Effects of Tartaric Acid on Gold Nanoparticle Synthesis: Optimization using Response Surface Methodology (RSM)

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**Abstract.** Gold nanoparticles (AuNPs) were synthesized using a chemical reduction method with NaAuCl₄ as the precursor, NaBH₄ as the reducing agent, and tartaric acid as the capping agent. The experimental design was developed using Face-Centered Central Composite Design (FC-CCD), with tartaric acid concentration (0.5; 1.0 and 1.5 M), sonication temperature (40; 60 and 80 ℃), and sonication time (10; 20 and 30 minutes) as the independent variables. The synthesized AuNPs were characterized by UV-Vis spectrophotometry, FTIR, TEM, and PSA. Results showed that tartaric acid played a critical role in nanoparticle formation. PSA analysis revealed that the Au-1 sample (without tartaric acid) exhibited an average size distribution of 103.9 nm, whereas the Au-2 sample (with tartaric acid) showed a reduced average size of 80 nm. TEM images confirmed that Au-1 particles displayed irregular morphology and less uniformity, while Au-2 particles exhibited smoother surfaces and more homogeneous size distribution. Response Surface Methodology (RSM) analysis generated 3D and contour plots, demonstrating optimized synthesis conditions: a sonication temperature of 56.85 °C (absorbance 0.32), a sonication time of 30 minutes (absorbance 0.84), and a tartaric acid concentration of 0.5 M (absorbance 1.06). These results highlight the importance of capping agents in controlling nanoparticle size and morphology, with potential implications for applications in catalysis, biosensing, and biomedical fields.

# INTRODUCTION

# Technology and science are experiencing rapid development globally, including in the fields of nanoscience, nanotechnology and nanomaterials. The application of various types of nanomaterials has been developed, one of which is nanoparticles. Nanoparticles exhibit unique physical, chemical and biological properties at the nanoscale compared to their counterparts at a larger scale or bulk particle [1]. Nanoparticle technology has various unique properties and advantages. Among them, nanoparticles have a larger surface area than other particles in the same amount, the smaller the size of a particle, the wider the surface area so that the affinity of the system increases. Then because of its particle size, nanoparticles have the ability to penetrate intercellular spaces that can be penetrated by colloidal particles, a higher ability to penetrate cell walls, both by diffusion, opsonication and flexibility. This flexible ability allows nanoparticles to be combined with other technologies and opens up broad potential to be developed in various fields and needs [2].

# Gold nanoparticles (AuNPs) have attracted much attention in the fields of science, research and technology development over the past few years. This is due to a number of unique advantages that gold nanoparticles have compared to other materials. Gold nanoparticles have optical properties that can be customized according to their size, the smaller the size, the higher the surface area. The optical property of gold nanoparticles is the presence of Surface Plasmon Resonance (SPR). This property allows for greater chemical reactivity and the ability to interact better with other molecules. Because of its SPR feature, gold nanoparticles have a high sensitivity to stimuli that can be applied as a biosensor [3]. Currently, research on the utilization of gold nanoparticles in the medical and biological fields continues to grow. Among them are cancer cell detection; targeted drug delivery, and antigens [4].

# The characteristics of gold nanoparticles are strongly influenced by the synthesis method [5]. Chemical reduction method is a widely practiced way of several methods of synthesizing gold nanoparticles, because of its convenience factor, relatively low cost and can be produced on a large scale and quantity. Various chemical agents, including trisodium citrate, ascorbic acid, and sodium borohydride (NaBH4), polyols, hydrogen peroxide, sulfite are reductants that are often used to make gold nanoparticles. The reduction process in the synthesis of gold nanoparticles is carried out by reducing Au3+ to Au0. When in its ionic form, Au3+ will repel each other with its fellow atoms due to the influence of similar charges. However, after being reduced to Au0 by the reductant, the charge of Au atoms will approach each other to become neutral, allowing Au atoms to approach and interact with each other through inter-metal bonds to form a nano-sized cluster [6]. The interaction between these atoms occurs very quickly and is often uncontrolled so that the previously desired gold particle size ranging from 1-100 nm changes rapidly into very large particles that can even exceed nanometer size. To prevent uncontrolled particle growth, a capping agent can be used.

