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GREEN APPROACH TO THE SYNTHESIS OF GOLD NANOPARTICLES WITH ANTIMICROBIAL ACTIVITY USING PLANT EXTRACTS BASED ON A DEEP EUTECTIC SOLVENT

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Gold nanoparticles were synthesized by reducing hydrogen tetrachloroaurate(III) trihydrate ($HAuCl_4 \cdot 3H_2O$) using plant waste (banana peel) extracts obtained using a deep eutectic solvent (DES) based on choline chloride. It was demonstrated that the plant waste (banana peel) extract obtained by DES allows the synthesis of spherical gold nanoparticles (Au NPs), characterized by a maximum plasmon resonance absorption peak at approximately λ=540–560 nm, with an average nanoparticle size range of 31–68 nm with a zeta potential value of −33 to −36 mV, depending on the initial concentration of the precursor stabilizer used in the synthesis process. Choline chloride-based DES was used as a new alternative to conventional solvents for ultrasonic extraction of active substances from plant waste, in particular banana peel. Low-temperature eutectic solvents based on choline chloride were compared with glycerol and lactic acid in a ratio of 1:3 and water 10–30%. It was found that choline chloride and glycerol in a ratio of 1:3 with a water content of 30% are highly effective for the extraction of flavonoid compounds from plant waste (banana peel). The influence of extraction parameters, namely sample-to-solvent ratio and extraction time, on the content of extracted flavonoids and antioxidant activity of the extract was studied using the methods of determining antioxidant activity by ferric ion reduction (FRAP) and the ABTS test (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid). It was established that the extracted flavonoid content using DES is 222–521 mg/100 g. It was established that the sample-to-solvent ratio (1:45–1:80) and the extraction time of 10–30 min allow obtaining the antioxidant activity value of banana peel extracts, determined by the FRAP and ABTS methods: 20–60 mmol/l and 15–35 mmol/l. The gold nanoparticles obtained using DES extracts of banana peel showed higher antibacterial activity against *E. coli* compared to the DES extract of banana peel and non-sterilized gold nanoparticles.

Keywords: gold nanoparticles, deep eutectic solvent, flavonoids, extract, banana peel, antioxidant activity, antimicrobial activity.

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Introduction

Nanoparticles of noble metals, due to their unique properties, are widely used in various industries. Gold nanoparticles deserve special attention, which exhibit a whole range of properties, namely catalytic, biocompatible, antioxidant properties and, according to modern developments of scientists and enterprises, are promising for use in biomedicine, medicine, pharmacy, catalysis, cosmetology, etc. [1–3]. Today, it is a well-established and experimentally confirmed

law that the properties of nanoparticles and the intensity of their manifestation depend on the physicochemical parameters of nanoparticles, stabilizer reagents, synthesis medium, etc [1–4]. The specified parameters and characteristics are determined by the synthesis methods and approaches used. Research on the synthesis of nanoscale metals using physical, chemical, and green synthesis techniques is growing in quantity these days [1–5].

Green synthesis techniques are gradually replacing physical and chemical processes due to concerns about high energy consumption, hazardous chemical emissions, the need for sophisticated equipment, and the synthesis conditions. Natural and eco-friendly ingredients (such as reducing agents) are used in green synthesis. Certain environmentally friendly materials can also be employed as dispersants and end-capping agents simultaneously, which lowers energy consumption and eliminates the need for hazardous and toxic chemicals. Currently, green synthesis relies primarily on microorganisms (fungi, bacteria, and algae) or extracts from leaves, flowers, roots, peelings, fruits, seeds of various plants, and agricultural waste. Green materials contain polyphenols, which can act as reducing agents to lower the valence of metal ions. Metal nanoparticles can be manufactured in the presence of green materials and under optimal conditions (temperature, concentration, ambient air, and so on). Bananas are the world's most important crop for agricultural production and trade. Their production and trade volumes have been steadily increasing to suit worldwide market demand. Banana peel is well known as a byproduct of food production that contains bananas. After processing, banana peels account for around 35% of the fruit's weight. According to recent studies, banana peel contains a high concentration of pectin, fibers, carotenoids, and phenolic (flavonoids) chemicals that can be isolated and used in medicinal, cosmetic, and nutraceutical goods [6].

