JBIC Journal of Biological Inorganic Chemistry (2022) 27:471–483
https://doi.org/10.1007/s00775-022-01944-5

ORIGINAL PAPER

Sensitive and highly selective colorimetric biosensing of vitamin-C and vitamin-B1 by flavoring agent-based silver nanoparticles

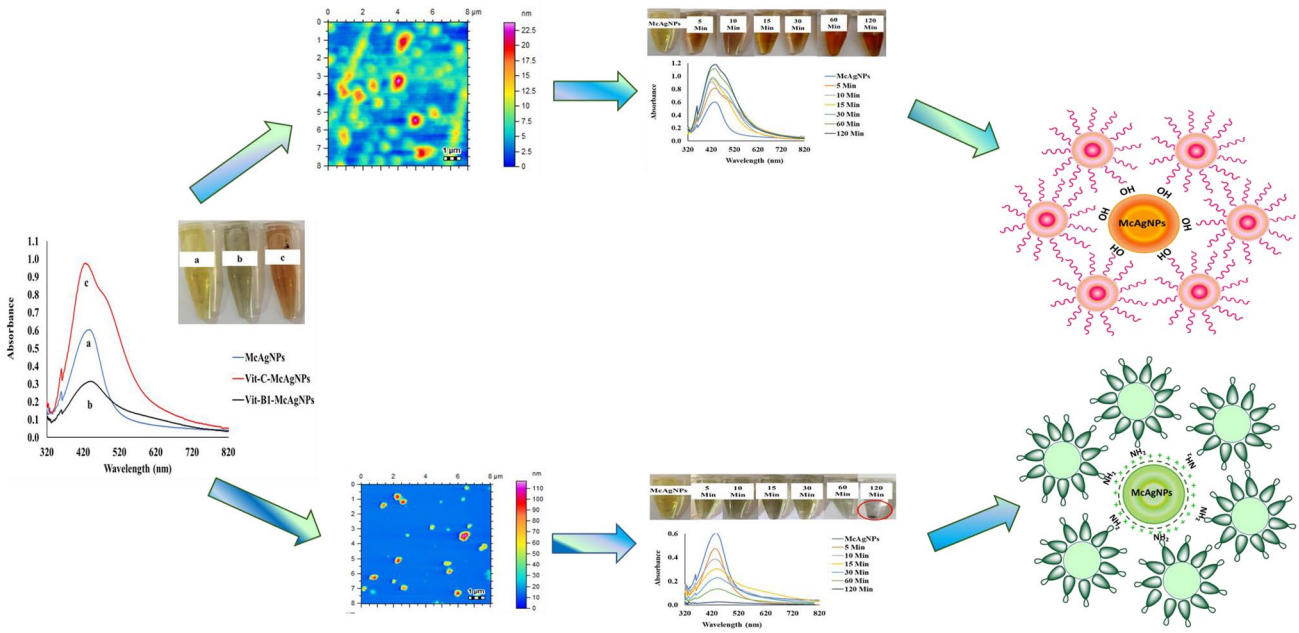
Syeda Sumra Naqvi[1] · Humera Anwar[1] · Asma Siddiqui[1] · Muhammad Raza Shah[2]

Received: 30 January 2022 / Accepted: 7 June 2022 / Published online: 12 July 2022

Abstract

A sensitive scheme was established for the detection of vitamin C (Ascorbic acid) and vitamin B1 (Thiamin HCl) using Maltol capped AgNPs (McAgNPs) as colorimetric sensor. The designed scheme showed an instant alteration in color from yellow to orange and green for vitamin-C and vitamin B1 sequentially. The probe was sensitive in a concentration range of (0–1 µM) with limit of detection 0.064 and 0.038 µM for vitamin C and vitamin B1 sequentially. The interaction mechanism between vitamin C and vitamin B1 and McAgNPs was evaluated by visible spectroscopy, FTIR, and AFM. Vitamin C attaches on the surface of nanoparticles by C=O group, while OH, C–S–C, and NH_2 groups are involved in the binding of vitamin B1 with McAgNPs. The Vit-C/Vit-B1-McAgNPs complexes were stable over a wide range of pHs. The size of McAgNPs increased after the interaction of vitamin C/vitamin B1 from 30–40 nm to 500 and 400 nm sequentially. The scheme was successfully applied for the detection of vitamin C and vitamin B1 in urine, plasma, water, and commercial pharmaceutical tablets with good recoveries. The scheme was ascertained to be more sensitive than many other formerly described schemes.

Graphical abstract



Keywords Colorimetric detection · AgNPs · Vitamin C · Vitamin B1 · Biosensor

✉ Syeda Sumra Naqvi
sumra.naqvi@gmail.com

Extended author information available on the last page of the article

Introduction

Nanomaterials have revealed incredible potential to influence the extensive field of nanobiotechnology and nanomedicine via their use in biosensing, drug delivery systems, bio-detection, and discovery of novel therapies for frightening disorders such as cancers, etc. [1, 2]**.** The ever-increasing exigence for detecting a broad variety of molecules at subdued concentrations with high specificity has provoked the development of exclusive strategies that integrate nanomaterials, biological essentials, and upgraded materials, which are jointly named as nano biosensors [3]. The first true biosensor was reported for the detection of oxygen in 1956 [4]. Sensors are a group of devices that create detectible responses to variation in chemical concentrations or physical circumstances. In general, a sensor includes a signal transducer and a sensing element and generates a signal proportionate to the analyte strength. With the properties of extraordinary sensitivity, quick response, and low cost, the sensors endure creating significant influence, specifically in medical and biological applications [5]. Metal NPs-based biosensors were first projected by Weissleder's group in a series of works [6].

Amongst the numerous metal-based NPs, gold (Au) and silver (Ag) NPs have been utilized for scheming innovative colorimetric detectors. Silver and gold have almost identical bulk matrix constants and certain physiochemical features. In contrasted to Au, Ag is inexpensive and could be anticipated to have utilized in extraordinary, delicate, and inexpensive colorimetric sensors [7]. AgNPs are usually show exceptionally unique biological, physical and chemical characteristics such as a strong surface, a high molar extinction coefficient, and an enhanced Raman scattering effect [8]. AgNPs have applications in extremely discriminating and highly sensitive bio and chemosensors owing to surface plasmon resonance absorption bands of their agglomerated forms. These agglomerated forms of AgNPs were widely operated to follow the molecular detection method [9].

Vitamins are naturally vigorous compounds which show different significant tasks in the normal function of the human body as they are intricate in several metabolic routes [10], self-maintenance, precluding of oxidative damage to organs and tissue, mineral metabolism, protein, and management of cell, hence, they are chemicals that we all want to remain healthy. All vitamins (except vitamin D and K) are obtained from numerous food products as they are not formed in sufficient quantities in our body [11].

Thiamine HCl (B-complex) and ascorbic acid (vitamin C) vitamins are water-soluble vitamins, present in various kinds of foods [12, 13].

Thiamine is also recognized as vitamin B1. Thiamine is commercially found as thiamine hydrochloride salt, $C_{12}H_{17}ClN_4OS{\cdot}HCl$ [14]. In carbohydrate metabolism, vitamin B1 performs a vital role in the neurotransmitters biosynthesis and in the making of anti-stress materials [15]. As a significant biological compound, it contributes to the metabolic procedures of proteins, lipids, and sugars [16]. The deficiency of vitamin B1 decreased concentrations of numerous cellular substrates and triggers increased levels of lactic acid that are produced from vitamin B1 pyrophosphate reliant enzymes. Moreover, growth-related, metabolic, and neurological complications can occur, encircling the brain and neurological malfunction. Critical vitamin B1 insufficiency has also been associated with beriberi (a prolonged cardiovascular disorder) and Wernicke Korsakoff syndrome (chronic neurological disorder) [17]. Vitamin B1 is stable at acidic pH but is unstable in basic pH. The salts of Thiamine can be light sensitive, altered by pH, reducing and oxidizing agents, and heat; therefore, should be kept under specific conditions [18].

