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COMPARATIVE STUDY OF GOLD NANOPARTICLES FORMATION BY EXTRACTS FROM TRANSGENIC AND NONTRANSFORMED *Bidens pilosa* L. ROOTS

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Aim. The study was aimed to compare the process of gold nanoparticles (AuNP) formation using extracts from transgenic and nontransformed roots of *Bidens pilosa* L., taking into account potential changes in the metabolism of transformed root cells following genetic transformation.

Methods. Transgenic roots and *Bidens pilosa* L. plants from the collection of the Institute of Cell Biology and Genetic Engineering of the National Academy of Sciences of Ukraine were used. The flavonoid content and reducing activity of the ethanol extracts were determined, and the extracts were then used to synthesize AuNPs with 0.07% $HAuCl_4$. Nanoparticles were characterized spectrophotometrically over the range λ = 300–700 nm (SPR) and by transmission electron microscopy (TEM); the size distribution of nanoparticles was calculated from measurements of 200 nanoparticles in each variant (ImageJ).

Results. Extracts from transgenic roots showed greater reducing activity than extracts from control roots, despite the same concentration of flavonoids in the standardized extracts. The addition of extracts from both transgenic and control roots to the $HAuCl_4$ solution resulted in a characteristic change in the solution's color. The presence of nanoparticles was visualized by TEM. SPR (surface plasmon resonance) maximum was located around 540–555 nm. An increase in the maximum SPR peak was observed as the concentration of extracts in the reaction mixtures increased. When using the extract from transgenic roots, a more heterogeneous population of nanoparticles was observed, with a larger proportion of AuNPs in the 20–40 nm size range.

Conclusions. Transformation of *B. pilosa* alters root metabolism, leading to increased reducing activity and affecting the process of "green" synthesis of gold nanoparticles. Extracts from both transgenic and non-transformed roots effectively promoted the synthesis of AuNPs, and increasing their concentration in the reaction mixture improved synthesis efficiency.

Keywords: *Bidens pilosa* L., genetic transformation, hairy roots, reducing activity, gold nanoparticles, "green" synthesis.

The "green" synthesis of metal nanoparticles has become a cornerstone of modern nanotechnology, a field that combines chemistry, biology, and materials science. In the 21st century, the synthesis of such nanoparticles is a progressive trend in biotechnology, driven by the need for environmentally friendly, reproducible, and biocompatible materials and technologies for their production. Unlike traditional chemical or physical methods, biogenic nanosynthesis involves the use of extracts from living objects (including plants) and exploits the reducing and stabilizing potential of natural metabolites, such as polyphenols, flavonoids, terpenoids and proteins, which can be synthesized in biological systems, in particular, in plants, fungi and microorganisms (Fig. 1). These biomolecules not only mediate the reduction of metal ions, but also affect the morphology, stability, and bioactivity of nanoparticles synthesized by

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"green" synthesis [1–3]. "Green" synthesis is a simple, safe, and relatively cheap biotechnological method for obtaining modern nanomaterials [4].

Metal nanoparticles can find applications in various fields, in particular, in medicine and industry. Gold nanoparticles (AuNPs), owing to their unique optical, electronic, and catalytic properties, have applications in biomedicine, electronics, and ecology. A review of current research highlights their multifunctionality and promise in interdisciplinary fields. In biomedicine, AuNPs are used for diagnostic imaging and targeted drug delivery for cancer therapy; they are also used in biosensors and nanoelectronics; they can be effective in detecting pollutants and in water purification [5–7]. It has been shown that nanoparticles affect various processes in plants, such as seed germination, photosynthetic apparatus, and activity of the antioxidant system; moderate concentrations of gold nanoparticles stimulate the growth of lateral roots, reduce oxidative stress in plant cells, and activate the synthesis of secondary metabolites in cells [8–10].

Polyphenols and flavonoids are among the important classes of secondary plant metabolites involved in the biogenic reduction of metal ions and the synthesis of nanoparticles. Their numerous hydroxyl groups and aromatic structures allow electron donation, facilitating the conversion of ionic precursors into stable nanoparticles. In addition, these compounds act as natural agents that prevent aggregation and ensure the stability of colloidal solutions [11–13]. It has been shown that flavonoids, notably quercetin, can be used directly to synthesize metal nanoparticles, thereby enabling the production of smaller, more homogeneous nanoparticles due to their strong reducing potential [14, 15]. In the work of Nemčeková et al. [16], the features of nanoparticles coated with gallic acid were investigated. At the same time, the chemical composition of various plant extracts allows targeted synthesis of nanoparticles of specific sizes, depending on the prevalence of certain chemical compounds.