Alternative environmentally friendly solvents, such as deep eutectic solvents (DESs), are also becoming more popular than conventional solvents, which are frequently associated with toxicity [7,8]. DESs are liquids made up of two components: hydrogen-bond donors (such as alcohol or sugar) and acceptors (quaternary ammonium salts). These components are easily available, inexpensive, recyclable, and non-toxic, allowing extracts to be reused without removing the solvent [5–9]. Choline chloride, which has a significant capacity to generate hydrogen bonds because of its chloride ion, a powerful hydrogen bond acceptor, is the basis for the most studied type of DES for separating bioactive chemicals. A stable eutectic mixture can be formed as a result of its efficient interaction with hydrogen-bond donors in the DES, such as organic acids, sugars, or glycerol. Many of the hydroxyl groups in polyphenols are capable of forming hydrogen bonds. Choline chloride facilitates the hydrogen-bond network in DES, which increases the solubility of polyphenols by efficiently breaking intermolecular hydrogen bonds within the polyphenols and improving their solvent interaction [9,10]. Choline chloride's capacity to behave as a strong hydrogen-bond acceptor and construct stable, efficient, and environmentally friendly DES makes it especially useful for polyphenol isolation. These qualities make DESs ideal solvents for sustainable and ecologically friendly extraction. DESs were shown to be more efficient than water, ethanol, methanol, and their mixes, resulting in higher values for all parameters compared to 30% ethanol [11,12]. In addition, in recent years, DES have been used separately for the synthesis of nanoparticles as a green, environmentally acceptable subclass of ionic liquids [7–10]. DES, in particular, created from a hydrogen bond donor and a quaternary ammonium salt, is a low-cost, environmentally friendly, and nontoxic method of producing nanomaterials with a low environmental footprint. Choline chloride-based DESs are the most popular ones due to their excellent solubilization of many metals.

The aim of the work was to study the use of DES based on choline chloride for the extraction of flavonoids from plant waste, banana peel, to study the antioxidant properties of the obtained extracts and the effectiveness of their use in the synthesis of gold nanoparticles.

Materials and methods

The peel of commercially available samples of Cavendish banana (Musa acuminata) was used as a plant source of extractable flavonoids. The dried banana peels and stored at 5^0C until extraction. To prepare the deep eutectic solvent (DES) based on choline chloride (acceptor) and donor component (lactic acid, glycerol), the components are mixed in a 1:3 molar ratio (Table 1). To create a uniform, transparent liquid, the weighed masses of the prescribed ingredients were mixed in a laboratory beaker with a magnet and placed on a magnetic stirrer at 60–80^0C.

Table 1

Solvent composition for extraction fruit by-products (banana peel)

Solvent composition	Molar ratio	Water content, %
Choline chloride+lactic acid	1:3	10
Choline chloride+lactic acid	1:3	30
Choline chloride+glycerol	1:3	10
Choline chloride+glycerol	1:3	30

To test total flavonoids, 0.5 mL of extract, 1.5 mL of 96% ethanol, 0.1 mL of 10% aluminum chloride, 0.1 mL of 1 M potassium acetate, and 2.8 mL of distilled water were combined in a glass tube. A blank sample was made in the same way, using the extraction. Instead of the extract, 0.1 mL of pure water was substituted for the aluminum chloride. After 30 minutes of reaction time, the absorbance at 415 nm was measured. A calibration curve was created for quercetin standard solutions with concentrations ranging from 10 to 100 mg/L. The results were given in mg per 100 g of dried banana peel [12,13].

The reducing antioxidant power assay (FRAP) was carried out [12,13]. To assess antioxidant capacity for a total volume of 10 mL, 1 mL of distilled water, 0.33 mL of the sample, 8.67 mL of FRAP reagent (the FRAP reagent is a mixture of three components: 2,4,6-tris(2-pyridyl)-s-triazine (TPTZ), ferric chloride ($FeCl_3$), Acetate buffer (pH 3.6) were pipetted into test tubes. The sample is then incubated at 37^{0}C for 30 minutes in the dark to avoid any interference from light-sensitive reactions. The absorbance was measured at 593 nm. The reducing antioxidant power assay (ABTS method) was carried out. Thus, for a 10 mL total volume, 741 μL of the diluted sample and 9.3 mL of the 1% ABTS were pipetted into test tubes. Solution: 1-minute incubation at 734 nm for absorbance measurement.

To prepare the gold NPs precursor solution, $HAuCl_4{\cdot}3H_2O$ is dissolved in deionized water to obtain a 1.0–3.0 mM solution. The reduction and formation of Au NPs are initiated by mixing the gold NPs precursor solution with the DES extract in a 1:10 v/v ratio, followed by heating the reaction mixture to 85–90^{0}C under continuous stirring. The successful formation of gold nanoparticles is indicated by a color change from pale yellow to pink, red, or purple.

