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Paper-Based Colorimetric Determination of Iron Using Cinnamon Nanoparticles and Copper Nitrate

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Abstract

A simple paper-based colorimetric sensor for the determination of iron is described, in which filter-paper strips coated with cinnamon nanoparticles and copper nitrate give an olive-green spot on contact with Fe^{3+}. The reagents are pre-loaded on the strip, so the sample is applied as a microlitre drop and the colour is read from a smartphone photograph: the red, green and blue (R, G, B) values of the spot are read with ImageJ software and converted into effective intensities against a blank strip. With 3% $Cu(NO_3)_2$ fixed throughout and strips given two dips in cinnamon nanoparticles, pH, the volume of iron solution, temperature and time were optimized. The best response was obtained at pH 7 with 2.86 µL of iron solution (159.6 µg Fe). The colour was established on contact at room temperature and stayed stable for 30 min, so no heating, incubation or timing is needed, and the strip responded to Fe^{3+} down to 100 ppm (mg/L). Unlike methods in which a colour reagent must be added to every sample or micro-fluidic channels must be patterned, the strip needs only 2.86 µL of sample, uses a natural-product reagent and requires nothing more than a smartphone camera and free image-analysis software, which makes it a simple and efficient tool for the determination of iron in water.

Keywords: cinnamon nanoparticles; colorimetric sensor; copper nitrate; iron; paper-based sensor

1 Introduction

Iron is an essential element but also one of the commonest constituents of natural waters, with concentrations of 0.5–50 mg/L reported in fresh waters [1]. WHO proposes no health-based guideline value for iron, because an intake of about 2 mg/L from drinking water presents no hazard to health and the taste and appearance of the water are usually affected below that level [1]. The Indian standard IS 10500:2012 limits iron in drinking water to 1.0 mg/L with no relaxation [2]. Iron in water therefore has to be checked routinely, preferably at the point of use.

Paper-based analytical devices (PADs) are a low-cost, portable alternative to laboratory instruments [3, 4]. Their colour read-out can be judged by eye or quantified from a scanner or smartphone photograph [5–7], and digital RGB analysis of paper spots has already been used for the quantitative determination of lead on paper optodes [8].

Several smartphone and paper-based methods for iron(III) have been reported. The iron(III)–thiocyanate reaction read with a smartphone gave a detection limit of 0.1 mg/L [9]; a butterfly pea anthocyanin paper sensor worked over 50–800 mg/L with a detection limit of 43 mg/L by ImageJ analysis [10]; and rutin-modified silver nanoparticles detected Fe^{3+} in solution at 17 nmol/L [11]. In the thiocyanate method and the nanoparticle probe the colour reagent is added to the sample in solution, and the paper sensor relies on a microfluidic design. Plant polyphenols are attractive natural reagents for iron because their catechol and galloyl groups bind Fe(III): an extract of *Terminalia*

chebula changes from green or pale yellow to blue with Fe^{2+} and Fe^{3+}, and the response was attributed mainly to tri-O-galloyl-β-D-glucose [12]. Cinnamon bark extract and powder contain water-soluble compounds that reduce silver ions to nanocrystalline silver [13], and cinnamon phytochemicals have been used to stabilize silver nanoclusters for colorimetric sensing [14].

Here we combine cinnamon nanoparticles with copper nitrate on filter paper to obtain a strip for the determination of iron. The strip has four advantages: (a) its main reagent is derived from cinnamon, a common natural product; (b) all reagents are on the paper, so a single drop of sample is applied and no colour reagent has to be added; (c) it is made by simple dipping steps without wax printing; and (d) it is read from a photograph by RGB analysis with a smartphone camera and free software. With 3% $Cu(NO_3)_2$ fixed throughout, we optimized pH, the volume of iron solution applied, temperature and time, and used the optimized strip for the determination of iron.

2 Experimental section

2.1 Apparatus and software

A smartphone camera was used to photograph the strips and a micropipette to apply the solutions. ImageJ software [15] was used to read the R, G and B values of the spots from the images.