Ascorbic acid (AA) also identified as vitamin C is a vital nutrient in numerous multicellular organisms, especially in humans. Vitamin C is one of the extremely significant vitamins which is also crucial for life and is participates in various vital physiological procedures, such as immune response, iron absorption, and so on [11]. Vitamin C is a water soluble vitamin and is found in variable amounts in vegetables, fruits, and organ meats (e.g. kidney and liver) [19]. Vitamin C is extensively used as an antioxidant and enzyme. It significantly occurs in foodstuffs, pharmaceutical, and biological fluids [20]. It contributes as a vital dynamic constituent into numerous key biochemical events linked to antiviral, bactericidal, or detoxifying cell activities [21]. Vitamin C has been normally implemented to stop and treat mental disorders, sterility, influenza, scurvy, cardiovascular diseases, capillary fragility, and cancer [22, 23]. Amongst chemists, it is utilized as a reagent for the synthesis of enzymatic reagents, fine chemicals, and nanoparticles. Consistent and routine detection of vitamin B1 and vitamin C by quick and sensitive procedures is of immense biomedical and clinical significance [24]. The recognition and quantification of vitamin B1 and vitamin C in products, food samples, and nutraceuticals is getting immense importance amongst medical experts, researchers and also in the pharmaceutical industry [19]. Various procedures have been applied to vitamin B1 and vitamin C detection including spectrophotometry [25], spectrofluorimetry [26, 27], chemiluminescence [28, 29], capillary zone electrophoresis [30, 31], colorimetric analysis [32, 33], and high performance liquid chromatography [25, 34, 35]. Certain of these procedures require complex sample formulation but the colorimetric scheme has excellent potential for vitamin B1 and vitamin C detection due to its speedy procedure, easy, and cost effectiveness [36].

In the present study, Maltol capped silver nanoparticles were synthesized by using flavoring agent maltol, which has been reported earlier by our research group. Maltol is a chelating ligand of natural origin, appealing to an ever-rising interest due to its nontoxicity and potential biological applications. Maltol controls the amount of metal contents in an organism and forms a stable complex with several metallic ions like Bi^{+3}, Fe^{+3}, Al^{+3}, V^{+3}, $^{+4}$, $^{+5}$, Ga^{+3}, In^{+3}, Ru^{+2} and, Zn^{+2}. Few of above complexes have already been confirmed as inventive drugs [37]. It is believed that the –OH, C=O, and C–O groups of Maltol are involved in the stabilization of the nanoparticles [38].

Considering above knowledge, we report the easy, sensitive and selective colorimetric detection of Vit-C and Vit-B1 by using previously synthesized McAgNPs which work as colorimetric biosensor. These nanoparticles were bright yellow but after interaction with Vit-C and Vit-B1, their color changed from yellow to orange and green respectively, because of the aggregation of nanoparticles. This method is free from interferences of other vitamins and metal ions. The Vit-C and Vit-B1 form a complex with McAgNPs. The McAgNPs were characterized before and after interaction with Vit-C and Vit-B1 by visible spectroscopy. The interaction mechanism of AgNPs with both vitamins was checked by FTIR and AFM studies. The applicability of the current method was checked in pharmaceutical tablets, water (lake and tap), and in biological fluids (urine and plasma).

Experimental

Materials and instrumentation

All vitamins including vitamin C (ascorbic acid), vitamin B1 (Thiamine HCl), vitamin B9 (Folic acid), vitamin B12 (Methylcobalamin, MeB12), vitamin B3 (nicotinic acid), vitamin D3 (Cholecalciferol), and vitamin B12 (Cyanocobalamin, CNCbl), and vitamin B6 (pyridoxine) were purchased from Merck (USA). Silver nitrate ($AgNO_3$), Maltol (3-hydroxy-2-methyl-4-pyrone), hydrochloric acid, and sodium hydroxide were purchased from Sigma Aldrich (USA). All the reagents were used without further purification. Throughout the experiment deionized (D.I) water was used.

All the spectroscopic measurements before and after interaction of McAgNPs with Vit-C and Vit-B1 were taken by a Visible spectrophotometer (Jenway-6301, Japan) provided with a quartz cuvette of path length 1 cm. The IR spectra was recorded using Fourier Transform Infrared spectrometer (Shimadzu, prestige-21, Japan) to study the interaction between McAgNPs and Vit-C and Vit-B1. Particle size distribution and surface morphology of McAgNPs before and after interaction with Vit-B1 and Vit-C was studied by Atomic Force Microscopy (AFM) (Agilent-5500, Agilent-USA), using 1.122 Pico view software in tapping mode.

Preparation of colloidal solution of McAgNPs

McAgNPs were synthesized by reduction of $AgNO_3$ using maltol according to our previous publication [39]. In a typical experiment, 3.0 mL of alkaline Maltol (pH = 11.00) was added drop wise to a boiled solution (15.0 mL) of $AgNO_3$ under constant stirring. Heating was stopped and stirring continued for 15 min until the reaction mixture turned bright yellow. The appearance of yellow color indicates the formation of McAgNPs. These nanoparticles were cooled and kept at room temperature (RT) (~ 28 ± 2 °C) for additional analysis. The synthesized AgNPs were characterized by visible spectroscopy with a SPR band at 436 nm.

Colorimetric detection of vitamins

The biosensing ability of McAgNPs was checked by interacting them with different vitamins including Vit-C, Vit-B1, Vit-B9, MeB12, Vit-B3, Vit-D3, and CNCbl, Vit-B6,. 300 µM of all water-soluble vitamins (Vit-C, Vit-B1, Vit-B6, MeB12, CNCbl) were prepared by dissolving a specific amount of them separately in 10.0 mL deionized water. Solutions of Vit-D3 and Vit-B9 were prepared in ethanol (70%) and NaOH (0.1 M), respectively. 1 mL of McAgNPs was interacted with 1 mL of vitamins (300 µM) in separate glass vials (1:1 v/v), then incubated for 10 min at RT (~ 28 ± 2 °C). During incubation the color of the Vit-B1 and Vit-C changed from yellow to green and orange sequentially, but all other mixtures remained unchanged. The spectral changes were recorded by visible spectroscopy. The interaction was also confirmed by the job's plot of continuous variation method and calibration curve method/standard curve was used for calculating the limit of detection (LOD). FTIR-spectroscopy was used to elucidate the binding capability of McAgNPs with sensed vitamins. Possible degree of aggregation after interaction of Vit-C and Vit-B1 was monitored by AFM.

Pretreatment of environmental and biological samples

The tap water was acquired from our lab (Federal Urdu University of Arts, Science, and Technology) and while the lake water was acquired from Lake Kenjhar (Thatta, Sindh Pakistan). To investigate the influence of interferences of coexisting substances in water samples, 1 mL of tap and lake water were individually spiked in Vit-C-McAgNPs and Vit-B1 complexes (1:1:1v/v ratio). These solutions were incubated for 10 min at RT (~ 28 ± 2 °C). The biological sample i.e., human blood plasma was collected from CBSCR (Centre of Bioequivalence Studies and Clinical Research),

University of Karachi, and a urine sample was collected from Dow Diagnostic Laboratory, Karachi. The blood sample was preserved at − 20 °C but the urine sample was examined immediately after the collection. Plasma and urine samples were separately diluted to 10 folds with deionized water. Individually urine and plasma samples were spiked in McAgNPs- + Vit-C and Vit-B1 complexes (1:1:1v/v ratio). All the solutions were incubated separately for 10 min at RT (~ 28 ± 2 °C). The spectral changes were monitored by visible spectrophotometer. Recovery studies were also done by spiking of variable concentration of Vit-C and Vit-B1 into urine and plasma samples, then these spiked samples were added in to McAgNPs. After incubation of 10 min, spectral changes were observed by visible spectrophotometer. The recoveries of Vit-C and Vit-B1 were calculated by the given formula:

$$\% \text{ Recovery} = \frac{\text{Calculated Vit} - \text{C/Vit} - \text{B1}}{\text{Actual Vit} - \text{B1/Vit} - \text{B1}} \times 100.$$

Pretreatment of samples for selectivity studies

Selectivity of the sensor has been confirmed by adding 300 µM of various vitamins such as Vit-B1, Vit-B9, MeB12, Vit-B3, Vit-D3, and CNCbl, into the Vit-C/Vit-B1-McAgNPs complexes separately. Moreover, the interference of metals ion (Zn^{+2}, Fe^{+2}, Mg^{+2}, Ni^{+2}, Mo^{+6}, Cd^{+2}, Ce^{+4}, Ba^{+2}, and Co^{+2}, in the detection of both vitamins was also studied by adding 300 µM of these metal ions into McAgNPs-Vit-C and Vit-B1 complexes. After incubating the solutions for 10 min spectral changes were monitored.

Pretreatment of pharmaceutical tablets

500 mg of Cecon chewable tablets and 100 mg of B-compound Forte manufactured by Ethical Laboratories (Pvt) Ltd and Abbott laboratories were purchased. For recovery studies, tablets were ground and dissolved in D.I water, stir the tablet solution for 5 min then filter the solution by using Whatman 540 filter paper to eliminate the solid insoluble suspended particles from the solution. Dilute the solution as the experiment requirement of concentration study. The different concentration of tablet solution was spiked/added into the McAgNPs, incubated the mixture for 10 min at RT. The spectral changes were observed by visible spectroscopy. Calibration curve was used to study/calculate % recovery of the Vit-C and Vit-B1 in the tablet.