Spectra of colloidal solutions were acquired using quartz cuvettes and a spectrophotometer UV-5800PC in the wavelength range of 190–700 nm. The zeta potential of colloidal solutions was determined using the Zetasizer Nano-25 (Malvern Instruments Ltd., Malvern, England).

The experiments for antibacterial activity were carried out against for both gram-negative (*E. coli*) bacteria using plate broth microdilution method, corroborating with the resazurin viability assay viability assay [14]. Nutrient media was utilized for evaluating bacterial growth in liquid broth culture. A dilution series of known amounts of Au NPs in wells on the plate was generated. Dimethyl sulfoxide (DMSO) was used as a negative control. Each well was filled with the *E. coli*, and then the plate was incubated at 37^{0}C for 18 hours. After incubation, 10 μl of resazurin solution was added to all wells except the control well and again incubated at 37^{0}C for 2 h. Following incubation, all wells were visually assessed for color change. The well indicating blue color in the lowest dilution was considered as the MIC. Absorbance was then read at 570 nm. The lowest concentration, which completely inhibits the growth of microbes, was recorded as the MIC values. All the experimental trials were performed in triplicate.

Results and discussion

A series of choline chloride-based ionic liquids were investigated for the extraction of flavonoids from two representative wastes (banana peals) (Table 2). The obtained data show that the use of different compositions of DESs with different donor component (lactic acid and glycerol) based on choline chloride for the studied raw materials (banana peal) is in the range 6.33–35.8 mg/L. It is known [10–12] that the DES choline chloride+glycerol (30% water) is more effective for extracting bioactive compounds from raw fruit compared to choline chloride+glycerol (10% water) and choline chloride+lactic acid (10–30%). Adding 30% water significantly decreases viscosity, enhancing solute diffusion and extraction efficiency, enhances polarity, improving solvation power for flavonoids, polyphenols, and other bioactive compounds in fruits [12]. Lactic acid provides acidity, which may selectively hydrolyze some glycosidic bonds but can also lead to degradation of pH-sensitive flavonoids and anthocyanins.

A study was conducted to optimize the extraction processes (sample:solvent ratio (g/mL), (SSR)) and time extraction of the studied raw materials. The study explored how SSR and extraction time affect the extracted concentration of flavonoids, as well as antioxidant activity as measured by FRAP and ABTS techniques (Fig. 1).

For by-products banana (peel), increasing SSR resulted in higher flavonoid (222–521 (mg/100 g) for banana peel. A higher solvent volume allows for better mixing and a larger contact area between the solvent and the sample. Ultrasonic waves create cavitation

Table 2

Solvent composition and flavonoids extracted amount from fruit processing by-products

Solvent DES composition (sample:solvent ratio=1:40)	Water content, %	Flavonoids mg/L
Choline chloride+lactic acid	10	6.33
Choline chloride+lactic acid	30	5.54
Choline chloride+glycerol	10	9.81
Choline chloride+glycerol	30	35.80

bubbles in the solvent, resulting in microstructural changes in the material. Larger volumes generate more cavitation bubbles, leading to improved cell structure disintegration and polyphenol release. Previous studies [5,11,12] have shown that increasing SSR during ultrasonic waves increases polyphenol production and antioxidant activity. The obtained determination results indicate one general trend, that increasing the ratio sample:solvent ratio increases antioxidant activity of banana peel extracts determined by FRAP and ABTS methods: 20–60 mmol/L and 15–35 mmol/L, which is a completely expected pattern. At the same time, it observed the decrease in FRAP, what is related with prolonged extraction time is likely due to antioxidant degradation, oxidation, polymerization, and solvent saturation effects. Optimizing extraction time is crucial to balancing maximum yield and preservation of antioxidant activity.

There is a relationship between higher antioxidant activity and higher reduction activity of the extract for the synthesis of nanoparticles (NPs). Studies [5,8–10] have shown a positive correlation between total phenolic content (TPC), total flavonoid content (TFC), and the efficiency of green synthesis of nanoparticles [1–5,7,8–10]. Extracts with higher DPPH, ABTS, FRAP antioxidant activity tend to produce smaller, more stable nanoparticles with better dispersion. Studies using plant extracts have shown that extracts with higher TFC (measured in mg QE/g or mg QE/L) exhibit stronger reducing power, leading to a faster reaction and more uniform Au NP formation.

The effectiveness of the obtained DES extracts on the synthesis and stabilization of gold nanoparticles was studied by reducing the gold NPs precursor without adding additional reagents. The spectra (Fig. 2) show that both SPR-based extracts reduce gold ions and form gold nanoparticles, as evidenced by the formation of characteristic peaks at 550–560 nm over the studied synthesis period of 10–60 min.