# In this study, tartaric acid was chosen as capping agent because tartaric acid is a complexation agent that can control nanoparticle size and morphology [7]. Tartaric acid is a salt compound that is biodegradable, non-toxic and non- carcinogenic [8]. In addition, it exhibits antimicrobial and antioxidant activity [9]. Structurally, tartaric acid contains two carboxyl groups that can attach to the gold surface and provide a steric barrier to prevent aggregation. One carboxyl group binds to the nanoparticle surface, while the negatively charged second carboxyl group stabilizes the nanoparticles through electrostatic repulsion [10].

# Determining the optimal conditions to produce nanoparticles with desired properties remains a complex challenge due to the interactions among multiple synthesis parameters. Traditional methods often rely on trial-and-error, which is labor-intensive and time-consuming. Recently, green synthesis routes using plant extracts or polysaccharides have been explored as alternatives, offering biocompatibility but often suffering from limited reproducibility and poor control over particle size distribution [11,12]. Similarly, other capping agents such as citrate or polyvinylpyrrolidone (PVP) are widely used, but they either lack additional functional properties or require more complex processing [13].

In this research, gold nanoparticles are synthesized using NaBH₄ as the reducing agent and tartaric acid as the capping agent, with process optimization performed through Response Surface Methodology (RSM). RSM provides a structured statistical framework that reduces the number of experiments while capturing both the main effects and interactions of multiple factors [14]. The novelty of this work lies in the integration of tartaric acid—a low-cost, biodegradable, and functionally active compound—as a capping agent, combined with a systematic RSM approach to optimize synthesis parameters. This approach not only ensures better control over nanoparticle size and morphology compared to conventional methods, but also highlights tartaric acid’s dual role as both a stabilizer and a bioactive functionalizer, offering potential advantages for biomedical and catalytic applications. To the best of our knowledge, tartaric acid has not yet been systematically optimized as a capping agent for gold nanoparticle synthesis using RSM, making this study a novel contribution to the field.

# EXPERIMENTAL

## Materials and Instruments

The instrument used in this research are glassware, micropipettes, digital analytical balance, magnetic stirrer, sonicator (ultrasonic cleaner PS-20), centrifuge, UV-Vis spectrometer (Thermo ScientificTM Genesys 10) to observe the absorbance at UV-Vis wavelengths, as well as a particle size analyzer (PSA) using the Zetasizer Nano ZS 90 instrument (Malvern Instruments Ltd., UK) in the size range of 0.1 - 10,000 nm, Fourier Transform InfraRed (FTIR) (Shimadzu Instrument Spectrum One 8400s) and Transmission Electron Microscopy (TEM, Jeol Jem-1400).The materials used in this study are NaAuCl4(s) (Maxlab) as a source of Au, NaBH4(s) (Sodium Borohydride), Tartaric Acid(s) (Sigma Aldrich) and aqua DM (l).

## Synthesis of Gold Nanoparticles

## Synthesis of AuNPs was carried out by dissolving 0.05 mg NaAuCl4(s) with aqua DM into 250 mL volumetric flask. Then added reductor NaBH4(s) as much as 0.0015 g into 10 mL of NaAuCl4(l) solution. The mixture was then added 0.35 mL of tartaric acid with a concentration according to the predetermined variation using a micropipette. The mixing of the ingredients was done in a dark bottle. This procedure was carried out with the independent variables of tartaric acid concentration, sonication temperature, and sonication time whose variations are shown in Table 1.

## TABLE 1 Variations of the independent variables used

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| --- | --- | --- | --- |
| **No** | **Tartaric Acid Consentration (M)** | **Sonication Temperature (℃)** | **Sonication Time (minute)** |
| 1 | 0.5 | 40 | 10 |
| 2 | 1.0 | 60 | 20 |
| 3 | 1.5 | 80 | 30 |

## RSM processing according to the Central Composite Face-Centered (FC-CCD) design of the three independent variables resulted in 22 sample variations shown in Table 2.