2.2 Chemicals and reagents

All chemicals were of analytical grade and distilled water was used throughout. Filter paper Whatman No. 40 was the support for the reagents.

Iron solution: A 1 M Fe^{3+} stock was prepared by dissolving 1.62 g $FeCl_3$ in 10 mL distilled water.

Copper nitrate solution: 3% $Cu(NO_3)_2$ was prepared by dissolving 0.150 g in 5 mL distilled water and was used throughout.

Buffer solutions: Buffers of pH 4, 7 and 9 were prepared using buffer tablets.

2.3 Procedure

Preparation of the paper strip. Strips of Whatman No. 40 filter paper were first dipped two times in the cinnamon nanoparticle suspension and dried in an oven; after that the strips were dipped in $Cu(NO_3)_2$ solution and dried in the oven again.

Mode of operation. Fe^{3+} solution was applied to the strip at room temperature as drops of 0.5714 µL, each containing 31.91 µg Fe; the volume applied is given in µL. An olive-green spot forms on the pale tan-yellow strip (Figure 1). Each strip was photographed and the R, G and B values of the spot were read from the image using ImageJ software and compared with those of a blank strip (strip without Fe^{3+}). Each optimization series was run on separately prepared strips and referenced to its own blank strips, so absolute effective intensities differ between series and are compared only within a series. The RGB model is an additive colour model in which red, green and blue light are combined to give a wide range of colours, and every colour can be described by its R, G and B values. The effective intensity of each channel was calculated as [8]

$$A_r = -\log\left(\frac{R_s}{R_b}\right) \quad (1)$$

$$A_g = -\log\left(\frac{G_s}{G_b}\right) \quad (2)$$

$$A_b = -\log\left(\frac{B_s}{B_b}\right) \quad (3)$$

where A_r, A_g and A_b are the effective intensities of the red, green and blue channels, and R_s, G_s, B_s and R_b, G_b, B_b are the R, G and B values of the sample and the blank, respectively. Where a channel value of the sample read zero, the effective intensity is undefined; such points are shown as open symbols in the figures, plotted with a sample value of 1, which gives a lower limit of the true value.

3 Results and discussion

Colour-forming reaction. On contact with Fe^{3+} the pale tan-yellow strip develops an olive-green (dark yellow-green) spot immediately (Figure 1). The colour is consistent with the formation of Fe(III) complexes of the polyphenolic compounds of cinnamon held on the nanoparticle-coated paper, whose catechol and galloyl groups coordinate Fe^{3+} and give intensely coloured complexes that absorb strongly in the visible region [11, 12]. The decrease in the R, G and B values of the spot is largest in the blue channel ($A_b > A_g > A_r$ in every series below), which makes the blue channel the most sensitive indicator of the colour change. The 3% $Cu(NO_3)_2$ applied over the nanoparticle layer completes the reagent system and was held constant in all experiments, and every spot was compared with a blank strip of the same series, so the changes in effective intensity reported below are due to the iron applied and to the parameter being studied.



Figure 1. Photograph of the paper strip after application of Fe^{3+} solution, showing the olive-green spot on the pale tan-yellow strip.

3.1 Effect of pH

The effect of pH was studied at pH 4, 7 and 9 in three independent sets (Figure 2, Table 1). The red and green effective intensities were lowest at pH 4 (A_r = 0.369, A_g = 0.487) and similar at pH 7 (0.506, 0.674) and pH 9 (0.524, 0.653), although the spread between sets was large (SD up to 0.23). The blue value of the sample read 0–2 in two of the three sets at pH 7 and at pH 9, so that A_b was at least 1.78 and 1.79 (lower limits), against 1.31 ± 0.09 at pH 4, which shows nearly complete colour development in the blue channel. In terms of the difference between the blank and sample channel values, pH 7 gave the largest green and blue differences (174.7 and 197.3). Therefore pH 7 was selected, which also avoids buffering of neutral water samples.