It was found that organic compounds extracted using DES from banana peels allow the reduction of gold ions in the range of 1.0–3.0 mmol/L, however, there is no directly proportional dependence of the

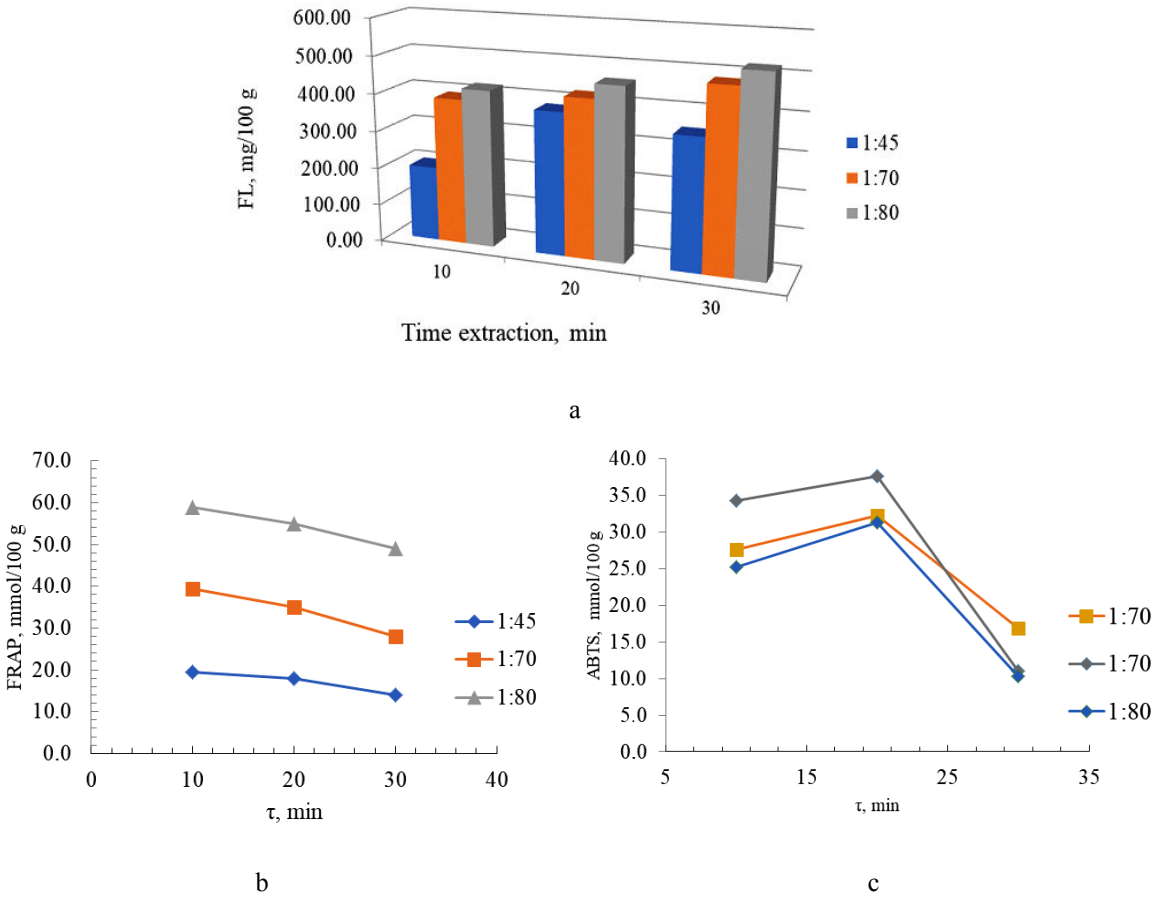

Fig. 1. Content of flavonoids as a function of extraction parameter, sample:solvent ratio and extraction time (a); antioxidant activity of banana peel extracts determined by FRAP (b) and ABTS (c) methods

change in absorbance and the values are: 0.63 a.u.; 1.2 a.u.; and 0.7 a.u. A regular pattern for the formation of gold nanoparticles has also been established, that an increase in the initial concentration of the precursor increases the size of the formed nanoparticles. This is characterized, firstly, by an increase in the PPR peak with an increase in the initial concentration of gold ions λ SPR=544−550 nm for 1.0 mmol/l, λ SPR=540−550 nm for 2.0 mmol/l, and λ SPR=555−560 nm for 3.0 mmol/l. For spherical gold nanoparticles, an SPR peak at 550 nm typically corresponds to a diameter of ~50−60 nm; 540 nm → ~30 nm; 560 nm → ~70−80 nm. Additionally, the size of gold nanoparticles was investigated by dynamic light scattering (Fig. 3).