All the provided facts (if valid) were presented as the mean ± SD of the triplicate trials. One-way analysis of variance (ANOVA) was applied to evaluate the information sets, while $P < 0.05$ was described as significant.

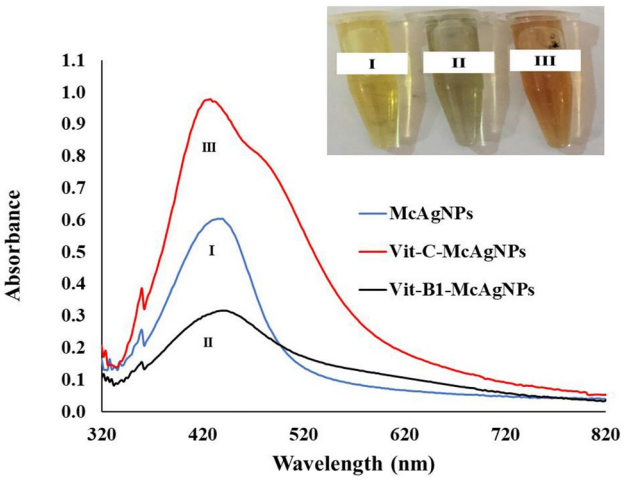


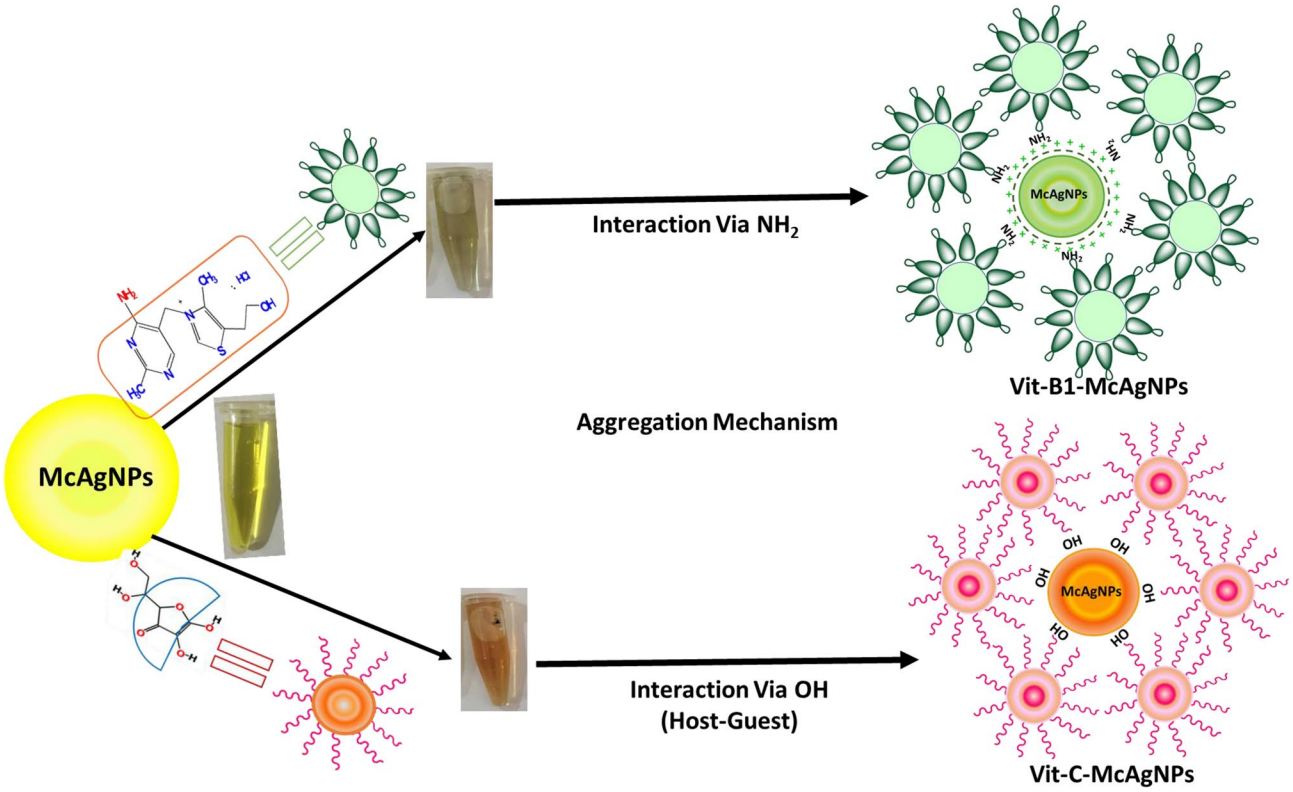
Fig. 1 Visible absorption spectra of McAgNPs (I) spectra of Vit-C-McAgNPs showing enhancement and shift in SPR band from 436 nm 490 nm (II) spectra of Vit-B1-McAgNPs showing quenching in SPR band at 436 nm (III). Insert: digital image showing change in a colorimetric property of McAgNPs after interaction of Vit-C and Vit-B1

Result and discussion

Colorimetric detection of vitamins

The color of the nanoparticles transformed instantly to orange and green from yellow respectively as the Vit-C and Vit-B1 were added into it. The spectral changes were recorded after 10 min of incubation, which verified the hyperchromic shift (enhancement) in absorption intensity at 436 nm with the arrival of new red shifted band at 490 nm, in the case of Vit-C. The Vit-C has strong antioxidant properties to break down the bond between capping agent and silver core and this is responsible for the enhancement in absorption peak and aggregation of nanoparticles [40]. The hyperchromic shift in absorption intensity could be attributed due to the existence of many O–H groups in the Vit-C structure, which can form strong hydrogen bonds with McAgNPs through host–guest interaction [41]

After the addition of Vit-B1, color of McAgNPs rapidly changed from yellow to green, and the absorption intensity at 436 nm also decreased (hypochromic shift) (Fig. 1). Hypochromic shift could be attributed to the interactions between OH, NH_2 and sulphur groups of the vitamin B1 and AgNPs. These groups have greater affinity toward AgNPs, and there is availability of more binding sites in Vit-B1 than other competing vitamins [17] (Scheme 1), furthermore, the McAgNPs have negative charges which were nullified by positively charged vitamin B1, which plausibly stimulated the aggregation of McAgNPs, consequently leading to hypochromic shift in their absorbance [42].



Scheme 1 Schematic design demonstrating the colorimetric changes and aggregation mechanism of McAgNPs after interaction of Vit-B1 and Vit-C

The binding ratio between McAgNPs and Vit-C/Vit-B1 was evaluated by job's plot method. Results revealed that maximum complexation was found to be 7:3 (Vit-C-McAgNPs) and 1:1 (Vit-B1-McAgNPs) (S1a, b).

The analytical capability of the McAgNPs in the presence of Vit-C and Vit-B1 was examined by varying concentrations in the range of 0.1–1 µM with linear regression $R^2 = 0.9884$ (Vit-C) and 0.9959 (Vit-B1). The mechanism followed Beer's law with good linear correlation. The limit of detection of Vit-C and Vit-B1 was determined to be 0.064 and 0.038 µM sequentially. (Fig. 2a, b). Additionally, the limit of detection of the projected study was compared with previously described methods. Our projected sensor was more sensitive than many other recently published sensors (Table 1).

Stability of Vit-C-McAgNPs and Vit-B1-McAgNPs Complexes at variable pH

pH variation (1–13) significantly affects the complexation of McAgNPs with Vit-C and/Vit-B1. The pH of McAgNPs before interaction of Vit-C and Vit- B1 was 7.32. The pH of complexes was varied from 1 to 13. The initial pH of Vit-C-McAgNPs complex was 4.17. There was no evident effect on the degree of aggregation of the complex at all pHs except at pH (1–2), absorbance intensity of Vit-C-McAgNPs complex was reduced greatly, possibly due to the oxidation of Vit-C or self-aggregation of McAgNPs. The absorbance intensity of Vit-C-McAgNPs complex was maximum at pH 4–5 because pH 4 facilitates the stability of complex and results were also verified by pKa (i.e., 4.10) of Vit-C [43]. The pH of Vit-B1-McAgNPs complex was determined to be 3.12. Vit-B1-McAgNPs complex remained stable at all pHs, but the degree of aggregation was high at an acidic range of pH i.e., (3–6) which might be attributed to the robust interparticle collaboration through hydrogen-bonding among protonated (–N and –NH) groups in Vit-B1 on the surface of McAgNPs. (Fig. 3a). The basic pH reduced the degree of aggregation which may be due to deprotonation of –NH group [44].