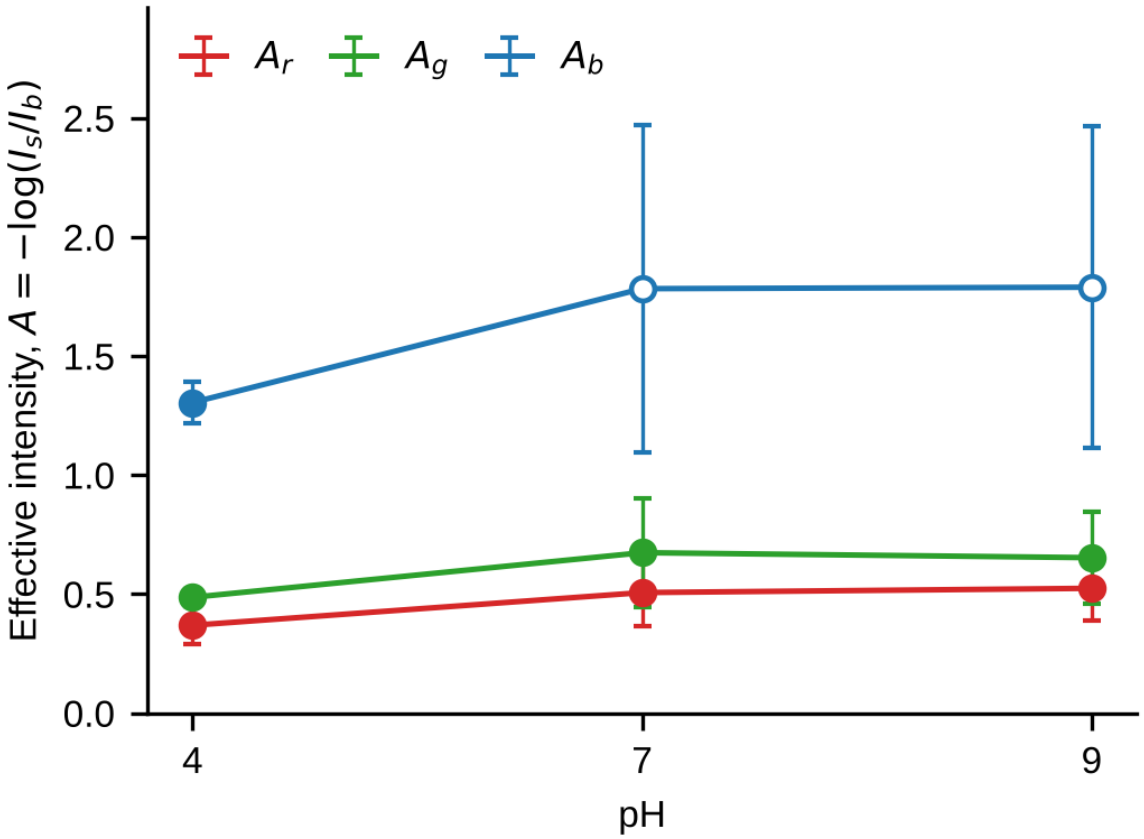


Figure 2. Effect of pH on the effective intensities (mean ± SD, n = 3 independent sets). Open symbols: sample channel value of 0 in one of the sets.

Table 1. Effect of pH on the response of the strip (mean ± SD, n = 3). ΔR, ΔG and ΔB are the blank minus sample channel values.

pH	A_r	A_g	ΔR	ΔG	ΔB
4	0.369 ± 0.080	0.487 ± 0.036	142.0 ± 24.1	156.3 ± 5.5	192.7 ± 17.7
7	0.506 ± 0.143	0.674 ± 0.230	166.3 ± 23.1	174.7 ± 21.5	197.3 ± 22.1
9	0.524 ± 0.137	0.653 ± 0.193	164.7 ± 18.9	156.3 ± 10.8	152.7 ± 4.5