The results obtained are consistent with the SPR peak data and an increase in the initial concentration will lead to an increase in the average size of the formed nanoparticles: dev=31±2.1 nm (IPD=0.19) for concentrations of Au^{3+} 1.0 mmol/L (Fig. 3,a), dev=53±3.3 nm (IPD=0.23) for 2.0 mmol/L (Fig. 3,b), and dev=68±1.2 nm (IPD=0.23) for 3.0 mmol/L (Fig. 3,c).

The kinetic curves of the intensity of the absorption maximum of the spectra and its position (Fig. 2,b,d,f) show the staged nature of the nucleation and growth processes of nanoparticles under conditions of homogeneous nucleation, which is characteristic

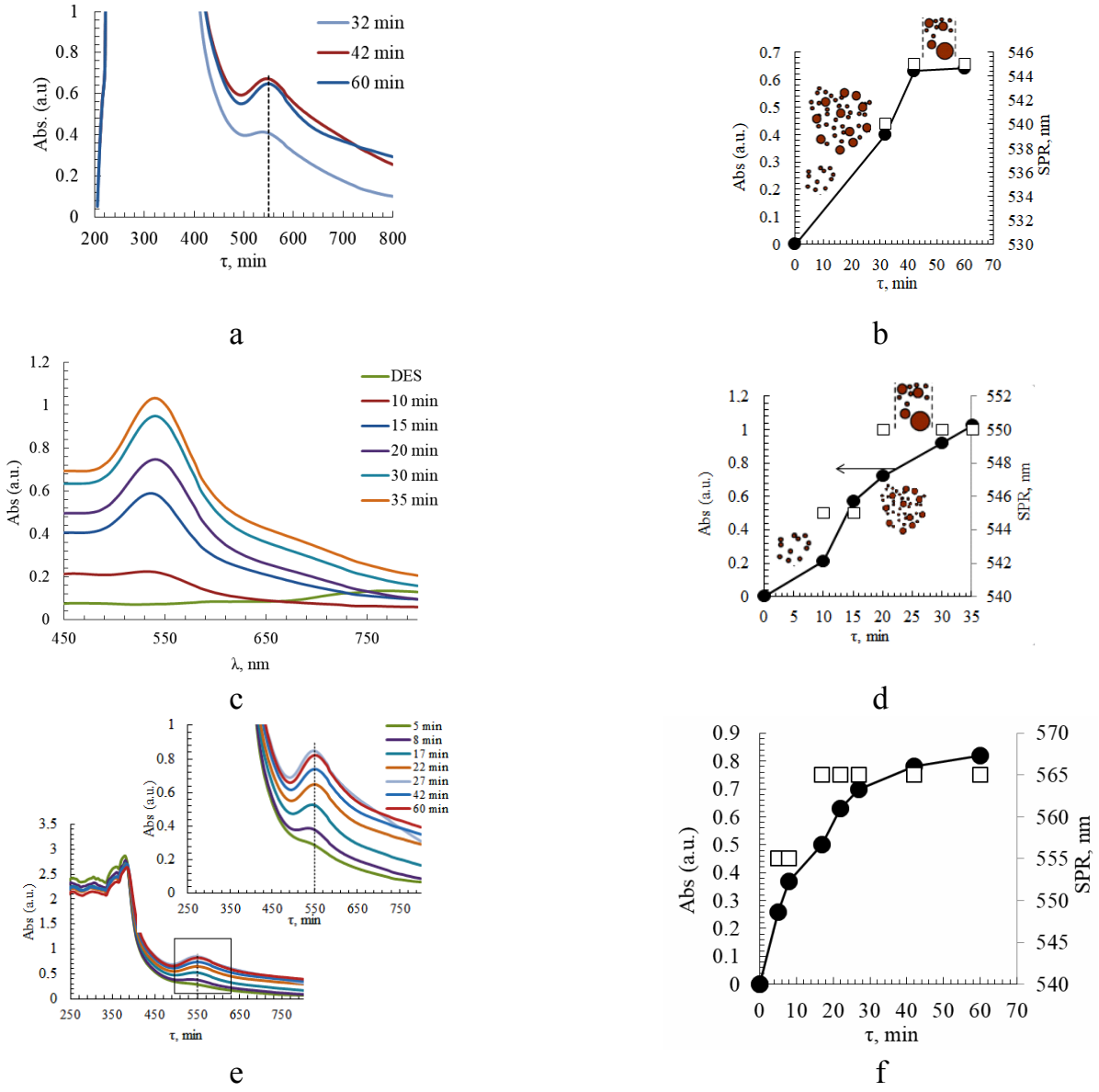

Fig. 2. UV-Vis spectra of Au NPs recorded for different concentrations of Au^{3+} 1.0 mmol/L (a, b); 2.0 mmol/L (c, d); 3.0 mmol/L (e, f) as a function of time of synthesis by DES obtained banana peel extract

