KONVERSI
Homepage:
https://ppjp.ulm.ac.id/journal/index.php/konversi

Sonochemical-assisted biosynthesis of silver nanoparticles using (*Cymbopogon nardus L.*) Essential oil: Advanced process optimization through response surface methodology

Guardiola Rosa Wira, Hijria Putri Maharani, Nove Kartika Erliyanti*, Renova Panjaitan, Caecilia Pujiastuti

Department of Chemical Engineering, Faculty of Engineering and Science, University of Pembangunan Nasional "Veteran" Jawa Timur, Gunung Anyar, Surabaya 60294, Indonesia

ARTICLE INFO

Article history:
Received: 12 February 2025
Received in revised form: 15 March 2025
Accepted: 16 April 2025

Keywords:
Silver Nanoparticles (AgNPs), essential oil, ultrasound, response surface methodology, central composite design

ABSTRACT

This research explores the fabrication and characterization of silver nanoparticles (AgNPs) using essential oil extracted from citronella leaves (*Cymbopogon nardus* L.) as a bioreductor. The synthesis was conducted via the sonochemical method, with pH variations to identify optimal conditions for maximizing AgNPs yield. Utilizing essential oil offers eco-friendly benefits and high efficiency in reducing metal ions. The highest yield, 8.67%, was obtained at pH 9.0280 and a sonication time of 59.7190 minutes. To optimize the synthesis process, statistical analysis was performed using Response Surface Methodology (RSM), employing Central Composite Design (CCD) to organize experimental runs and analyze the influence of processing parameters. The model exhibited strong alignment with the experimental data, showing an adjusted R^2 of 0.9684. A high F-value of 30.61 and a low p-value of 0.0009 indicated the regression model's statistical significance in explaining yield variability. Furthermore, the lack-of-fit p-value of 0.0359 confirmed that the model predictions were consistent with experimental results. UV-Vis spectroscopy confirmed the successful formation of AgNPs, with characteristic absorption peaks in the 400–450 nm range. This study underscores the potential of plant-derived bioreductors as green alternatives to conventional chemical reducers in nanoparticle synthesis. The integration of sonochemical methods with robust statistical optimization presents an efficient, scalable approach for producing AgNPs with desirable properties.

1. Introduction

Silver nanoparticles (AgNPs) have gained significant interest in the field of nanotechnology attributable to their diverse properties, including electronic, optical, magnetic, chemical, and physical properties [1]. The synthesis of AgNPs can generally be categorized into three main methods, namely physical, chemical, and biological methods or environmentally friendly methods. Physical methods generally involve high temperature and pressure conditions [2], while chemical methods can negatively impact the environment and human health as the result of employing hazardous substances [3]. The biological method, known as green synthesis, typically uses plant extracts in the fabrication of nanoparticles. In nanoparticle synthesis, the reduction ability of metal ions increases as the concentration of secondary metabolites increases [4].

Essential oils contain two to three components of secondary metabolites with high concentrations, ranging from 20-70%, which can overcome the limitations of the use of plant extracts [5]. One promising environmentally friendly approach is the use of essential oils as natural metabolites from plants. The abundant and versatile essential oils have been used in various fields, such as cosmetics, perfumes, pharmaceuticals, and food flavors [6]. The active components in essential oils have the ability to reduce metal ions as well as stabilize the resulting nanoparticles [7].

For example, citronella essential oil (*Cymbopogon nardus L.*) contains a large number of active components, including citronellol and geraniol [8]. The essential oil derived from citronella leaves exhibits promise as a bioreductor of nanoparticles due to its high secondary metabolite content, which is 88.49%, consisting of citronellol (13.72%), citronellal (56.96%), and geraniol (13.72%) [9]. The essential oil derived from citronella leaves exhibits promise as a bioreductor and stabilizer in the fabrication of nanoparticles [10]. The reaction mechanism of geraniol in silver ion reduction:

$$C_{10}H_{18}O + 2Ag^{+} \rightarrow C_{10}H_{1}O + 2Ag^{o} + 2H^{+} \quad (1)$$