3.2 Volume of iron solution

The volume of Fe^{3+} solution applied was varied from 0.57 to 5.71 µL (1 to 10 drops of 0.5714 µL, each containing 31.91 µg Fe; Figure 3). The red and green effective intensities were highest at 2.86 µL (A_r = 0.373, A_g = 0.479; 159.6 µg Fe) and decreased on either side (A_r = 0.289 and A_g = 0.385 at 5.71 µL). The blue value of the sample was 37 and 28 at 0.57 and 1.14 µL, fell to 0–3 between 1.71 and 4.00 µL (zero at 1.71, 2.29 and 3.43 µL), and rose again to 18 at 5.71 µL (A_b = 1.099), so colour development was essentially complete between 1.71 and 4.00 µL. A volume of 2.86 µL was selected as the optimum.

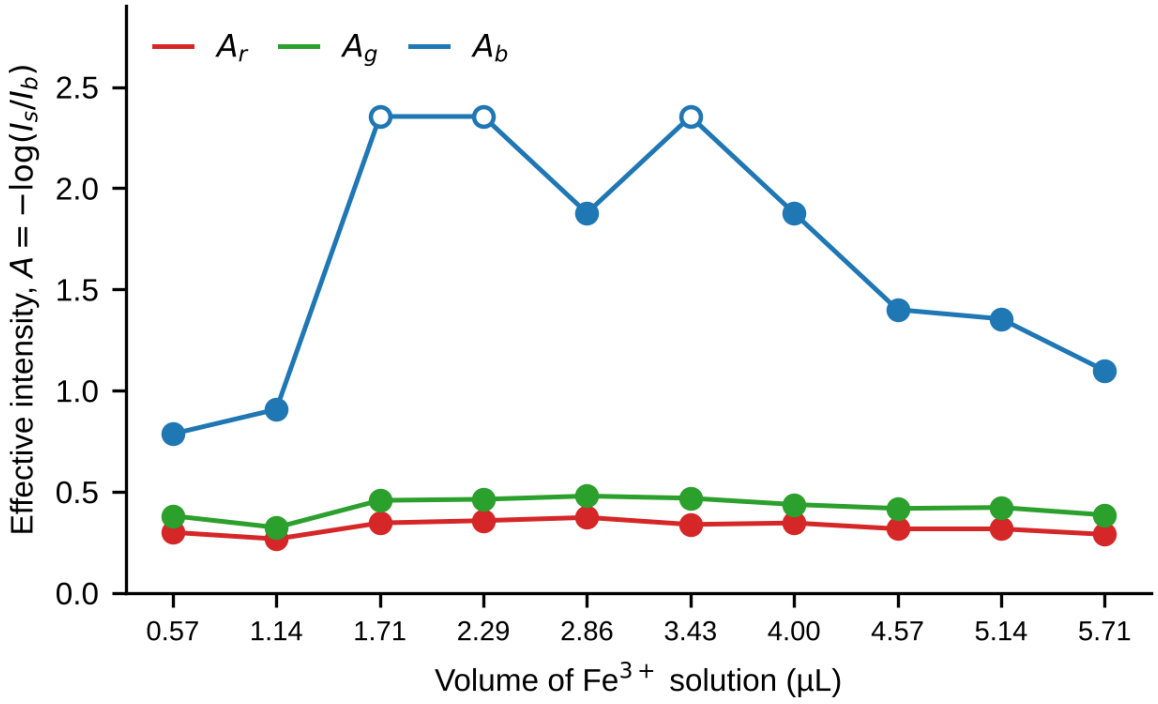


Figure 3. Effect of the volume of Fe^{3+} solution on the effective intensities. Open symbols: sample channel value of 0.