**TABLE 2** Research desaign

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| --- | --- | --- | --- | --- | --- | --- |
| **No.** | **CCF Desing** | | | **Research Design** | | |
| **X0** | **X1** | **X2** | **Tartaric Acid Consentration (M)** | **Sonication Temperature (℃)** | **Sonication Time (minute)** |
| 1 | -1 | -1 | -1 | 0.5 | 40 | 10 |
| 2 | -1 | 1 | -1 | 0.5 | 80 | 10 |
| 3 | -1 | -1 | 1 | 0.5 | 40 | 30 |
| 4 | -1 | 1 | 1 | 0.5 | 80 | 30 |
| 5 | 1 | -1 | -1 | 1.5 | 40 | 10 |
| 6 | 1 | 1 | -1 | 1.5 | 80 | 10 |
| 7 | 1 | -1 | 1 | 1.5 | 40 | 30 |
| 8 | 1 | 1 | 1 | 1.5 | 80 | 30 |
| 9 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 10 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 11 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 12 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 13 | 0 | -1 | 0 | 1.0 | 40 | 20 |
| 14 | 0 | 1 | 0 | 1.0 | 80 | 20 |
| 15 | 0 | 0 | -1 | 1.0 | 60 | 10 |
| 16 | 0 | 0 | 1 | 1.0 | 60 | 30 |
| 17 | -1 | 0 | 0 | 0.5 | 60 | 20 |
| 18 | 1 | 0 | 0 | 1.5 | 60 | 20 |
| 19 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 20 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 21 | 0 | 0 | 0 | 1.0 | 60 | 20 |
| 22 | 0 | 0 | 0 | 1.0 | 60 | 20 |

## Characterization

Absorbance measurements using a UV-Vis Spectrophotometer instrument serve to confirm that AuNPs have been formed and to determine the effect of the capping agent used, namely tartaric acid. The reaction solution of 22 samples was tested using UV-Vis spectrophotometer in the wavelength range of 400 - 800 nm for 15 days. The measurement data were then processed using excel, OriginPro, and RSM software.

The synthesis of AgNP was monitored using a UV-Vis spectrophotometer within the wavelength range of 400-800 nm. The optimal absorbance results at specific wavelengths were used as reference data for further analysis using Response Surface Methodology (RSM). RSM analysis was carried out using Python programming through the Anaconda Jupyter Notebook. Further characterization was conducted using a Particle Size Analyzer (PSA), Fourier-Transform Infrared Spectrometer (FTIR) within the wavelength number range 400-4000 cm-1 and Tunneling Electron Microscopy (TEM) to assess the distribution of particle sizes formed. The DFT calculation was conducted using ORCA and Avogadro for electronic structure visualization. The Bayesian analysis was carried out using PyMC a Python library.

# RESULTS AND DISCUSSION

## Synthesis and Optimization of AuNP

Synthesis of gold nanoparticles (AuNPs) was carried out as many as 22 samples according to the Central Composite Face-Centered (FC-CCD) design that had been made using RSM. The synthesis was carried out by dissolving 0.05 mg NaAuCl4 (s) into 250 mL volumetric flask with aqua DM. Then added reductor NaBH4 (s) as much as 0.0015 grams into 10 mL of NaAuCl4 (l) solution. The mixture was then added 0.35 mL of tartaric acid with a concentration according to the predetermined variation using a micropipette. This procedure was carried out with variations in tartaric acid addition concentration (0.5; 1; 1.5 M), sonication temperature (40; 60; 80 ℃) and sonication time (10; 20; 30 min) [15]. Fig. 1 shows the color change of NaAuCl4 and NaAuCl +NaBH4 +Tartaric acid solutions. The change in color of the solution from yellowish to ruby red indicates the reduction of Au3+ to Au0 and is an early indication of the formation of gold nanoparticles [16]. This color change is caused by the principle of surface plasmon resonance (SPR). The color of AuNPs can vary due to their LSPR properties, this phenomenon occurs in the visible light region of the electromagnetic spectrum [17]. The reaction that occurs is shown in equation 1:

NaAuCl4 + 3NaBH4 + 6H2O → Au + 4NaCl + 3BH3OH + 6H3BO3 (1)

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| **a**  **b** |

**FIGURE 1.** (a) NaAuCl4 solution (b) NaAuCl4 + NaBH4 + Tartaric Acid solution

The formation of gold nanoparticles was confirmed by the appearance of absorbance peaks at a maximum wavelength of 500-600 nm in UV-Vis spectrophotometer testing [18]. In Fig. 2, a comparison of the UV-Vis spectra of NaAuCl4, NaAuCl +NaBH4 + tartaric acid and tartaric acid ([0.5]; [1.0]; [1.5]) solution samples is shown. The spectra results show that only the NaAuCl4 + NaBH4 + tartaric acid solution sample has an absorbance peak that appears at the maximum wavelength of 534 nm. While in testing the sample solution of NaAuCl4 and tartaric acid (0.5; 1; 1.5 M) no peak was formed in the wavelength range of 500-600 nm, which indicates that the sample solution of NaAuCl4 + NaBH4 + tartaric acid has been formed as gold nanoparticles.