Study [11], reported that bioreductors containing hydroxyl (-OH) and carbonyl (-CO) groups form a double electrical layer, thereby preventing agglomeration of AgNPs. The conversion of silver ions into silver nanoparticles through alcohol oxidation produces aldehyde groups [12]. The synthesis method has a significant effect on the size of the nanoparticles produced. Conventional approaches often

* Corresponding author. Tel.: +628563057767
Email: http://nove.kartika.nke.tk
http://dx.doi.org/10.20527/k.v14i1.21906

This open access article is distributed under a Creative Commons Attribution (CC-BY-SA) 4.0 license

produce nanoparticles of larger size due to high temperature conditions that can damage stabilizing agents [11]. In contrast, non-conventional methods such as microwave irradiation can lead to agglomeration and larger sizes of AgNPs [13]. Although less widely explored, sonochemical methods offer advantages such as rapid reactions, milder conditions, as well as uniform and high-quality production of nanoparticles [14].

Therefore, an environmentally friendly approach using natural materials is gaining more and more attention in the sustainable synthesis of AgNPs. Factors such as pH and sonication time affect the size of the AgNPs produced. Based on the explanation above, research on the use of sonochemical methods in the synthesis of AgNPs with citronella leaf essential oil (*Cymbopogon nardus L.*) as a bioreductor has never been done before. However, the silver nanoparticles produced in the synthesis do not always have a uniform size and yield, so an optimization process is needed to determine the optimal yield of the synthesis of AgNPs with essential oils as bioreductor. Therefore, in this study, the Design Expert DX 13® Program with e Central Composite Design (CCD) based Response Surface Methodology (RSM) is employed to examine and determine the optimal process conditions to obtain maximum nanoparticle yield. This research is intended to optimize the conditions of the synthesis process of silver nanoparticles (AgNPs) using essential oils as bioreductor by considering pH variables and sonication time using the Response Surface Methodology (RSM). Optimization is carried out to determine the best conditions that produce yield with the best response which will then be characterized using UV-Vis. This research is expected to be a source of basic information in the development and scaling up of essential oil-based AgNPs synthesis for wider applications.

2. Materials and Methods

2.1. Materials

The raw material for nanoparticle synthesis includes 10gr silver nitrate precursor ($AgNO_3$ analysis) Merck, Sodium Hydroxide analysis (NaOH 0.1N), and distilled water (H_2O) as the solvent. The equipment used in this research includes an analytical balance, centrifuge, 10mL beaker glass, measuring cylinder, cleaning bath sonicator (40 Hz, Bandelin Electronic), aluminum foil, and a pH meter. The AgNPS was characterized using Hitachi UH-5300 UV-VIS spectrophotometer.

2.2. Methods

2.2.1. Extraction of (Cymbopogon nardus L.)

The bioreductant used in this study is citronella leaf essential oil (*Cymbopogon nardus L.*). The preparation of essential oil extraction from citronella leaves follows the method outlined in previous research [15] using salt as a solvent and UMAE method.

2.2.2. Synthesis of silver nanoparticle

To prepare a 1 mM silver nitrate ($AgNO_3$) solution, $AgNO_3$ was dissolved in 100 mL of distilled water. The synthesis of silver nanoparticles was initiated by mixing 4 mL of the 1 mM $AgNO_3$ solution with 1 mL of citronella leaf essential oil in a beaker. The pH was then adjusted by gradually adding 0.1 M NaOH., monitored using a pH meter according to the specified variables (7,8,9,10,11). The mixture then underwent sonochemical treatment for varying durations (20, 40, 60, 80, and 100 minutes). Following sonication, the solution was subjected to centrifugation at 4000 rpm for a duration of 20 minutes. After centrifugation, the yield of the nanoparticles was analyzed by weighing each sample. The silver nanoparticle colloid was stored at room temperature for 24 hours and subsequently subjected to further characterization. The apparatus setup for AgNPs synthesis is presented in Figure 1 below.