Stability of Vit-C-McAgNPs and Vit-B-McAgNPs complex at variable ionic strengths

The stability of nanoparticles and their complexes are extremely important because of their vital usage in variable biological applications. Whereas aggregation can amend their in vivo and in vitro comportment of the nanoparticles. The presence of high concentration of electrolyte supports the aggregation of nanoparticles, and it can be explained on

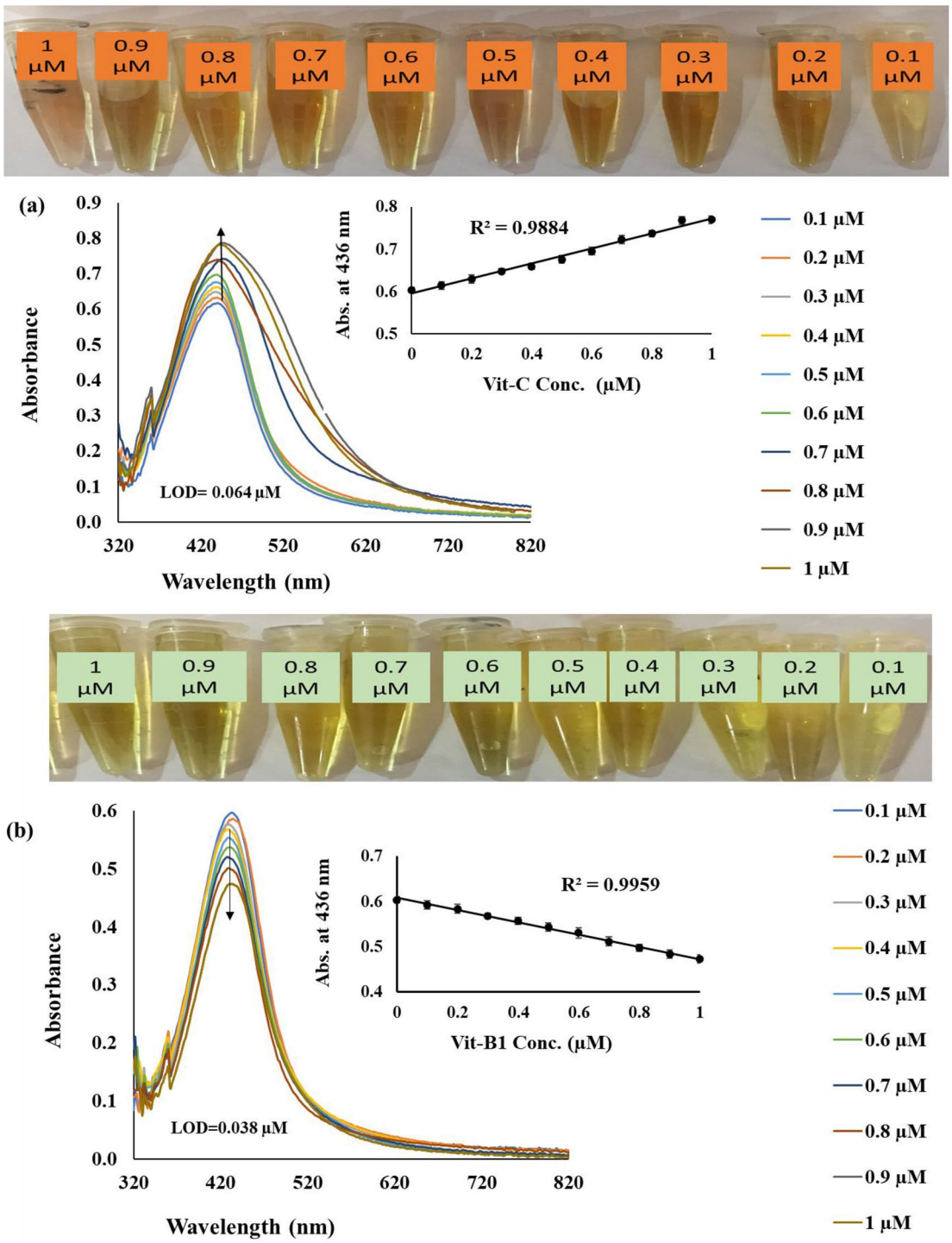


Fig. 2 **a** Spectral transformation of McAgNPs in the existence of varying concentrations of Vit-C (0–1 µM). Inert: showing linear regression line and digital image showing color variation of Vit-C-McAgNPs. **b** Spectral transformation of McAgNPs in the existence of varying concentrations of Vit-B1 (0–1 µM). Inert: showing linear regression line and digital image showing color variation of Vit-B1-McAgNPs

the basis of DLVO (Derjagun Landan Vewey Overbeek) theory. As the concentration of electrolyte increases the repulsive electrostatic repulsion between the neighboring ions decreases and it causes aggregation of nanoparticles [45, 46]. The effect of electrolyte on the stability of Vit-C-McAgNPs and Vit-B-McAgNPs complexes were studied in the

Table 1 Evaluation of Limit of Detection (LOD) of McAgNPs with other reported methods

Analytes	Probe used	Linear range (μM)	LOD (μM)	References
Vit-C	Carbon black nanoballs	0.05–2.75	5.7	[49]
	N-CDs	1–750	0.3	[30]
	Graphene oxide nanocomposite	283–2330	34.7	[50]
	BNS-CDs@Fe^{+3}	1–110	0.3	[51]
	DNA decorated AuNPs	0–20	2.5	[52]
	CDs/AuNCs on-off-on	0.15–5	0.105	[53]
	McAgNPs	0–1	0.064	Present work
Vit-B1	(β-FeOOH) NRDs	N/A	0.044	[33]
	Arg-GQDs	0.1–8.0	0.053	[28]
	AgNPs	4–1.2	0.05	[15]
	Copper-based MOFs	4–700	1	[54]
	$Y2O_3$: Eu NPs	0–44	0.144	[26]
	AuNPs	0.5–3	0.5	[55]
	McAgNPs	0–1	0.038	Present work

concentration range of 0.1–1000 mM at (RT) (~ 28 ± 2 °C) in 1:1 v/v ratio. Figure 3b shows that the Vit-C-McAgNPs and Vit-B-McAgNPs complexes were stable in low concentration range. There is no obvious change in absorption intensity and color of both complexes in the concentration range of 0.1–5 mM, As the concentration of electrolyte increases from 5 mM, gradual decrease in the absorption intensity (with clear change in color) was observed. It indicates that the high concentration of electrolyte supports the high degree of aggregation of Vit-C-McAgNPs and Vit-B-McAgNPs complexes.

Aggregation mechanism of Vit-C-McAgNPs and Vit-B1-McAgNPs at variable time

Aggregation mechanism of Vit-C-McAgNPs and Vit-B1-McAgNPs complexes was monitored between 0 and 120 min. As the Vit-C and Vit-B1were added into McAgNPs separately the color of the solution started to transform from yellow to orange (Vit-C) and green (Vit-B1) which indicate the formation of complexes. Absorption intensity of Vit-C-McAgNPs increases by the passage of time with an increase in the intensity of color from light orange to dark orange within 120 min of interaction (Fig. 3c). Formation of the Vit-B1-McAgNPs complex was started just after the addition of Vit-B1 into McAgNPs, the absorption intensity decreases with transformation in color from yellow to green. As the time of interaction increases from 10 to 120 min, gradual decline in absorption intensity was observed. The variable change in color (green to colorless) with the formation of visible aggregates was also observed (Fig. 3d). The alteration in color and absorption intensity indicated the formation of nanoaggregates.

Mechanism of interaction By FTIR-spectroscopy

The mechanism of interaction related to Vit-C and Vit-B with McAgNPs was monitored by FTIR-spectroscopy, to check the involvement of functional groups in the complex formation. The FTIR-spectra of Vit-C and Vit-B1 (separately) were compared with complex of McAgNPs with both vitamins. The FTIR-spectra of Vit-C showed a characteristic band of OH (stretches) at 3401.62 and 3210.80 cm^{-1}. The band of C=C (stretching), C=O (stretching), C–O–C (stretching), C–O–H (bending), and C–C (ring), at 1654.14, 1751.96, 1271.16, 1242.82, and 871.82 cm^{-1} were recorded. Spectrum of Vit-C-McAgNPs complex revealed that the peak of O–H becomes broad and shifted which may be due to the presence of moisture that can't interfere with the analysis because the FTIR-spectra of water does not show intense band. Results also revealed that C=O completely disappeared while the peak of C–O–C, and C–O–H is shifted to lower wavenumber, which reveals the involvement of these groups in the formation of Vit-C–McAgNPs complex. The disappearance of C=O is evidence that the Vit-C attached on the surface of McAgNPs through C=O group (Fig. 4a).