for nanoparticle dispersion. As nanoparticles grow, the absorption maximum shifts to a longer wavelength, which is characteristic of larger particles (Fig. 4).

Studies [9,15] discuss the antimicrobial properties of multiple DESs, Au NPs/DES including antibacterial and antifungal activities. Samples (bare Au NPs, Au NPs-banana DES DES-extract) were tested for antibacterial effectiveness against Gram-negative bacteria *E. coli* bacteria (Table 3). Non-stabilized nanoparticles, DES-extract and Au/DES-extract mediate have antibacterial efficacy against pathogens, as indicated. Results showed that the MIC of Au-bare and Au-DES-banana extract NPs was 50 and 15 μg/mL, indicating that the antibacterial activity of Au-bare NPs against *E. Coli* strain was less effective than that of the Au-DES-extract NPs.

It was found that pure nanoparticles exhibit a lower antimicrobial activity compared to stabilized ones and the extract obtained. Such data are in full agreement with the known ones, since it is known that both extracts and DES by themselves are characterized by high antimicrobial activity, while gold dispersions themselves exhibit insignificant antimicrobial properties and only at high concentrations.

Conclusions

The study demonstrated that choline chloride-based deep eutectic solvents (DES) with glycerol in a 1:3 ratio and 30% water content were highly effective for extracting flavonoid compounds from banana peel. This approach outperforms conventional solvents, highlighting the potential of DES as an environmentally friendly and efficient extraction medium. The study investigated the influence of the sample-to-solvent ratio (SSR) and extraction time on flavonoid extraction and antioxidant activity. It was found that an optimal SSR range of 1:45 to 1:80 and extraction times between 10 to 30 minutes yielded high antioxidant activity, as measured by FRAP and ABTS assays (20–60 mmol/L and 15–35 mmol/L, respectively). This indicates that the process can be fine-tuned to achieve desired results. The flavonoid content in the banana peel extracts ranged from 222 to 521 mg/100 g, indicating a significant potential for utilizing banana peel as a natural source of bioactive compounds. The antioxidant activity, determined by both FRAP and ABTS methods, supports the value of banana peel extracts in functional applications. The use of banana peel-based DES extracts facilitated the synthesis of gold nanoparticles (Au NPs) through the reduction of hydrogen tetrachloroaurate ($HAuCl_4 \cdot 3H_2O$). The resulting spherical Au NPs exhibited a size range of 31–68 nm and a zeta potential of −33 to −36 mV, with the size and surface charge being adjustable depending on the initial precursor concentration. This demonstrates the flexibility and potential of DES for nanoparticle synthesis. The synthesized gold nanoparticles displayed significant antibacterial activity, particularly against E. coli, with a minimum inhibitory concentration (MIC) of 15 μg/mL. This suggests that the DES-based gold nanoparticles, derived from banana peel extracts, could be utilized as antibacterial agents in biomedical and environmental applications. The study highlights the potential of DES-based extraction and nanoparticle synthesis as a green chemistry alternative. By using a waste byproduct (banana peel) and an eco-friendly solvent system (DES), this approach offers a sustainable solution for both the extraction of valuable compounds and the synthesis of functional nanoparticles.

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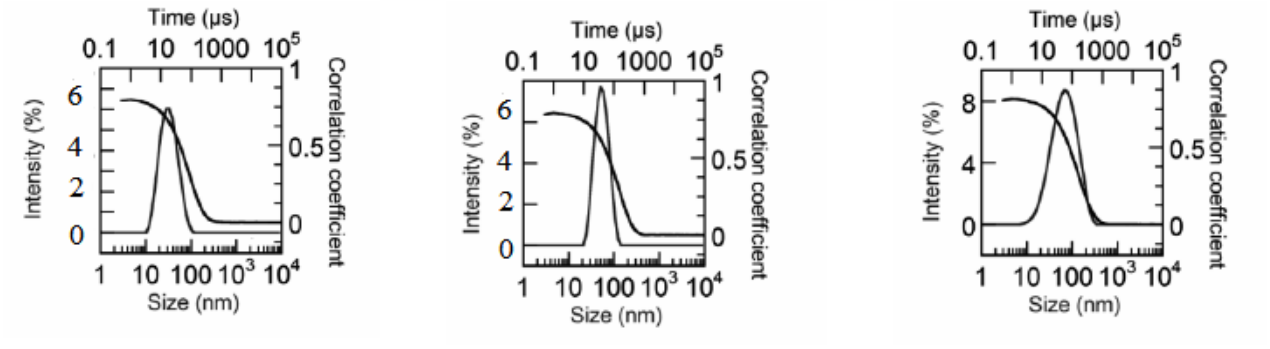