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**FIGURE 2.** Comparison of UV-Vis Spectra of NaAuCl4 solution, NaAuCl4 + NaBH4 + Tartaric acid solution, Tartaric Acid [0.5]; [1]; [1.5]

The density functional theory (DFT) study conducted using ORCA software revealed that the AgNP structure involving interaction between silver and the oxygen in the carbonyl group exhibited a final single-point energy of -510.4745 eV, whereas the structure involving interaction between silver and nitrogen exhibited a final single-point energy of -510.4733 eV. The energy difference between these two structures is not notably significant. However, their electronic transitions under UV-Vis irradiation yield distinct results. The spectra of the Ag-O structure exhibited three peaks at 357, 364, and 486 nm, as shown in Fig. 3(a). Three peaks were also observed in the Ag-N structure, but at higher wavelengths, 373, 396, and 489 nm, as depicted in Fig. 3(c). As the UV-Vis spectra obtained in this study consist of a single broad peak, the DFT spectra peaks were broadened to 50 units, as illustrated in Figs 3 (b) and (d). Upon broadening, both structures yield almost identical spectra with peaks at approximately 380-390 nm and 490 nm. Thus, the spectrum pattern was in accordance with the experimental data. Given that the DFT study involved only one chain of vinyl pyrrolidone, further validation is required for comprehensive verification [19].

The UV-Vis spectra displayed in Fig. 3(a) sample Au-1 and (b) sample Au-2, show that the test results of sample Au-1 have absorbance ranging from 0.678-1.024 which appears at wavelengths between 534-540 nm. Sample Au-2 has an absorbance ranging from 1.058-1.505 which appears in the wavelength between 528-534 nm. From both UV-Vis spectrophotometer analysis results for 15 days, it shows that sample Au-2 has a higher absorbance, which indicates that more nanoparticles are formed than sample Au-1 which has a lower absorbance value. Fig. 3(c) shows the overlay curve of the comparison of the absorbance values of the two samples for 15 days. The linear equation produces a regression coefficient for sample Au-1 of -0.0038 while sample Au-2 is -0.0204. A smaller regression coefficient reflects slower changes in absorbance, thus better stability. Accordingly, Au-1 demonstrated higher stability over time than Au-2, likely due to the stronger influence of NaBH₄ as the reducing agent. In contrast, the addition of tartaric acid in Au-2 appeared to slow or partially contain the reduction process, leading to less stability despite higher nanoparticle formation.

Comparable trends have been reported in the literature. For instance, citrate-stabilized AuNPs typically exhibit a surface plasmon resonance (SPR) band around 520–540 nm, with stability extending beyond several weeks under ambient conditions. Similarly, PVP-capped AuNPs have shown improved dispersion stability compared to small organic acids but often produce broader SPR peaks due to size heterogeneity [20]. In contrast, plant-extract-mediated AuNPs, while environmentally friendly, often display rapid aggregation and a red-shift in SPR after a few days, indicating limited stability [21]. Compared to these findings, the present study demonstrates that tartaric acid significantly increases nanoparticle formation (higher absorbance, 1.058–1.505) but at the expense of long-term stability, as reflected in its faster regression slope (–0.0204) compared to citrate- or PVP-capped systems.

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**FIGURE 3.** UV-Vis spectra (a) Sample Au-1 (b) Sample Au-2 (c) Comparison of absorbance over 15 days

Fig. 4 shows the color documentation of the Au-1 and Au-2 sample solutions. Nanoparticle materials have unique optical properties [22]. Gold nanoparticles can change color along with changes in size, gold nanoparticles that have aggregated will change color from intense red or purplish to colorless to blue. Fig. 4 from the documentation shows that both samples have a purplish color. Sample Au-2 shown in Fig. 4(b) appears to have a more concentrated solution color than sample Au-1 shown in Fig. 4(a). The resulting concentrated color means that the solution has a higher concentration or higher absorbance.

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**FIGURE 4.** Sample documentation (a) Au-1 (b) Au-2 (days 2, 5, 8, 11, and 15)

Testing using a UV-Vis spectrophotometer explains that the addition of tartaric acid in the synthesis of gold nanoparticles can affect the amount of particle formation as shown in the higher absorbance value and color of the resulting solution.