The spectra of Vit-B1 showed a characteristic bands of –NH (–NH_2) (stretching), O–H (stretching), N–H (stretching), C–N (stretching), C–O (stretching), and C–S–C (stretching) at 3489.62, 3185.56, 1614.36, 1379.60, 1043.87, and at 741.52 cm^{-1} [47]. After the formation of complex between Vit-B1 and McAgNPs the bands of NH_2, OH and C–S–C completely disappeared, whereas minor quenching in the intensity of other bands was observed. The above fact proves the linkage of Vit-B1 with McAgNPs through NH_2, OH, and C–S–C groups (Fig. 4b).

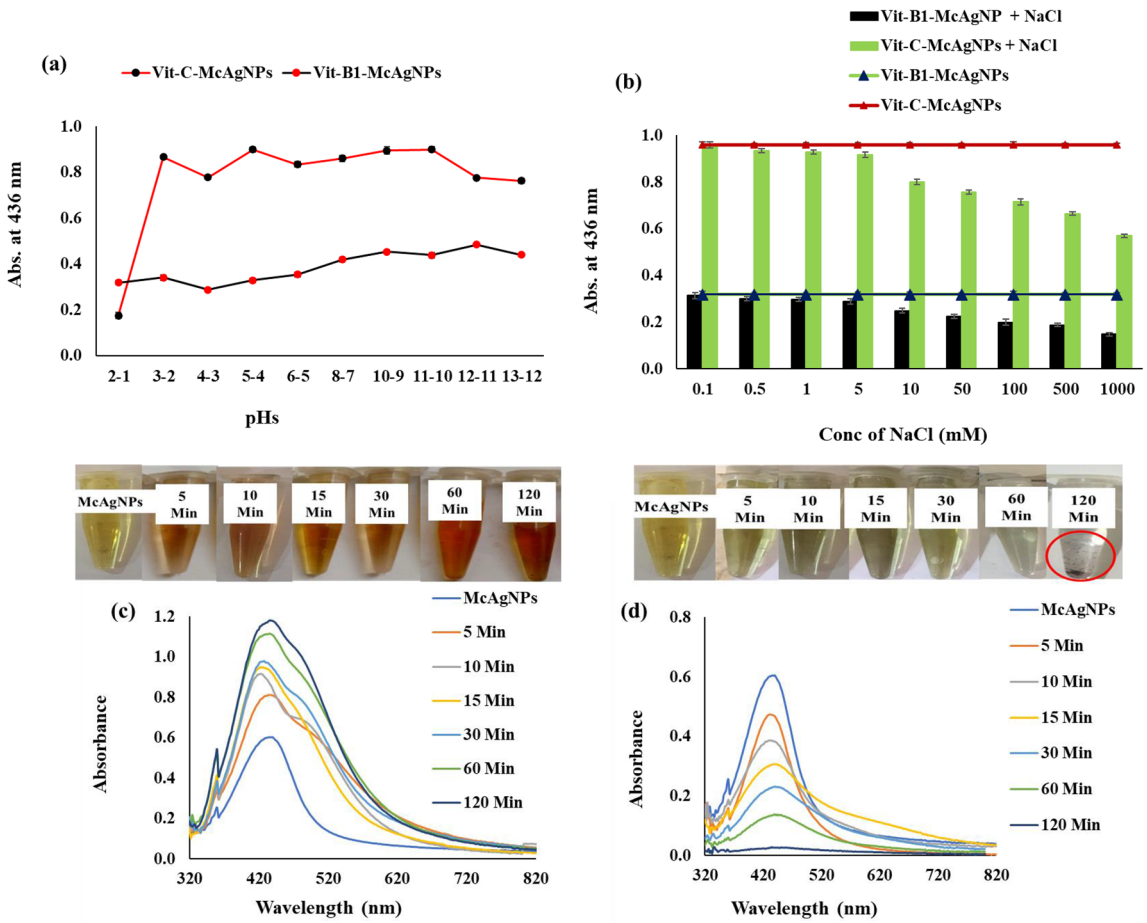


Fig. 3 Effects of variable parameters on Vit-C-McAgNPs and Vit-B1-McAgNPs complexes **a** effect of variable pH, **b** ionic strength, **c** time on the aggregates formation of Vit-C-McAgNPs and **d** Vit-B-McAgNPs complexes. Inert: showing the color changes at different time interval after interaction of these vitamins with McAgNPs

Size evaluation of the aggregates by AFM

The aggregation mechanism, of McAgNPs before and after the interaction of both vitamins was evaluated by AFM. Results showed that the size of McAgNPs before interaction of Vit-C and Vit-B1 was found to be 30–40 nm with maximum peak height of 17.8 nm (S2a–c) [39]. After the addition of Vit-C the size of the NPs increased from 30 to 500 nm with maximum peak height of 17.5 nm. Addition of Vit-B1 showed a size of 400 nm with maximum peak height of 10.6 nm, this proves the aggregation of NPs (Fig. 5a–d). The formation of large size randomly packed aggregates may be due to change in dielectric environment of McAgNPs after the addition of both vitamins. The results were complemented with formation of visible aggregates in case of Vit-B1 (see Fig. 3d) and appearance of small shoulder peak at 490 nm in case of Vit-C (see Fig. 1).

Selectivity studies

Proficient selectivity for target investigation is essential for a newly originated sensing scheme with possible applications [48]. Vit-C and Vit-B1 are very essential constituents of human diet. In the body, both vitamins play a significant role in metabolic processes that have been linked to antiviral and bactericidal outcomes [42]. Consequently, the discriminating detection of Vit-C and Vit-B1 in the presence of other coexisting substances such as vitamins and metals are necessary. The sensing capability of McAgNPs was estimated against different vitamins including Vit-C, Vit-B1, Vit-B9, MeB12, Vit-B3, Vit-D3, CNCbl, and Vit-B6 (Fig. 6a). We also investigated whether interfering species affected the detection of Vit-C and Vit-B1. The selectivity of the proposed method was studied in the existence of other potential interfering 300 µM of vitamins (Vit-B9, Vit-B6, MeB12), Vit-B3, CNCbl and Vit-D3) and a variety of 300 µM of metal ions (Zn^{2+}, Fe^{2+}, Mg^{2+}, Ni^{2+}, Mo^{6+}, Cd^{2+}, Ce^{4+}, Ba^{2+}, and Co^{2+}). These were interacted with Vit-C-McAgNPs and