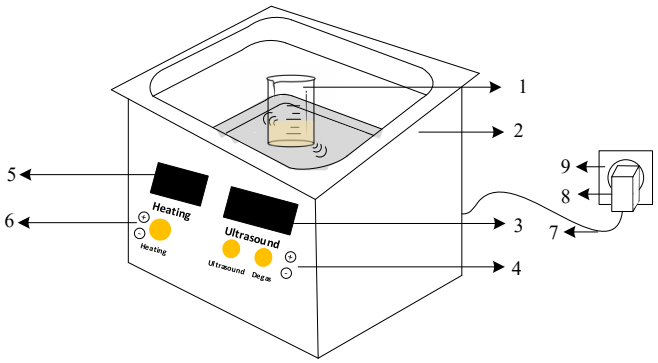

Fig. 1. The scheme of biosynthesis AgNPs sonochemical method

Description:

1. Beaker glass
2. Sonicator body
3. Timer indicator
4. Timer adjustment button
5. Temperature indicator
6. Temperature adjustment button
7. Power cable
8. Power plug
9. Power outlet

2.2.3. Data analysis

The yield of silver nanoparticles (AgNPs) is calculated by comparing the mass of AgNPs obtained with the mass of raw materials [14], as shown in Equation (2). Analysis of Variance (ANOVA) is is utilized to analyze the impact of linear, quadratic, and interactive variables associated with pH and sonication time in the AgNPs synthesis process. The implementation of Response Surface Methodology (RSM) and subsequent data analysis were carried out using Design Expert version 17. Table 1 presents the experimental run order, variable conditions, and results based on the Central Composite Design (CCD), which consists of 11 experiments, including 3 repetitions at the center point, conducted randomly. The yield of the obtained nanoparticles is calculated as follows equation 2 below [16].

$$Yield(\%) = \left(\frac{m_1 - m_2}{m_1}\right) \times 100 \quad (2)$$

Remark:

Yield (%): Yield of AgNPs
m_1 = : total mass of synthesized Ag-NPs
m_2 = : total mass of raw material

Table 1. CCD design with AgNPs yield serving as the response factor

Run	Factor 1 (A) pH	Factor 2 (B) B:Sonochemical Time (Minutes)	Response Yield (%)
1	9	60	8.2710
2	9	20	7.9256
3	9	60	8.6769
4	7	60	5.6652
5	11	100	6.6684
6	7	20	3.5781
7	11	60	7.0733
8	9	60	8.4833
9	7	100	4.4283
10	9	100	8.068
11	11	20	5.3953

3. Results and Discussion

From Table 1, there are three repetitions on the center point that have different result. Differences can be caused by inaccurate to calculate the yield of AgNPs. The optimal yield point of AgNPs can be modeled through the application of Central Composite Design (CCD) within the Response Surface Methodology (RSM) framework. The application of RSM can be utilized to screen independent variables and identify the most significant main effects among multiple potential factors [17]. The CCD design was chosen due to its capability to comprehensively explore the response surface and identify optimal conditions. The experimental design matrix obtained is presented in Table 1. The evaluation of the influence of pH (Factor A) and sonochemical time (Factor B) on the synthesis yield indicates that both factors significantly affect the reaction outcome. The maximum response (8.6769) was measured in the center point (Run 1), while the lowest response was recorded in Run 9.

This study proposes a quadratic model, as indicated in Table 2. Data processing with the Design Expert tool yielded a R^2 score of 0.9684. The established linear connection of residuals implies that any errors in the data follow a normal distribution with no signs of problems. This confirms that the errors adhere to a normal distribution and support the experimental model [18]. this suggests that the Quadratic model has a high degree of goodness-of-fit with the experimental data. Adjusted R^2 value is 0.9367 and Predicted R^2 value is 0.7486, for a model to be considered reliable, its R^2 should fall within the 0-1 range, with values closer to 1 signifying a better fit to the experimental data [19]. The difference between adjusted and predicted to R^2 values is 0.1881. The R^2 value always exceeds the corrected and projected R^2 values. For statistical fit, the difference between anticipated and adjusted R^2 values must be less than 0.2 [20]. Even after adjusting for the amount of variables, this supports the stability of the model. A high Adjusted R2 value shows that the model is dependable in forecasting new data variations in addition to being well-fitted to the available data. [20]. A second-order polynomial equation in terms of coded factors was used to determine the link between each response and the chosen parameters. The following equation describes the quadratic model, as presented in Equation (3) below.