3.3 Temperature and time

The effect of temperature was studied at room temperature, 40, 45 and 50 °C, reading the strips instantly and after 5, 10, 15, 20 and 25 min (and 30 min at room temperature; Figure 4). At room temperature the response was established instantly (A_r = 0.466, A_g = 0.595; sample B value 2) and remained nearly constant for 30 min (A_r = 0.40–0.47, A_g = 0.49–0.60; Figure 4a). At 40 °C the effective intensities were of the same order (A_g = 0.418–0.575, with a maximum at 10 min; Figure 4b). At 45 °C the red and green effective intensities were higher (A_r = 0.526–0.827, A_g = 0.671–0.972, with a maximum at 20 min; Figure 4c), and at 50 °C they were lower (A_g = 0.387–0.533; Figure 4d). Because the colour is already essentially complete on contact at room temperature (sample blue value 2) and the reading stays stable for 30 min, no heating or waiting is needed, and room temperature with immediate measurement was selected.

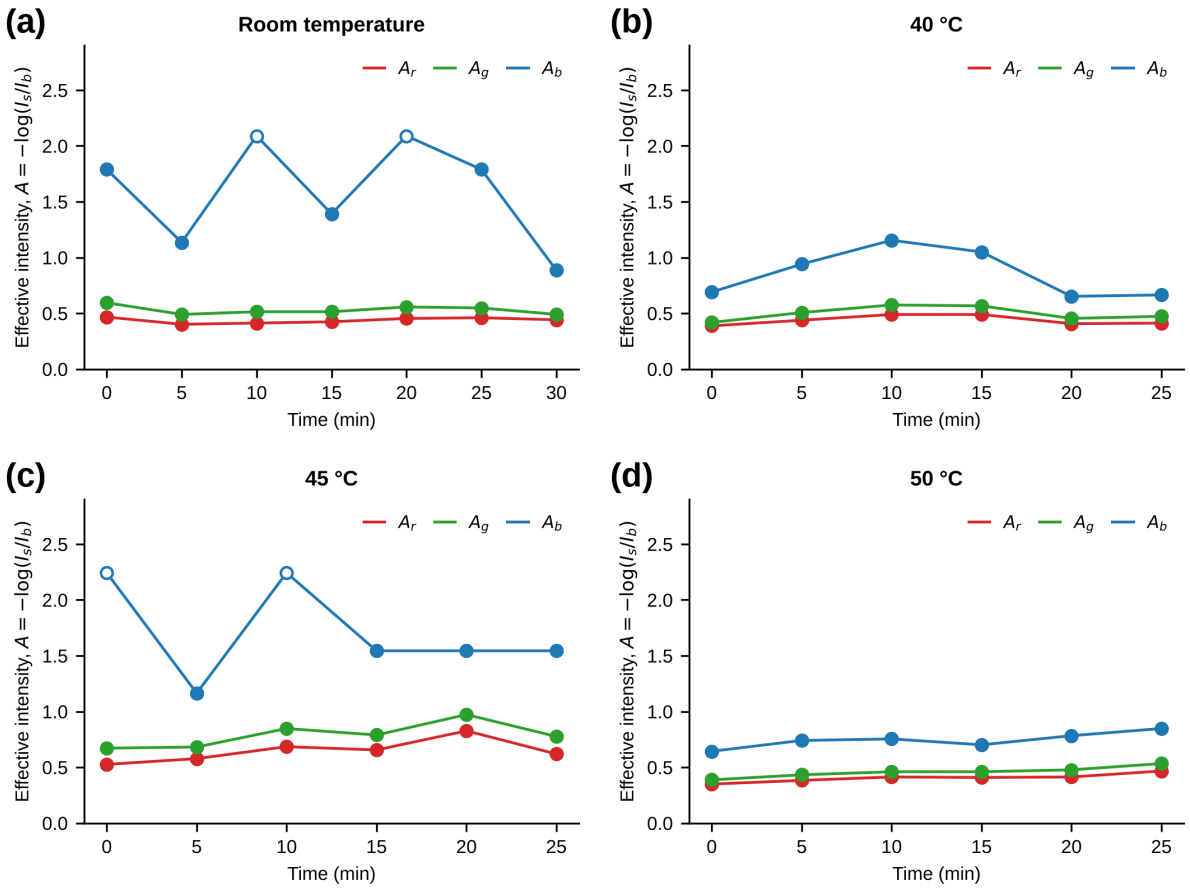


Figure 4. Effect of temperature and time on the effective intensities: (a) room temperature, (b) 40 °C, (c) 45 °C and (d) 50 °C. Open symbols: sample channel value of 0.