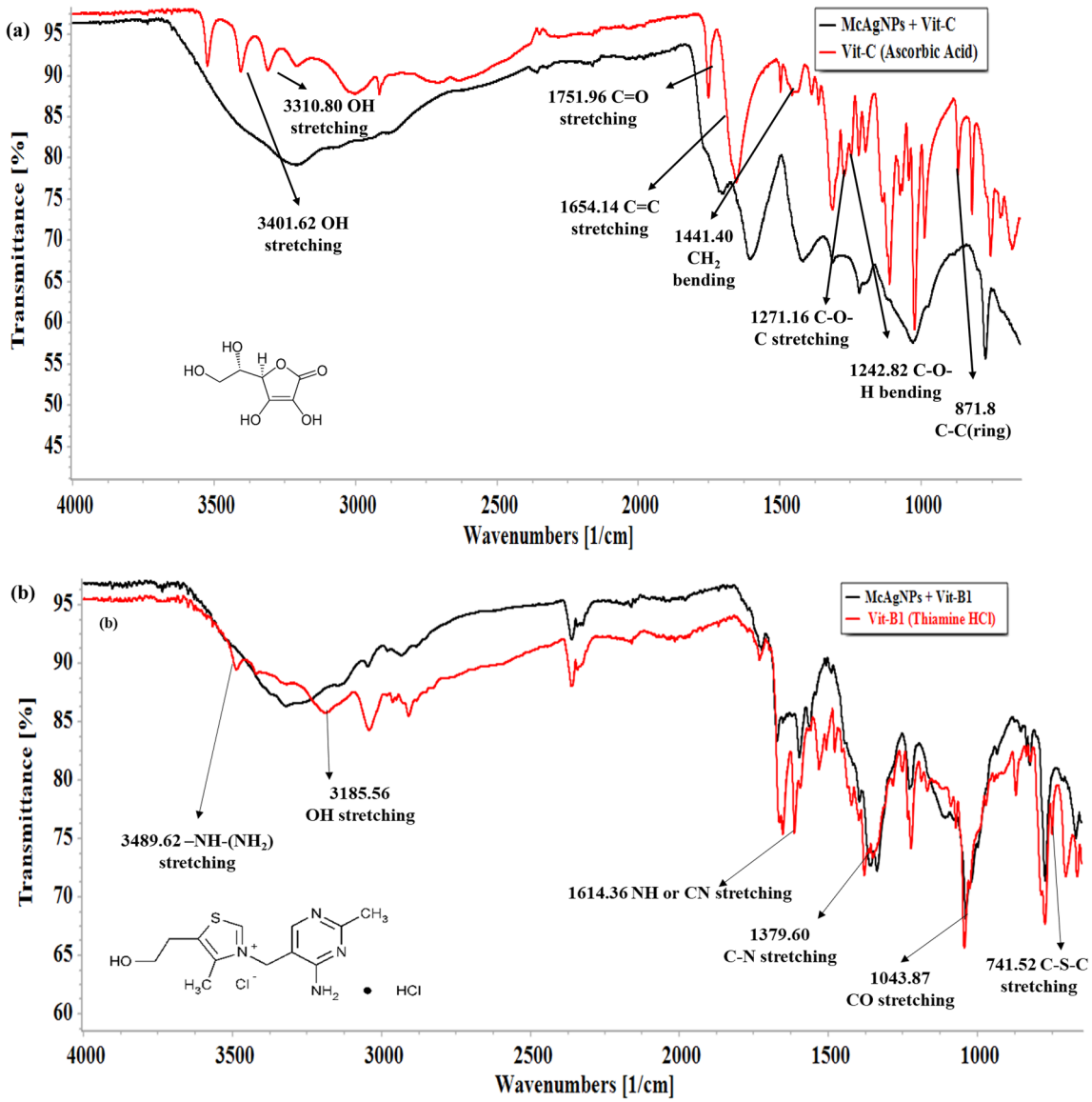


Fig. 4 The FTIR-spectra **a** Vit-C and McAgNPs + Vit-C, **b** Vit-B1 and McAgNPs + Vit-B1

Vit-B-McAgNPs complexes. Results reveal that there is no observable transformation in the absorption intensity and color of Vit-C-McAgNPs (orange) and Vit-B-McAgNPs (green) complexes, indicating that the interfering species in the matrix have no profound effect on the selective sensing abilities of McAgNPs (Fig. 6b, c). If both the vitamins (Vit-C and Vit-B1) are present in a single matrix they exhibit a slight interference for each other.

Application in real samples

To authenticate the practicality of the projected colorimetric scheme, the method was employed for the detection of both vitamins in urine, blood plasma lake water, and tap water. The spiking results show that the ingredients in urine, plasma, tap water and lake water does not impede the detection of both vitamins (Fig. S3a, b). The recovery experiments were also done in pharmaceutical tablets, Urine, plasma, tap, and lake water by spiking method. Considerable recovery rates in the range of 96–106% were achieved, which suggested the consistency and accuracy of the proposed sensing scheme for the detection of Vit-C and Vit-B1 in real samples (Table 2).

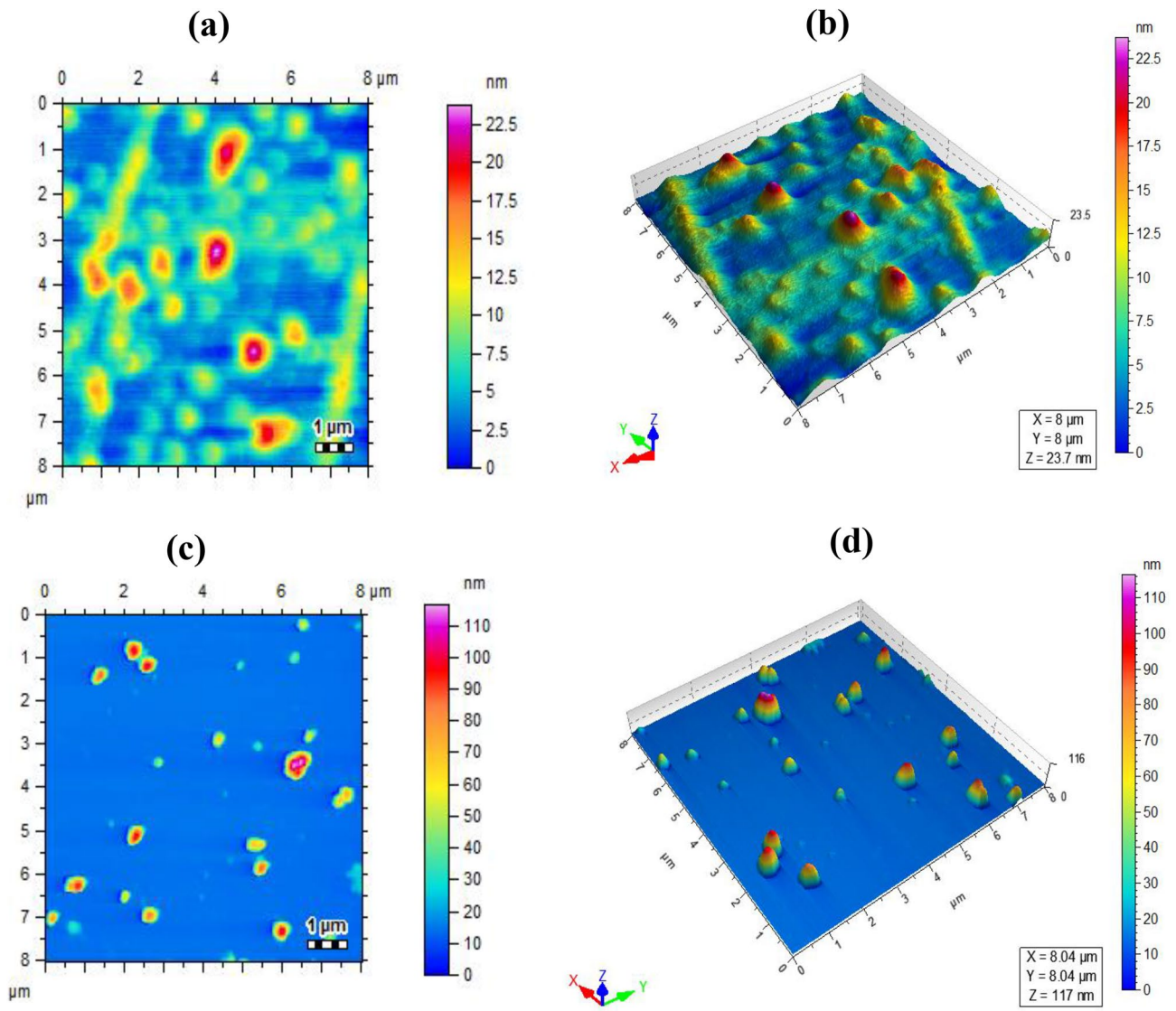


Fig. 5 AFM images showing aggregation of McAgNPs after interaction of Vit-C and Vit-B1 **a** morphology and **b** 3-D image of Vit-C-McAgNPs. **c** Morphology and **d** 3-D image of Vit-B1-McAgNPs

Conclusion

Herein, we have developed an easy and sensitive colorimetric sensor for the detection of Vit-C and Vit-B1 with a remarkable detection limit (0.068 and 0.038 µM). The existence of Vit-C and Vit-B can encourage the aggregation of nanoparticles to trigger a colorimetric change from yellow to orange and green for Vit-C and Vit-B sequentially. Our proposed scheme was free from interferences of competing, vitamins, metals, biological, environmental, and pharmaceutical samples. It is suitable for the detection of Vit-C and Vit-B1 in urine, plasma, water samples, and commercial pharmaceutical samples with good recovery rates (96–106%). To the best of our knowledge, it is the first report in which McAgNPs were used as a colorimetric sensor for vitamins.