$$\textit{Yield AgNPs}: +8.66 + 0.9109A + 0.3776B + 0.1057AB - 2.57A^2 - 0.9389 \quad (3)$$

Description:

A = pH
B = Sonochemical Time

According from the equation, the coefficient of each factor quantitatively represents its relative effectiveness in influencing the yield of silver nanoparticles (AgNPs). pH (A) has the highest positive influence on AgNPs yield, as its coefficient (0.9109) is significantly larger than that of sonochemical time (0.1057). The yield of AgNPs increases on pH, because a pH change causes the plant's metabolism to change in charge and even impacts its ability to chelate and decrease metal ions during the process, changing the size, shape, and yield of the NPs that are formed [10]. The use of essential oils in conjunction with pH has a significant influence on the nanoparticle reduction reaction. The reduction of Ag^+ to Ag^0 occurs simultaneously with the proton (H^+) donation from essential oils, while sodium (Na^+) stabilizes the negatively charged essential oils through electrostatic interactions [21]. In general, this reaction achieves equilibrium in electron donation due to the excess of essential oils. Silver in its zero-valent state (Ag^0) is not inherently considered a nanoparticle; however, through a sequential agglomeration process known as nucleation stages (I) and (II), silver nanoparticles are formed. These nanoparticles can be stabilized by their crystalline structure and the presence of essential oils in the AgNPs solution post-synthesis [9].

Sonochemical time also plays a role in AgNP synthesis by enhancing cavitation effects and improving reaction kinetics, ultimately leading to higher yield [22]. Prolonged ultrasonic exposure accelerates nanoparticle agglomeration and sedimentation, increasing overall mass. Studies confirm that while cavitation initially reduces nanoparticle size, extended exposure promotes growth through nucleus fusion and aggregation, highlighting the intricate balance between dispersion and coalescence in optimizing synthesis conditions [14].

Table 2. Statistical Models with AgNPs yield serving as the response factor

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	1.76	0.1899	-0.0126	-0.7680	54.32	
2FI	1.88	0.1913	-0.1552	-3.2913	131.85	
Quadratic	**0.4409**	**0.9684**	**0.9367**	**0.7486**	**7.72**	**Suggested**
Cubic	0.4329	0.9817	0.9390	-0.9884	61.09	Aliased

Table 3. Analysis of Variance (ANOVA) with AgNPs yield serving as the response factor

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	29.75	5	5.95	30.61	0.0009	significant
A-pH	4.98	1	4.98	25.61	0.0039	
B-Sonochemical Time	0.8556	1	0.8556	4.40	0.0900	
AB	0.0447	1	0.0447	0.2300	0.6518	
A^2	16.69	1	16.69	85.83	0.0002	
B^2	2.23	1	2.23	11.49	0.0195	
Residual	0.9721	5	0.1944			
Lack of Fit	0.8897	3	0.2966	7.19	0.1245	not significant
Pure Error	0.0824	2	0.0412			
Cor Total	30.72	10				

Table 4. Experiment and predicted of AgNPs yield serving as the response factor

Variabel	Experiment 1	Experiment 2	Experiment 3	RSM Prediction
pH	9	9	9	9.0280
Sonochemical Time (Minutes)	60	60	60	59.7190
Yield of AgNPs (%)	8.2710	8.6769	8.4833	8.6700