3.4 Optimum conditions

The optimum conditions found for the paper strip are summarized in Table 2.

Table 2. Summary of the optimized conditions for the iron strip

Parameter	Range studied	Optimum	Basis for selection
$Cu(NO_3)_2$ concentration	Fixed	3%	Used throughout
Dips in cinnamon nanoparticles	Fixed	2	Used throughout
pH	4, 7, 9	7	Largest ΔG and ΔB; A_r, A_g similar to pH 9
Fe^{3+} solution applied	0.57–5.71 µL	2.86 µL (159.6 µg Fe)	Highest A_r and A_g; blue value ≤ 3
Temperature	Room temperature, 40, 45, 50 °C	Room temperature	Response established on contact; no heating needed
Measurement time	Instant–30 min	Instant	Response stable for 30 min

3.5 Determination of iron and comparison with reported sensors

Under the optimized conditions (3% $Cu(NO_3)_2$, two dips in cinnamon nanoparticles, pH 7, 2.86 µL of iron solution, room temperature and immediate reading) the strip responded to Fe^{3+} down to 100

ppm (100 mg/L), which corresponds to about 0.29 µg of Fe in the 2.86 µL applied. Table 3 compares the strip with the iron sensors discussed in the Introduction. In the thiocyanate method [9] and in the nanoparticle probe [11] the colour reagent is added to every sample in solution, and the paper sensor of [10] relies on a microfluidic design, whereas in the proposed strip all the reagents are already on the paper and the sample is applied as a single 2.86 µL drop.

Table 3. Comparison of the proposed strip with reported iron sensors

Sensor	Reagent	Format and read-out	Reported performance
Hassan et al. [9]	Fe(III)–thiocyanate	Solution; smartphone	Detection limit 0.1 mg/L
Aryal et al. [10]	Butterfly pea anthocyanin	Paper microfluidic device; smartphone, ImageJ	50–800 mg/L; detection limit 43 mg/L
Coutinho et al. [11]	Rutin-modified silver nanoparticles	Solution; chromogenic probe	Detection limit 17 nmol/L
This work	Cinnamon nanoparticles and 3% $Cu(NO_3)_2$	Dipped filter-paper strip; 2.86 µL sample; smartphone, ImageJ	Response down to 100 ppm

The strip has the following practical advantages. (i) The colour is established on contact at room temperature and stays stable for 30 min, so no heating, incubation or timing is needed. (ii) The best response is at pH 7, so neutral water samples need no buffering. (iii) Only 2.86 µL of sample is used, and no colour reagent has to be added to it. (iv) The reagent is a natural product and the strip is made by simple dipping, without wax printing or microfluidic channels. (v) The determination needs only a smartphone camera and free software, so it can be carried out on site, and the strip responds in the same concentration region as the paper sensor of [10].

4 Conclusion

A paper strip coated with cinnamon nanoparticles and copper nitrate gives an immediate olive-green spot with Fe^{3+}, which can be quantified from a smartphone photograph by RGB analysis and used for the determination of iron. With 3% $Cu(NO_3)_2$ and two dips in cinnamon nanoparticles fixed throughout, the best response was obtained at pH 7 with 2.86 µL of iron solution (159.6 µg Fe), room temperature and immediate read-out, and the strip responded to Fe^{3+} down to 100 ppm. The colour was stable for 30 min at room temperature. As all the reagents are on the strip, the sample is applied as a single microlitre drop with no reagent added, no heating or timing is needed, and only a smartphone camera and free software are used. The strip is therefore a simple, rapid and low-cost alternative to solution-based colour reagents and microfluidic paper sensors, and it offers a practical basis for the on-site determination of iron in water.