Fig. 3. DLS size distribution of NPs synthesized by DES obtained banana peel extract for different concentrations of Au^{3+} 1.0 mmol/L (a); 2.0 mmol/L (b); and 3.0 mmol/L (c)

of advanced measures for determining and disposal of pollutants entering the environment as a result of military actions (2024–2026).

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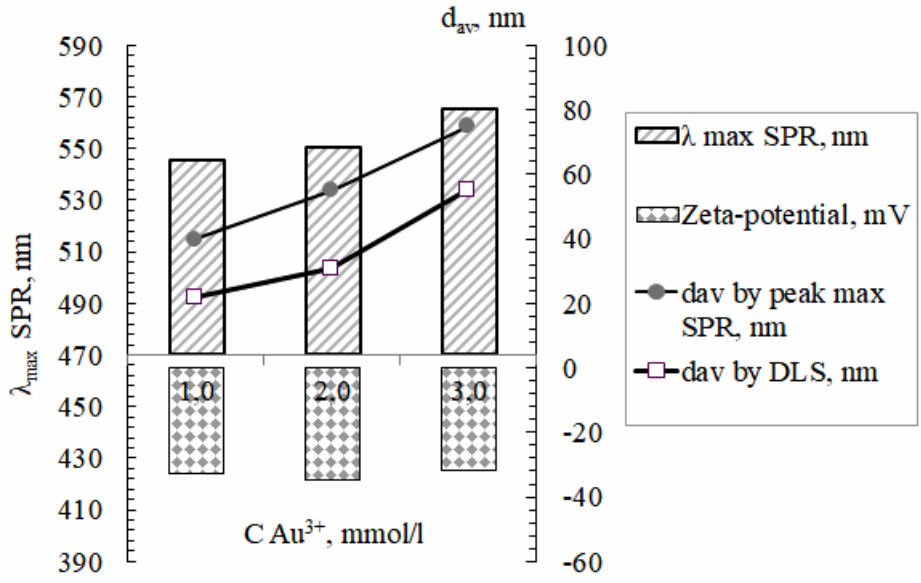

Fig. 4. Dependence of the dimensional characteristics of nanoparticles SPR, d_{av} by peak max SPR, d_{av} by DLS method and zeta-potential on the initial concentration of Au^{3+}

Table 3

Antibacterial effect on *Escherichia coli (E. coli)* *

Sample	Inhibitory effect of Au NPs (OD at 570 nm)) concentration of Au NPs					
	100 μg/ml	50 μg/ml	25 μg/ml	12.5 μg/ml	6.0 μg/ml	0.5 μg/ml
Bare plasma synthesis Au NPs	2.37±0.01	1.94±0.03	1.81±0.01	1.70±0.01	1.62±0.03	1.53±0.01
AuNPs-banana DES	0.9±0.02	1.11±0.01	1.11±0.02	1.20±0.01	1.25±0.03	1.30±0.02
DES-banana extract	1.4±0.02	1.6±0.01	1.70±0.02	1.50±0.02	1.45±0.03	1.430±0.03

Note: * – MIC value of Au-bare NPs=50 μg/ml; MIC value of DES-extract=22 μg/ml; MIC value of Au-DES-extract NPs=15 μg/ml.