Table 3 presents the statistical outcomes of the ANOVA test. ANOVA is utilized to determine whether the coefficients of linear, interaction and quadratic terms should be included or excluded from the model based on the p-value [20]. The ANOVA results highlight pH as the most significant factor influencing AgNPs yield, with strong statistical relevance. A low p-value of 0.0009 and a high F-value of 30.61 show that the regression model is statistically significant and adequately accounts for the fluctuations in AgNPs production [20]. With an F-value of 25.61 and a p-value of 0.0039, pH (A) had the largest impact on yield among the individual parameters, indicating that pH has a major impact on AgNP production and stability. The formation of nanoparticles with a high yield is reported [23] that the synthesis of AgNPs under alkaline pH conditions tends to produce a darker color, with sedimentation resulting in a characteristic solution color, such as gray or brown.

In contrast, the influence of sonochemical time (B) is relatively minor, as indicated by an F-value of 0.8556 and a p-value of 0.0900. While it contributes to the synthesis process, its effect does not reach statistical significance at the 95% confidence level. The interaction term (AB), with an F-value of 0.0447 and a p-value of 0.6518, suggests an insignificant synergistic relationship between pH and sonochemical time. Conversely, the quadratic terms exhibit pronounced statistical significance, particularly A^2, which yields an F-value of 16.69 and a p-value of 0.0002, and B^2, with an F-value of 2.23 and a p-value of 0.0195. The detailed data are presented in Table 3.

The results underscore the substantial non-linear effects of both pH and sonochemical time on AgNPs yield, implying that extreme parameter values may induce deviations from the optimal synthesis conditions. Table 4 shows the relationship between yield and the variables that affect this experiment. The difference between experimental yield and the RSM predicted yield is obtained by calculating the average experimental yield and determining its deviation from the RSM predicted value. The deviation is then divided by the RSM predicted yield and multiplied by 100% to obtain the percentage error, resulting in 0.0223. Since the error value is lower than the acceptable threshold ($P < 0.05$ with $\alpha = 0.05$), the experimental results are considered consistent with the predicted values [20].

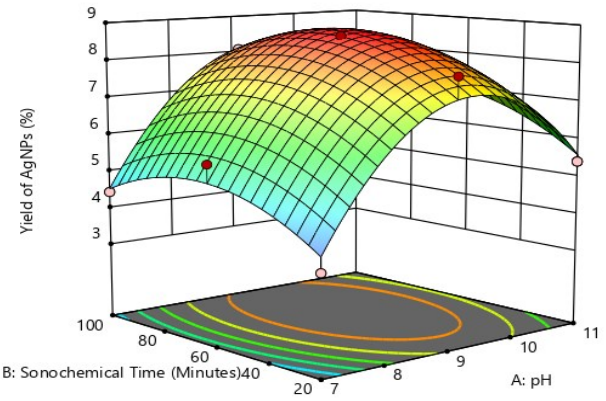

Fig. 2. SEQ Figure * ARABIC 2. 3D AgNPs yield, pH, and sonochemical time interaction plot

The regression equation obtained from the constructed model is graphically represented by a 3D surface response plot in Figure 2 reveals a curved relationship, where both parameters significantly influence the yield. As shown, the AgNPs yield increases with rising pH and sonication time up to an optimal point. Its two primary functions are (i) to examine how factors interact and (ii) to identify the ideal circumstances for each parameter in order to maximize the yield of AgNPs. The yield of AgNPs tends to increase at higher pH levels and with longer sonochemical durations. However, after reaching a certain point, this increase begins to slow down or even decline. The optimal conditions are achieved at pH 9 and a sonochemical time of 60 minutes, confirming that an alkaline environment significantly enhances AgNPs yield. Alkaline conditions also enhance the reactivity of the solution. According to [24], a basic environment promotes more efficient

proton release from reducing agents, accelerating the reduction of silver ions into metallic silver particles. This increase in reaction kinetics establishes a significant relationship that contributes to the enhanced yield of AgNPs.