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References

[1] World Health Organization. *Iron*. In: Guidelines for drinking-water quality. 4th ed. incorporating the 1st and 2nd addenda. Chemical fact sheets [Internet]. Geneva: WHO; 2022. https://cdn.who.int/media/docs/default-source/wash-documents/water-safety-and-quality/chemical-fact-sheets-2022/iron-fact-sheet-2022.pdf

[2] Bureau of Indian Standards. *IS 10500:2012 Drinking water – specification (second revision)* [Internet]. New Delhi: BIS; 2012. https://www.bis.gov.in/other/DrinWatIS10500.pdf

[3] Martinez AW, Phillips ST, Butte MJ, Whitesides GM. Patterned paper as a platform for inexpensive, low-volume, portable bioassays. *Angew Chem Int Ed*. 2007;46(8):1318–20. https://doi.org/10.1002/anie.200603817

[4] Yetisen AK, Akram MS, Lowe CR. Paper-based microfluidic point-of-care diagnostic devices. *Lab Chip*. 2013;13(12):2210–51. https://doi.org/10.1039/c3lc50169h

[5] Kant T, Shrivas K, Tejwani A, Tandey K, Sharma A, Gupta S. Progress in the design of portable colorimetric chemical sensing devices. *Nanoscale*. 2023;15(47):19016–38. https://doi.org/10.1039/d3nr03803c

[6] Berasarte I, et al. Chemometrics and digital image colorimetry approaches applied to paper-based analytical devices: a review. *Anal Chim Acta*. 2025;1339:343577. https://doi.org/10.1016/j.aca.2024.343577

[7] Markus V, Paul AA, Marks RS, Caleb J. Smartphone digital image colorimetry: an affordable easy-to-use technique. *Anal Lett*. 2026;59(1):158–76. https://doi.org/10.1080/00032719.2025.2474573

[8] Sharma RD, Joshi S, Amlathe S. A new optical analytical method for quantitative determination of lead on paper platform and its application for removal from aqueous sample. *J Chem Pharm Res*. 2015;7(6):27–36.

[9] Hassan J, Shermeh SM, Koohi MK, Pourshaban-Shahrestani A. A green chemical analysis of iron (III) in water sample using a smart phone. *MethodsX*. 2024;12:102724. https://doi.org/10.1016/j.mex.2024.102724

[10] Aryal P, Indrianingsih AW, Henry CS. Smartphone-enabled green anthocyanin sensor for Fe(III) sensing on paper using capillary-driven microfluidics. *Green Anal Chem*. 2024;8:100091. https://doi.org/10.1016/j.greeac.2023.100091

[11] Coutinho MS, et al. Rutin-modified silver nanoparticles as a chromogenic probe for the selective detection of Fe3+ in aqueous medium. *RSC Adv*. 2019;9:30007–11. https://doi.org/10.1039/c9ra06653e

[12] Sen S, Singh T, Im J, et al. Terminalia chebula: a novel natural product colorimetric sensor for Fe2+ and Fe3+ ions. *J Anal Sci Technol*. 2022;13:39. https://doi.org/10.1186/s40543-022-00348-z

[13] Sathishkumar M, Sneha K, Won SW, Cho CW, Kim S, Yun YS. Cinnamon zeylanicum bark extract and powder mediated green synthesis of nano-crystalline silver particles and its bactericidal activity. *Colloids Surf B Biointerfaces*. 2009;73(2):332–8. https://doi.org/10.1016/j.colsurfb.2009.06.005

[14] Elgamouz A, et al. Cinnamon extract's phytochemicals stabilized Ag nanoclusters as nanozymes 'peroxidase and xanthine oxidase mimetic' for simultaneous colorimetric sensing of H2O2 and xanthine. *Colloids Surf A Physicochem Eng Asp*. 2022;647:129035. https://doi.org/10.1016/j.colsurfa.2022.129035

[15] Schneider CA, Rasband WS, Eliceiri KW. NIH Image to ImageJ: 25 years of image analysis. *Nat Methods*. 2012;9(7):671–5. https://doi.org/10.1038/nmeth.2089