Regulatory bodies consider that a primary nanomaterial is a nanoparticle (NP) when at least one of its dimensions is in the range of 1-100 nm [23]. Regulatory bodies consider that a primary nanomaterial is a nanoparticle (NP) when at least one of its dimensions is in the range of 1-100 nm [24] the properties of nanoparticles can be influenced by their size, the smaller the size, the higher the activity. The results of the analysis using PSA containing the average size distribution of the Au-1 and Au-2 samples are presented in Fig. 5. The histogram in Fig.5 shows that sample Au-1 has an average size distribution of 103.9 nm. The Au-2 sample has an average size distribution of 80 nm. From the comparison of the two histograms produced, it can be seen that the Au-1 sample has a non-uniform size distribution with a nano size that has a larger range than the Au-2 sample. Based on the data from the PSA analysis, the addition of tartaric acid in the synthesis of gold nanoparticles shown in sample Au-2 proved to be influential in the formation of its nanosize.

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**FIGURE 5.** Size distribution histograms of samples Au-1 and Au-2

Measurement using transmission electron microscopy (TEM) is an accurate measurement technique in obtaining data on the morphological shape and size distribution of gold nanoparticles [24]. The size of nanoparticles usually has a diameter of 1-100 nm and the smaller the size, the higher the activity [25]. TEM characterization results of Au-1 and Au-2 samples are shown in Fig. 6. Both samples, Au-1 and Au-2, show that the morphological shape is spherical. However, in Fig. 6(a) it can be seen that the morphological shape of the Au-1 sample has an irregular nano surface and the particle size is less uniform. In Fig. 6(b) which shows the Au-2 sample has a smoother particle surface and almost uniform nano size. From the analysis using TEM instrument, we found that the addition of tartaric acid in the synthesis of gold nanoparticles can affect the formation of particle morphology.

Wei et al. (2021), studied about PVP-capped AuNPs, exhibited improved uniformity but often with larger average diameters exceeding 90–100 nm [20]. Similarly, plant-extract-mediated AuNPs have been reported to form irregular morphologies due to the uncontrolled presence of reducing phytochemicals [26]. Compared to these reports, our Au-2 nanoparticles capped with tartaric acid exhibited smoother morphology and a smaller, more uniform particle size (~80 nm), suggesting that tartaric acid provides a better balance of reduction control and surface stabilization.

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**FIGURE 6.** The absorbance of AuNP using (a) sodium borohydride, (b) ascorbic acid, and (c) glucose

Measurements using Fourier Transform Infra-Red (FTIR) instruments produce data in the form of infrared spectra from the absorption or emission of samples that can be used to identify atomic bonds or functional groups. In this study, testing using FTIR instruments was also used to identify the interaction of tartaric acid in the synthesis of gold nanoparticles. Spectra from testing samples using FTIR are shown in Fig. 7.

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**FIGURE 7.** FTIR Spectra for AuNPs

The FTIR spectra in Fig. 7 of tartaric acid samples show a peak at a wave number of about 3440 cm-1 which is a typical absorption of OH stretch groups. The absorption peaks at 1732 cm-1, 1631 cm-1, and 1300 cm-1 indicate the presence of C=O, C=C and C-C groups, respectively. In the results of the FTIR spectra of samples Au-1 and Au-2 showed a peak at a wave number of 3440 cm-1 which indicates the absorption of -OH stretch groups derived from water solvents and a peak at a wave number of 1630 cm-1 indicating the vibration of angular deformation, namely stretching and bending of water molecules contained in the sample [27, 28]. In the Au-2 sample, a new absorption peak appears at 1732 cm-1 which indicates the absorption of the C = O group from the added tartaric acid compound. The peak can be formed because the Au atom does not interfere too much with the vibrations of the C=O group of tartaric acid. The interaction between the C=O group on tartaric acid when Au atoms are added is shown in Fig. 8. In the spectra of sample Au-2 also appears how many peaks in wave numbers below 1500 cm-1, this is caused by dipole interactions with tartaric acid which shifts the wavelength of the peak but does not form a covalent bond.