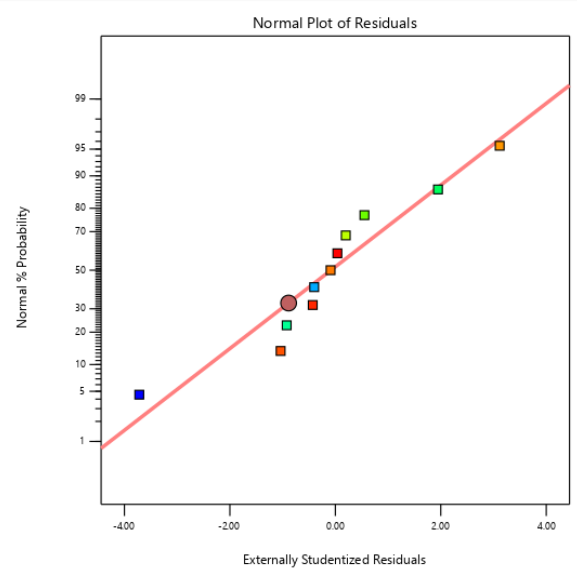

Fig. 3. Normal plot of residual

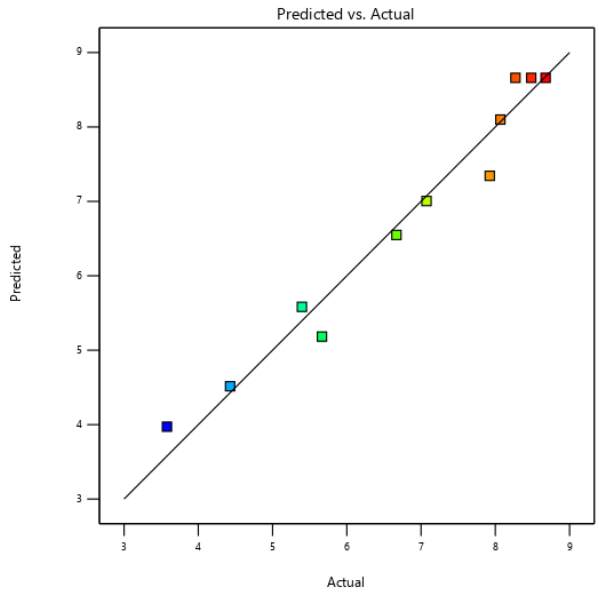

Fig. 4. Relationship between predicted vs actual AgNPs

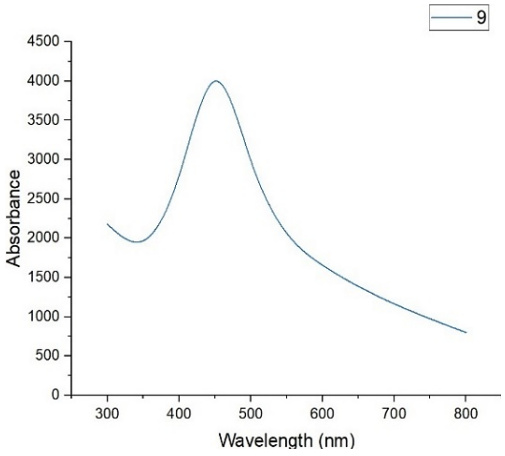

Figure 5. The UV-Vis spectrum of AgNPs

The response data for yield is normally distributed, as shown by the graph of the normal plot of residuals, which shows the relationship between actual and expected values in Figure 3. It closely resembles the normality line. This implies that the actual outcomes closely match the DX 17 Software projections. The data points in Figure 4 are dispersed around the diagonal line, suggesting that the predictive model estimates the experimental outcomes with a high degree of accuracy. The model is deemed reasonably valid for estimating AgNPs yield due to the close distribution of data to the ideal line, indicating that the difference between actual and anticipated values is minimal.