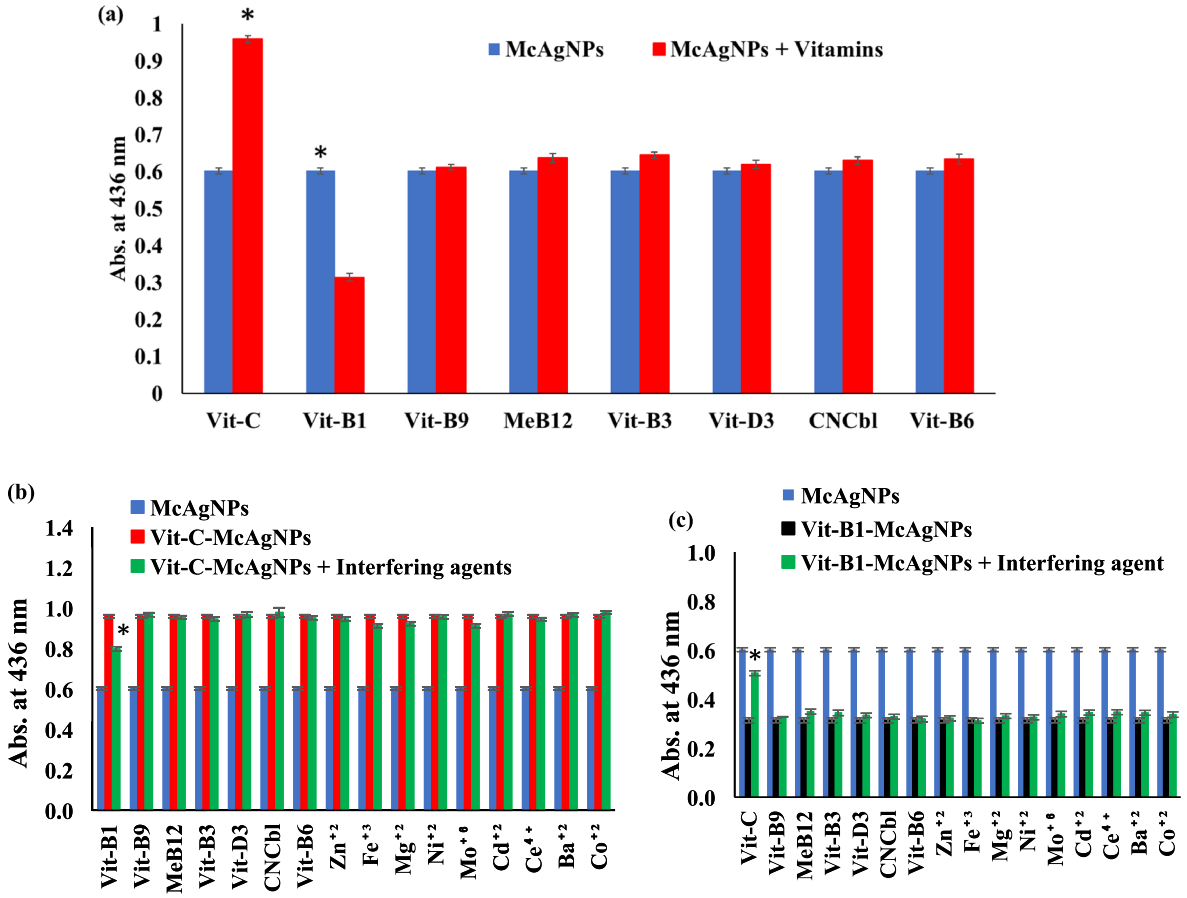


Fig. 6 Application of McAgNPs as a biosensor for different Vitamins. Asterisk (*$P < 0.05$) specifies statistical significance (**a**), selectivity of McAgNPs system for the detection of Vit-C (**b**) and Vit-B1 (**c**) in the presence of interfering Vitamins and metals

Table 2 Determination of Vit-C and Vit-B1 in Water (Lake and Tap), Pharmaceutical Tablets, Biological fluids (Urine and Plasma)

	McAgNPs + Vit-C			McAgNPs + Vit-B1		
	Added (μM)	Found (μM)	% recovery	Added	Found	% recovery
Lake water	50	48	96.0	50	48	96.0
	100	99	99.0	100	96	96.0
Tap water	50	49	98.0	50	49	98.0
	100	97	97.0	100	97	97.0
Pharmaceutical tablet	80	82	102.5	80	84	105.0
	100	102	102.0	100	106	106.0
Urine	50	49	98.0	50	52.0	104.0
	100	105	105.0	100	102	102.0
Blood plasma	50	52	104.0	50	51	102.0
	100	106	106.0	100	103	103.0

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00775-022-01944-5.

Author contributions Conceptualization and supervision, SSN, and HA; methodology, SSN, and HA; validation, SSN, and HA; formal analysis, SSN, HA, AS, and MRS; resources, SSN, HA and MRS; data curation, SSN, HA, and MRS; writing-original draft preparation, SSN, HA; writing-review and editing, SSN, AS and HA.

Funding This research did not receive any specific grant from funding agencies the public, commercial, or not for profit sectors.

Declarations

Conflict of interest Authors declared no conflict of interest. All authors contributed significantly and have read and agreed to submit the manuscript to this journal.

References

1. Malekzad H, Zangabad PS, Mirshekari H, Karimi M, Hamblin MR (2017) Noble metal nanoparticles in biosensors: recent studies and applications. Nanotechnol Rev 6:301–329
2. Shrivas K, Nirmalkar N, Thakur SS, Deb MK, Shinde SS, Shankar R (2018) Sucrose capped gold nanoparticles as a plasmonic chemical sensor based on non-covalent interactions: application for selective detection of vitamins B1 and B6 in brown and white rice food samples. Food Chem 250:14–21
3. Bellan LM, Wu D, Langer RS (2011) Current trends in nanobiosensor technology. Wiley Interdiscipl Rev Nanomed Nanobiotechnol 3:229–246
4. Bhalla N, Jolly P, Formisano N, Estrela P (2016) Introduction to biosensors
5. Li Y, Schluesener HJ, Xu S (2010) Gold nanoparticle-based biosensors. Gold Bull 43:29–41
6. Jiang S, Win KY, Liu S, Teng CP, Zheng Y, Han M-Y (2013) Surface-functionalized nanoparticles for biosensing and imaging-guided therapeutics. Nanoscale 5:3127–3148
7. Sui N, Liu F, Li T, Wang L, Wang T, Liu M, Yu WW (2017) Colorimetric detection of ascorbic acid based on the trigger of gold nanoparticles aggregation by Cr (III) reduced from Cr (VI). Anal Sci 33:963–967
8. Chen X, Schluesener HJ (2008) Nanosilver: a nanoproduct in medical application. Toxicol Lett 176:1–12
9. Shanmugaraj K, Ilanchelian M (2016) Colorimetric determination of sulfide using chitosan-capped silver nanoparticles. Microchim Acta 183:1721–1728
10. David IG, Florea M-A, Cracea OG, Popa DE, Buleandra M, Iorgulescu EE, David V, Badea IA, Ciucu AA (2015) Voltammetric determination of B 1 and B 6 vitamins using a pencil graphite electrode. Chem Pap 69:901–910
11. Zhang Y, Zhou W-E, Yan J-Q, Liu M, Zhou Y, Shen X, Ma Y-L, Feng X-S, Yang J, Li G-H (2018) A review of the extraction and determination methods of thirteen essential vitamins to the human body: an update from 2010. Molecules 23:1484
12. Hacisevki A (2009) An overview of ascorbic acid biochemistry. Ankara Üniversitesi Eczacılık Fakültesi Dergisi 38:233–255
13. Rezaei B, Shahshahanipour M, Ensafi AA (2017) In situ production of silver nanoparticles for high sensitive detection of ascorbic acid via inner filter effect. Mater Sci Eng C 71:663–668
14. Moreno P, Salvado V (2000) Determination of eight water-and fat-soluble vitamins in multi-vitamin pharmaceutical formulations by high-performance liquid chromatography. J Chromatogr A 870:207–215
15. Rajamanikandan R, Ilanchelian M (2017) Simple and visual approach for highly selective biosensing of vitamin B1 based on glutathione coated silver nanoparticles as a colorimetric probe. Sens Actuators B Chem 244:380–386
16. Tan J, Li R, Jiang Z-T (2011) Determination of thiamine (vitamin B1) in pharmaceutical tablets and human urine by titania-based ligand-exchange hydrophilic interaction chromatography. Anal Methods 3:1568–1573
17. Zielinski MV (2014) Determination of thiamine in solution by UV-visible spectrophotometry: the effect of interactions with gold nanoparticles
18. Gul W, Zahid S, Perveen S, Ahmad I (2014) Methods of analysis of thiamine: a review. RADS J Pharm Pharm Sci 2:39–47
19. Devaki SJ, Raveendran RL (2017) Vitamin C: sources, functions, sensing and analysis. In: Vitamin C. InTech
20. Shi H, Xu Y, Wang Y, Song W (2010) Assembly of ferrocenylhexanethiol functionalized gold nanoparticles for ascorbic acid determination. Microchim Acta 171:81–89
21. Ivanov S, Tsakova V, Mirsky VM (2006) Conductometric transducing in electrocatalytical sensors: detection of ascorbic acid. Electrochem Commun 8:643–646
22. Mudabuka B, Ondigo D, Degni S, Vilakazi S, Torto N (2014) A colorimetric probe for ascorbic acid based on copper–gold nanoparticles in electrospun nylon. Microchim Acta 181:395–401
23. Yang YJ, Li W (2014) CTAB functionalized graphene oxide/multiwalled carbon nanotube composite modified electrode for the simultaneous determination of ascorbic acid, dopamine, uric acid and nitrite. Biosens Bioelectron 56:300–306
24. Kayamori Y, Katayama Y, Urata T (2000) Nonenzymatic elimination of ascorbic acid in clinical samples
25. Mo Q, Liu F, Gao J, Zhao M, Shao N (2018) Fluorescent sensing of ascorbic acid based on iodine induced oxidative etching and aggregation of lysozyme-templated silver nanoclusters. Anal Chim Acta 1003:49–55
26. Moghaddam AB, Gudarzy F, Ganjkhanlou Y (2014) A fluorescent probe for detecting thiamine using the luminescence intensity of nanoparticles. J Fluoresc 24:1025–1030
27. Tan H, Li Q, Zhou Z, Ma C, Song Y, Xu F, Wang L (2015) A sensitive fluorescent assay for thiamine based on metal-organic frameworks with intrinsic peroxidase-like activity. Anal Chim Acta 856:90–95
28. Nemati F, Zare-Dorabei R, Hosseini M, Ganjali MR (2018) Fluorescence turn-on sensing of thiamine based on arginine–functionalized graphene quantum dots (Arg-GQDs): central composite design for process optimization. Sens Actuators B Chem 255:2078–2085
29. Wang J, Peng X, Li D, Jiang X, Pan Z, Chen A, Huang L, Hu J (2018) Ratiometric ultrasensitive fluorometric detection of ascorbic acid using a dually emitting CdSe@ SiO 2@ CdTe quantum dot hybrid. Microchim Acta 185:42
30. Zhang Y, Fang X, Zhao H, Li Z (2018) A highly sensitive and selective detection of Cr(VI) and ascorbic acid based on nitrogen-doped carbon dots. Talanta 181:318–325
31. Ding Y, Zhao J, Li B, Zhao X, Wang C, Guo M, Lin Y (2018) The CoOOH–TMB oxidative system for use in colorimetric and test strip based determination of ascorbic acid. Microchim Acta 185:131
32. Rostami S, Mehdinia A, Jabbari A (2017) Seed-mediated grown silver nanoparticles as a colorimetric sensor for detection of ascorbic acid. Spectrochim Acta Part A Mol Biomol Spectrosc 180:204–210
33. Purbia R, Paria S (2018) Green synthesis of single-crystalline akaganeite nanorods for peroxidase mimic colorimetric sensing