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**FIGURE 8.** Interaction of C=O group on tartaric acid when Au atoms added

**Optimization of Tartaric Acid-Gold Nanoparticle Synthesis by *Response Surface Method- Central Composite Face-Centered***

This study used Response Surface Methodology (RSM) with Central Composite Face-Centered (FC-CCD) experimental design as modeling and analysis to find the optimal conditions of independent variables that produce maximum and minimum values of the response variable. The combination of independent variables used in this study are variations in tartaric acid concentration, temperature (℃), and sonication time (minutes). The Central Composite Face-Centered (CCF) experimental design resulted in 22 independent variable combination data which can be seen in Table 2.

The 22 independent variable combination data can be described in values -1, 0, and 1. The value -1 describes the smallest variable value, the value 0 describes the middle variable value and the value 1 describes the largest variable value. This independent variable combination data will be used as a reference for conducting experiments in the amount of sample solution preparation. The quadrantic model generated in this study produces data displayed in Table 3.

**TABLE 3** Response surface model coefficient parameters

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| --- | --- | --- | --- | --- | --- | --- |
| **Intersep** | **Koef** | **Std err** | **t** | **P>|t|** | **[0,025** | **0,975]** |
| **1** | 2.4970 | 1.5460 | 1.6150 | 0.1320 | -0.8710 | 5.8650 |
| **X0** | 0.0451 | 0.0550 | 0.8190 | 0.4290 | -0.0750 | 0.1650 |
| **X1** | -0.1678 | 0.0800 | -2.0860 | 0.0590 | -0.3430 | 0.0070 |
| **X2** | -3.3662 | 1.6090 | -2.0930 | 0.0580 | -6.8710 | 0.1390 |
| **X02** | -0.0006 | 0.0000 | -1.2480 | 0.2360 | -0.0020 | 0.0000 |
| **X0 X1** | 0.0005 | 0.0010 | 1.0370 | 0.3200 | -0.0010 | 0.0020 |
| **X0 X2** | 0.0057 | 0.0100 | 0.5490 | 0.5930 | -0.0170 | 0.0280 |
| **X12** | 0.0033 | 0.0020 | 1.8920 | 0.0830 | -0.0010 | 0.0070 |
| **X1 X2** | 0.0210 | 0.0210 | 1.0110 | 0.3320 | -0.0240 | 0.0660 |
| **X22** | 1.0731 | 0.7060 | 1.5210 | 0.1540 | -0.4640 | 2.6100 |

Based on Table 3, equation 2 is obtained which shows the 2nd order polynomial function of the relationship between the absorbance produced with the treatment variation in the synthesis. The quadratic polynomial equation was used to match the experimental response. The quadratic model was chosen as the best model due to the highest order polynomial with high F-value, lower P-value, and high R2 [29]

Z=2.4970 + (0.0451X0) + (-0.1678X1) + (-3.3662X2) + (0.0006X02) + (0.0005X0X1) + (0.0057X0X2) + (0.0033 X12) + (0.0210X1X2) + (1.0731X22) ……...……. (2)

Fig. 9 is a residual value graph that shows the absorbance results of the research against the predicted absorbance results. Statistically, the relationship between research variables and predictions is shown by the coefficient of determination or (R2) whose value can be divided into 3 parts, namely the range 0-0.4 is not correlated; the range 0.4-0.7 is correlated and the range 0.7-1.0 is highly correlated. From data processing using RSM, the coefficient of determination is 0.6738. The resulting coefficient of determination indicates that the regression model explains 67% of the relationship between the independent variable and the dependent variable, which means that the model has a fairly good predictive ability. There is 32% variability that is not explained by the model or it can be interpreted that there are independent variables that do not make a significant contribution to the prediction of the dependent variable.

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**FIGURE 9.** Graph of residual values

Fig. 10 shows a plot of residuals against the number of trials. The residual is the difference between the observed value and the predicted value. Normality of data is important because with a normal distribution, the data can be considered as a representation of the population [30]. Data processing using RSM used the Shapiro-Wilk test and Anderson-Darling test to check the normality of the residuals. In the Shapiro-Wilk test, the statistical value is 0.9606 and the p-value is 0.5032. A statistical value of 0.9606 is used to determine how closely the data follows a normal distribution. A W value closer to 1 indicates that the data is closer to the normal distribution. The p-value of 0.5032 indicates that the value is much greater than the commonly used significance level of 0.05. From the Shapiro-Wilk test data obtained, it is concluded that there is not enough evidence to reject the null hypothesis (H0), which states that the data is a normal distribution. The Anderson-darling test is a test used to measure the distance between the research data sample and the hypothesized data. The greater the resulting distance, the greater the likelihood that the sample does not come from the hypothesized distribution. In the Anderson-darling test, the anderson-darling statistical value (A2) is 0.2518 and the critical values are (0.51; 0.58; 0.696; 0.812; 0.966) with a significant level (15; 10; 5; 2.5; 1). From the test statistic data (0.2518), it is found that it has a value smaller than all the critical values given (0.51 at 15% significance level to 0.966 at 1% significance level). This means that there is no significant difference from the normal distribution. Shapiro-Wilk and Anderson-Darling tests can explain that the residuals obtained have a normal distribution.