UV-Vis spectrophotometry serves as a fundamental analytical technique to confirm the successful synthesis of silver nanoparticles (AgNPs) by correlating absorbance intensity with specific wavelengths characteristic of nanoparticle formation. The technique allows for the rapid, non-invasive detection of surface plasmon resonance (SPR) peaks, which are indicative of nanoparticle presence, concentration, and size distribution [25]. The formation of AgNPs at optimum conditions was confirmed according to Figure 5 by the maximum absorption peak in the 400-450 nm wavelength range, with the highest absorbance of 4 observed at pH 9 and 60 minutes of sonochemical treatment. The evidence presented in this study is strengthened [26] which posits that the number of particles can be detected via UV-Vis spectroscopy, thereby serving as an indicator of particle yield. The number of nanoparticles can be detected through UV-Vis light absorption, where absorbance intensity is directly proportional to the number of particles formed [19].

4. Conclusion

This research effectively refined the synthesis process of silver nanoparticles (AgNPs) by leveraging citronella essential oil as a bioreductor, employing Response Surface Methodology (RSM). The optimal parameters were identified at a pH of 9.0280 and a sonochemical duration of 59.7190 minutes, yielding the maximum AgNPs production. Statistical analysis conducted using Design Expert revealed that the ANOVA results substantiate the chosen model's robustness in explaining the data. This assertion is supported by a highly significant p-value, an elevated coefficient of determination (R^2), and a negligible disparity between adjusted R^2 and predicted R^2, affirming the model's strong fit to the experimental findings.

References

[1] P. Rauwel, S. Küünal, S. Ferdov, E. Rauwel, A Review on the Green Synthesis of Silver Nanoparticles and Their Morphologies Studied via TEM, Adv. Mater. Sci. Eng, 2015 (2015) 1-9.

[2] R.F. Talabani, S.M. Hamad, A.A. Barzinjy, U. Demir, Biosynthesis of Silver Nanoparticles and Their Applications in Harvesting Sunlight for Solar Thermal Generation, Nanomaterials, 11, (2021) 1-19.

[3] E.M. Modan, A.G. PlÄƒiaÈ™u, Advantages and Disadvantages of Chemical Methods in the Elaboration of Nanomaterials, Ann. Dunarea Jos Univ. Galati. Fascicle IX, Metall. Mater. Sci, 43, (2020) 53-60.

[4] H. Ayu, Kinetika Sintesis Nanopartikel Perak Dari Larutan AgNO3 Dengan Menggunakan Ekstrak Bungkil Biji Jarak Pagar (Jatropha curcas L.) Sebagai Reduktor, IPB, (2015) 01-48.

[5] S. Mazraedoost, G. Behbudi, Basic Nano Magnetic Particles and Essential Oils: Biological Applications, J. Environ. Treat. Tech, 9, (2021) 609-620.

[6] W.E. Kosimaningrum, A.B. Pitaloka, A.S. Hidayat, W. Aisyah, S. Ramadhan, M.A. Rosyid, Sintesis Nanopartikel Perak Melalui Reduksi