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ЗЕЛЕНИЙ ПІДХІД ДО СИНТЕЗУ НАНОЧАСТИНОК ЗОЛОТА З АНТИМІКРОБНОЮ АКТИВНІСТЮ З ВИКОРИСТАННЯМ РОСЛИННИХ ЕКСТРАКТІВ НА ОСНОВІ ГЛИБОКОГО ЕВТЕКТИЧНОГО РОЗЧИННИКА

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Наночастинки золота було синтезовано шляхом відновлення гідроген тетрахлораурату (III) гідрату ($HAuCl_4 \cdot 3H_2O$) з використанням екстрактів рослинних відходів (бананової шкірки), одержаних за допомогою низькотемпературного евтектичного розчинника (НЕР) на основі холін хлориду. Продемонстровано, що екстракт рослинних відходів (бананової шкірки), одержаний НЕР дозволяє синтезувати сферичні наночастинки золота (НЧ Au), що характеризуються максимальним піком поглинання плазмонного резонансу приблизно при λ=540–560 нм, з діапазоном середнього розміру наночастинок 31–68 нм із значенням дзета-потенціалу −33÷−36 мВ, залежно від початкової концентрації прекурсора-стабілізатора, що використовується в процесі синтезу. НЕР на основі холін хлориду використовувався як новий альтернативний звичайним розчинникам для ультразвукової екстракції активних речовин з відходів рослинної сировини, зокрема бананової шкірки. Було здійснено порівняння низькотемпературних евтектичних розчинників на основі холін хлориду з гліцерином і молочною кислотою у співвідношенні 1:3 і водою 10–30%. Було встановлено, що холін хлорид та гліцерин у співвідношенні 1:3 із вмістом води 30% є високоефективними для екстрагування флавоноїдних сполук із рослинних відходів (шкірки банану). Досліджено вплив параметрів екстрагування, а саме: співвідношення зразка до розчинника і час екстракції на вміст екстрагованих флавоноїдів і антиоксидантну активність екстракту за допомогою методів визначення антиоксидантної активності за допомогою відновлення іонів заліза (FRAP) і тест (ABTS) (2,2'-азинобіс(3-етилбензотіазолін-6-сульфонова кислота). Встановлено, що екстрагований вміст флавоноїдів з використанням НЕР становить (222–521 (мг/100 г). Встановлено, що співвідношення зразок:розчинник (1:45÷1:80) і час екстрагування 10–30 хв дозволяє отримати значення антиоксидантної активності екстрактів бананової шкірки, визначене методами FRAP і ABTS: 20–60 ммоль/л і 15–35 ммоль/л. Одержані наночастинки золота з використанням НЕР-екстрактів бананової шкірки показали вищу антибактеріальну активність до *E. coli* порівняно з екстрактом НЕР-бананової шкірки та нестабілізованими наночастинками золота.

Ключові слова: наночастинки золота, глибокий евтектичний розчинник, флавоноїди, екстракт, бананова шкірка, антиоксидантна активність, антимікробна активність.

GREEN APPROACH TO THE SYNTHESIS OF GOLD NANOPARTICLES WITH ANTIMICROBIAL ACTIVITY USING PLANT EXTRACTS BASED ON A DEEP EUTECTIC SOLVENT

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Gold nanoparticles were synthesized by reducing hydrogen tetrachloroaurate(III) trihydrate ($HAuCl_4 \cdot 3H_2O$) using plant waste (banana peel) extracts obtained using a deep eutectic solvent (DES) based on choline chloride. It was demonstrated that the plant waste (banana peel) extract obtained by DES allows the synthesis of spherical gold nanoparticles (Au NPs), characterized by a maximum plasmon resonance absorption peak at approximately λ=540−560 nm, with an average nanoparticle size range of 31−68 nm with a zeta potential value of −33 to −36 mV, depending on the initial concentration of the precursor stabilizer used in the synthesis process. Choline chloride-based DES was used as a new alternative to conventional solvents for ultrasonic extraction of active substances from plant waste, in particular banana peel. Low-temperature eutectic solvents based on choline chloride were compared with glycerol and lactic acid in a ratio of 1:3 and water 10−30%. It was found that choline chloride and glycerol in a ratio of 1:3 with a water content of 30% are highly effective for the extraction of flavonoid compounds from plant waste (banana peel). The influence of extraction parameters, namely sample-to-solvent ratio and extraction time, on the content of extracted flavonoids and antioxidant activity of the extract was studied using the methods of determining antioxidant activity by ferric ion reduction (FRAP) and the ABTS test (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid). It was established that the extracted flavonoid content using DES is 222−521 mg/100 g. It was established that the sample-to-solvent ratio (1:45−1:80) and the extraction time of 10−30 min allow obtaining the antioxidant activity value of banana peel extracts, determined by the FRAP and ABTS methods: 20−60 mmol/l and 15−35 mmol/l. The gold nanoparticles obtained using DES extracts of banana peel showed higher antibacterial activity against E. coli compared to the DES extract of banana peel and non-sterilized gold nanoparticles.

Keywords: gold nanoparticles; deep eutectic solvent; flavonoids; extract; banana peel; antioxidant activity; antimicrobial activity.

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