Based on the RSM-processed model, 3-D surface plots and model contour plots were generated to show the influence of variables and their interactions. A total of three sets of plots were generated and each plot showed the influence and interaction of two variables [31]. The response surface method was used to establish the interaction between parameters and their effect on the synthesis yield of gold nanoparticles. In this study, a model with three variables was used, these responses were formed respectively with two targeted variables in combination while one other variable was fixed. The targeted variables are [tartarate], sonication temperature (℃), and sonication time (min). While the other variable that is fixed or constant is absorbance.

The optimum state in the 3-D surface plot is shown in the reddest color zone. The zone outside the red color (orange to yellow) on the 3-D surface plot shows the minimum zone. The 3-D surface plot and contour plot of the model resulting from the interaction between variables are shown in Fig. 11 (a, b, c).

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**FIGURE 10.** Histogram plot of residuals against number of trials

The interaction between sonication time (min) and sonication temperature (℃) in the synthesis of gold nanoparticles is shown in Fig. 11(a). The 3-D surface plot and contour plot of the model yielded optimum values of sonication temperature between 56-73 ℃ and sonication time around 40 min. The interaction between sonication temperature (℃) and [tartarate] in the synthesis of gold nanoparticles is shown in Fig. 11 (b). The 3-D surface plot and contour plot of the model yielded optimum values of temperature between 42-60℃ and addition of tartaric acid with concentration [0.5]. The interaction between sonication time (minutes) and [tartaric] in the synthesis of gold nanoparticles is shown in Fig. 11 (c). In contrast to the two previous 3-D plots, in Plot 3-D the interaction between sonication time (minutes) and tartaric acid concentration produces minimum data. There is an increase in absorbance when the sonication time used is less than 30 minutes and the addition of tartaric acid with a concentration greater than [0.5].

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| (a) | (b) | (c) |

**FIGURE 11.** 3-D surface plot and model contour plot interaction results between (a) sonication time (min (b) temperature sonication (℃) (c) tartarate concentration

From the three 3-D plots and contour responses that have been analyzed, it can be concluded that the optimization of the three parameters obtained the optimal sonication temperature at 56.85 ℃ which resulted in an absorbance of 0.32, the optimal sonication time is 30 minutes which resulted in an absorbance of 0.84, and the addition of tartaric acid with a concentration of 0.5 M which resulted in an absorbance of 1.06. The conclusion is shown in Fig. 12.

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**FIGURE 12.** Plot of optimization results with RSM.

# CONCLUSION

# Based on the results and discussion of this study, it can be concluded that the synthesis of gold nanoparticles with the addition of tartaric acid was successfully carried out, as indicated by the purple-reddish solution color and the absorbance peak at a wavelength of 534 nm. The addition of tartaric acid influenced the absorbance of the solution, with higher absorbance corresponding to greater nanoparticle formation. Particle size was also affected by tartaric acid, as shown by PSA results: sample Au-1 (without tartaric acid) had an average size distribution of 103.9 nm, while sample Au-2 (with tartaric acid) exhibited a smaller average size distribution of 80 nm. TEM analysis further confirmed that tartaric acid affected nanoparticle morphology, with Au-1 producing irregular shapes and less uniform particle sizes, whereas Au-2 produced smoother surfaces and more homogeneous particle sizes. These findings highlight the potential of tartaric acid-stabilized gold nanoparticles for applications in drug delivery, biosensing, and catalytic processes, where uniform particle size and morphology are critical. As future work, stability testing under different environmental conditions and biological assays such as antimicrobial or cytotoxicity studies are recommended to evaluate the long-term performance and biocompatibility of the synthesized nanoparticles.

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