Spontan Menggunakan Reduktor Alami Ekstrak Kulit Lemon Serta Karakterisasinya Sebagai Antifungi Dan Antibakteri, J. Integr. Proses, 9, (2020) 34-43.
[7] S. Sajjad, S.A.K. Leghari, N. Ryma, S.A. Farooqi, Green Synthesis of Metal Based Nanoparticles and Their Applications, in Green Metal Nanoparticles, Wiley, , (2018) 23â€“77.
[8] A.P. Wicaksono, F.A. Afandi, G.R. Wira, M. Fayzza, N.K. Erliyanti, Characterization of Essential Oil from Red Citronella Leaves (Cymbopogon nardus L.), Konversi, 13, (2024) 61-67.
[9] Riyanto, M. Mulwandari, L. Asysyafiiyah, M.I. Sirajuddin, N. Cahyandaru, Direct synthesis of lemongrass (Cymbopogon citratus L.) essential oil-silver nanoparticles (EO-AgNPs) as biopesticides and application for lichen inhibition on stones, Heliyon, 8, (2022) 1-15.
[10] M. Yusuf, Silver Nanoparticles: Synthesis and Applications, Cham: Springer Int. Publ, 4, (2019).
[11] M.L. Bere, J. Sibarani, M. Manurung, Sintesis Nanopartikel Perak (NPAg) menggunakan Ekstrak Air Daun Kemangi (Ocimum sanctum Linn.) dan Aplikasinya dalam Fotodegradasi Zat Warna Metilen Biru, Cakra Kim. (Indones. E-J. Appl. Chem.), 7, (2019) 155-164.
[12] K. Tahir, An efficient photo catalytic activity of green synthesized silver nanoparticles using Salvadora persica stem extract, Sep. Purif. Technol, 150, (2015) 316-324.
[13] H. Agarwal, S. Venkat Kumar, S. Rajeshkumar, Antidiabetic Effect of Silver Nanoparticles Synthesized Using Lemongrass (Cymbopogon Citratus) Through Conventional Heating and Microwave Irradiation Approach, J. Microbiol. Biotechnol. Food Sci, 7, (2018) 371-376.
[14] B. CalderÃ³n-JimÃ©nez, A.R. Montoro Bustos, R. Pereira Reyes, S.A. Paniagua, J.R. Vega-Baudrit, Novel pathway for the sonochemical synthesis of silver nanoparticles with near-spherical shape and high stability in aqueous media, Sci. Rep, 12, (2022) 1-17.
[15] A.P. Wicaksono, F.A. Afandi, C. Pujiastuti, N.K. Erliyanti, R. Panjaitan, Ultrasound Microwave Assisted Extraction on Citronella Leaves Using Ionic Solvent, Rekayasa Bahan Alam dan Energi Berkelanjutan, 8, (2024) 38-46.
[16] A. Lukum, Dasar-dasar Kimia Analitik, Gorontalo: Univ. Negeri Gorontalo, (2022).
[17] S. Lamidi, N. Olaleye, Y. Bankole, A. Obalola, E. Aribike, I. Adigun, Applications of Response Surface Methodology (RSM) in Product Design, Development, and Process Optimization, Response Surf. Methodol. - Res. Adv. Appl, (2023).
[18] S. Chowdhury, F. Yusof, M.O. Faruck, N. Sulaiman, Process Optimization of Silver Nanoparticle Synthesis Using Response Surface Methodology, Procedia Eng, 148, (2016) 992-999.
[19] F. Yusof, S. Chowdhury, N. Sulaiman, M.O. Faruck, Effect of process parameters on the synthesis of silver nanoparticles and its effects on microbes, J. Teknol, 80, (2018) 115-120.
[20] S.D.A., Response Surface Methodology-A Statistical Tool for the Optimization of Responses, Glob. J. Addict. Rehabil. Med, 7, (2023) 1-7.
[21] A.P.Z. De Melo, Antibacterial activity, morphology, and physicochemical stability of biosynthesized silver nanoparticles using thyme (Thymus vulgaris) essential oil, Mater. Res. Express, 7, (2020).
[22] J. Jiang, G. OberdÃ¶rster, P. Biswas, Characterization of size, surface charge, and agglomeration state of nanoparticle dispersions for toxicological studies, J. Nanoparticle Res, 11, (2009) 77-89.
[23] P.M. Gurubasavaraj, Effect of Concentration and pH on the Size of Silver Nanoparticles Synthesized by Green Chemistry, Org. Med. Chem. Int. J, 3, (2017) 1-5.
[24] N. Kutsevol, V. Chumachenko, V. Shkodich, N. Temnikova, M. Rawiso, V. Solntsev, Green route synthesis of nanosilver into polyelectrolyte solutions at high pH value, Mol. Cryst. Liq. Cryst, 640, (2016) 90-97.
[25] D.F. Nury, Biosynthesis of Silver Nanoparticles Using Leaves Extract of Jatropha Curcas L, Konversi, 12, (2023) 57-61.
[26] M. Alauhdin, A. Dzulfiqar, A.O. Herlistyawan, Sintesis Cepat Nanopartikel Perak dengan Irradiasi Gelombang Mikro dan Aplikasinya sebagai Antibakteri pada Kain Katun, J. Ris. Kim, 13, (2022) 226-235.