of ultralow-level vitamin B1 and sulfide ions. ACS Appl Nano Mater 1:1236–1246
34. Lynch P, Young IS (2000) Determination of thiamine by high-performance liquid chromatography. J Chromatogr A 881:267–284
35. Garnero C, Longhi M (2010) Development of HPLC and UV spectrophotometric methods for the determination of ascorbic acid using hydroxypropyl-β-cyclodextrin and triethanolamine as photostabilizing agents
36. Vilela D, González MC, Escarpa A (2012) Sensing colorimetric approaches based on gold and silver nanoparticles aggregation: chemical creativity behind the assay. A review. Anal Chim Acta 751:24–43
37. Naqvi SS, Anwer H, Siddiqui A, Zohra RR, Ali SA, Shah MR, Hashim S (2021) Novel synthesis of maltol capped copper nanoparticles and their synergistic antibacterial activity with antibiotics. Plasmonics 16:1915–1928
38. Naqvi S, Anwer H, Ahmed SW, Siddiqui A, Shah MR, Khaliq S, Ahmed A, Ali SA (2020) Synthesis and characterization of maltol capped silver nanoparticles and their potential application as an antimicrobial agent and colorimetric sensor for cysteine. Spectrochim Acta Part A Mol Biomol Spectrosc 229:118002
39. Naqvi S, Anwer H, Ahmed SW, Siddiqui A, Shah MR, Khaliq S, Ahmed A, Ali SA (2019) Synthesis and characterization of maltol capped silver nanoparticles and their potential application as an antimicrobial agent and colorimetric sensor for cysteine, Spectrochimica Acta Part A Mol Biomol Spectrosc 118002
40. Liu H, Na W, Liu Z, Chen X, Su X (2017) A novel turn-on fluorescent strategy for sensing ascorbic acid using graphene quantum dots as fluorescent probe. Biosens Bioelectron 92:229–233
41. Tan X, Gou Q, Yu Z, Pu Y, Huang J, Huang H, Dai S, Zhao G (2020) Nanocomposite based on organic framework-loading transition-metal co ion and cationic pillar [6] arene and its application for electrochemical sensing of l-ascorbic acid. Langmuir 36:14676–14685
42. Luo Y, Miao H, Yang X (2015) Glutathione-stabilized Cu nanoclusters as fluorescent probes for sensing pH and vitamin B1. Talanta 144:488–495
43. Gao Y, Yan X, Li M, Gao H, Sun J, Zhu S, Han S, Jia L-N, Zhao X-E, Wang H (2018) A "turn-on" fluorescence sensor for ascorbic acid based on graphene quantum dots via fluorescence resonance energy transfer. Anal Methods 10:611–616
44. Khan U, Niaz A, Shah A, Zaman MI, Zia MA, Iftikhar FJ, Nisar J, Ahmed MN, Akhter MS, Shah AH (2018) Thiamine-functionalized silver nanoparticles for the highly selective and sensitive colorimetric detection of Hg 2+ ions. New J Chem 42:528–534
45. Fuller M, Köper I (2018) Polyelectrolyte-coated gold nanoparticles: the effect of salt and polyelectrolyte concentration on colloidal stability. Polymers 10:1336
46. Li D, Huang Y, Li J (2005) Influence of configuration of carboxylic acid capping ligands on the salt-induced aggregation of gold clusters. J Colloid Interface Sci 283:440–445
47. Mallakpour S, Sadaty MA (2016) Thiamine hydrochloride (vitamin B1) as modifier agent for TiO_2 nanoparticles and the optical, mechanical, and thermal properties of poly (vinyl chloride) composite films. RSC Adv 6:92596–92604
48. Kong W, Wu D, Li G, Chen X, Gong P, Sun Z, Chen G, Xia L, You J, Wu Y (2017) A facile carbon dots based fluorescent probe for ultrasensitive detection of ascorbic acid in biological fluids via non-oxidation reduction strategy. Talanta 165:677–684
49. Baytak AK, Aslanoglu M (2018) A novel sensitive method for the simultaneous determination of ascorbic acid, dopamine, uric acid and tryptophan using a voltammetric platform based on carbon black nanoballs. Arab J Chem. https://doi.org/10.1016/j.arabjc.2018.01.005
50. dos Santos PL, Katic V, Toledo KC, Bonacin JA (2018) Photochemical one-pot synthesis of reduced graphene oxide/Prussian blue nanocomposite for simultaneous electrochemical detection of ascorbic acid, dopamine, and uric acid. Sens Actuators B Chem 255:2437–2447. https://doi.org/10.1016/j.snb.2017.09.036
51. Liu Y, Wei Z, Duan W, Ren C, Wu J, Liu D et al (2018) A dual-mode sensor for colorimetric and "turn-on" fluorescent detection of ascorbic acid. Dyes Pigm 149:491–497. https://doi.org/10.1016/j.dyepig.2017.10.039
52. Malashikhina N, Pavlov V (2012) DNA-decorated nanoparticles as nanosensors for rapid detection of ascorbic acid. Biosens Bioelectron 33:241–246. https://doi.org/10.1016/j.bios.2012.01.011
53. Niu W-J, Shan D, Zhu R-H, Deng S-Y, Cosnier S, Zhang X-J (2016) Dumbbell-shaped carbon quantum dots/AuNCs nanohybrid as an efficient ratiometric fluorescent probe for sensing cadmium (II) ions and l-ascorbic acid. Carbon 96:1034–1042. https://doi.org/10.1016/j.carbon.2015.10.051
54. Tan H, Li Q, Zhou Z, Ma C, Song Y, Xu F et al (2015) A sensitive fluorescent assay for thiamine based on metal-organic frameworks with intrinsic peroxidase-like activity. Anal Chim Acta 856:90–95. https://doi.org/10.1016/j.aca.2014.11.026
55. Rao KJ, Paria S (2014) Green synthesis of gold nanoparticles using aqueous Aegle marmelos leaf extract and their application for thiamine detection. RSC Adv 4:28645–28652. https://doi.org/10.1039/C4RA03883E

Authors and Affiliations

Syeda Sumra Naqvi[1] · Humera Anwar[1] · Asma Siddiqui[1] · Muhammad Raza Shah[2]

[1] Department of Chemistry, Federal Urdu University of Arts, Science and Technology, Gulshan-E-Iqbal Campus, Karachi 75300, Pakistan

[2] H.E.J. Research Institute of Chemistry, International Center for Chemical and Biological Sciences (ICCBS), University of Karachi, Karachi 75270, Pakistan