.08 $\pm$ 1.76
Plemazol 10	7.86	4.00	11.79	98.25 $\pm$ 1.95
	7.86	8.00	15.68	97.75 $\pm$ 2.40
	7.86	12.0	19.66	98.33 $\pm$ 2.28

^aMean value of three measurements.

4. Conclusion

This study presents the first application of a BB mixture as an environmentally friendly brominating agent for the quantification of MCPH in pharmaceutical formulations. The suggested method is simple, rapid, and highly sensitive compared to many previously reported visible spectrophotometric methods. The suggested method involves the bromination of MCPH with a BB mixture in an acidic medium, which generates bromine *in situ*, thereby replacing the use of hazardous elemental bromine conventionally employed in such reactions. The residual bromine is then quantified through its reaction with MB dye, and the increase in MB absorbance is recorded. From a practical standpoint, the suggested method offers several distinct advantages for routine quality control applications: it eliminates the need for heating or extraction steps, avoids the use of toxic organic solvents, employs cost-effective and readily available reagents, and demonstrates good accuracy and precision. Furthermore, common excipients present in commercial tablet formulations do not interfere with the analysis, confirming the method's selectivity. These features make the suggested method a reliable, environmentally friendly, and practically viable alternative for the routine quality control analysis of MCPH in pharmaceutical tablets.

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Data Availability

The data are available from the corresponding author upon request.

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