The reaction conditions of biogenic synthesis of metal nanoparticles, especially the composition of the extract and the associated reducing activity, influence the size and shape of the nanoparticles, which, in turn, modulate their optical and catalytic properties. That is why studies are being conducted using plant extracts from different species, each with a distinct spectrum of secondary metabolites. However, the achievements of modern plant biotechnology, including genetic transformation using the soil *Rhizobium rhizogenes* bacterium, have enabled the use of transgenic plant tissues, such as hairy roots, to induce metabolite biosynthesis and effectively produce metal nanoparticles [17, 18]. The use of biotechnological roots may have several advantages related to the change in the metabolism of transformed plant cells, the activation of the synthesis of secondary metabolites, including polyphenols with high reducing activity, due to the special activity of the genes of the bacteria *R. rhizogenes* transferred to their genome (metabolic reprogramming) [19, 20]. This approach is consistent with the principles of "green" chemistry, emphasizing the use of renewable biological resources and minimizing environmental impact. The scheme (Fig. 1) illustrates the process of "green" synthesis

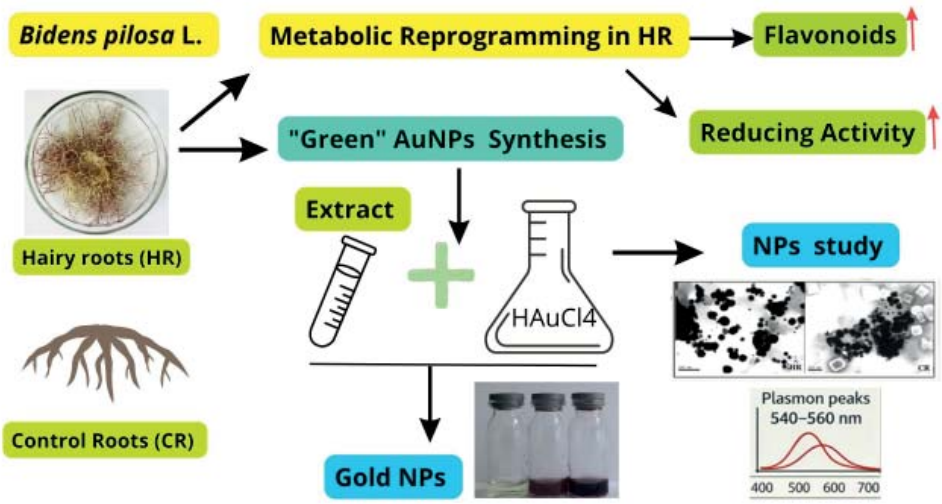


Fig. 1. **Scheme of the process of gold nanoparticles "green" synthesis**

of gold nanoparticles (AuNPs) from plant extracts. Metabolic reprogramming in the roots leads to the accumulation of flavonoids and phenolic compounds, which act as natural reducing agents and stabilizers when interacting with $HAuCl_4$.

Bidens pilosa L. (Asteraceae family) is a cosmopolitan herbaceous plant widely distributed in tropical and subtropical regions. Traditionally, *B. pilosa* has been used in ethnomedicine for its anti-inflammatory, antimicrobial, and antidiabetic properties [21–24]. Phytochemical studies have shown that these plants are rich in polyphenols (flavonoids, phenolic acids), terpenoids, and fatty acids, which contribute to their diverse biological activities [21, 25, 26]. Compounds such as polyphenols have strong antioxidant and reducing properties, which allow them to act as natural reducing agents in the biosynthesis of metal nanoparticles and to influence the stability and bioactivity of the resulting colloidal nanoparticle solutions. Previously [27], we found that genetic transformation increased flavonoid content in transgenic roots of *B. pilosa*. Such differences may alter the reducing activity of extracts from transgenic roots relative to the untransformed control and also affect the process of "green" synthesis of metal nanoparticles.

Despite significant advances toward "green" synthesis of metal nanoparticles, challenges remain in both the synthesis and application of nanoparticles, particularly regarding toxicity, biocompatibility, and the standardization of preparation and characterization methods. The lack of unified protocols for the characterization of nanoparticles and biological tests often limits the reproducibility and application of nanoparticles. In addition, an important task for researchers remains finding ways to optimize the process of "green" synthesis by identifying plants with high levels of compounds that have reducing and stabilizing properties. The aim of our study was to compare the synthesis of gold nanoparticles using extracts from transgenic and non-transformed *B. pilosa* roots in order to determine how genetic transformation affects the biochemical pathways of the synthesis of specific biologically active compounds participated in the formation and stabilization of the nanoparticles.

Materials and Methods

Cultivation of plant material and extraction. Transgenic roots and plants of *Bidens pilosa* L. from the collection of the Institute of Cell Biology and Genetic Engineering of the National Academy of Sciences of Ukraine were used. Plants and hairy roots were grown *in vitro* on Murashige and Skoog (Duchefa) half-strength agar medium (1/2MS) at 24 °C. To prepare extracts, the roots of untransformed and transgenic plants were homogenized in 70% ethanol. The extracts were centrifuged (Eppendorf 5415 C microcentrifuge) at 14,000 rpm for 10 minutes, and the supernatant was collected and used for further research.

Determination of flavonoid content. A previously described modified spectrophotometric method [28] was used. The absorption of the reaction mixture was measured using a UV-Vis spectrophotometer (Fluorat-02 Panorama) at 510 nm. The flavonoid content in the extracts was calculated using a calibration curve ($y = 0.812x$) and expressed as rutin equivalents (mg RE/ml). The obtained samples were standardized by appropriate dilution to a concentration of 0.5 mg RE/ml.

Analysis of reducing power. The reducing capacity of the standardized extracts was assessed by reacting them with a 0.1% $FeCl_3$ solution, as previously optimized by us [18]. The absorption was measured at 700 nm using a UV-Vis spectrophotometer (Fluorat-02 Panorama). The reducing capacity was expressed as equivalent concentrations ($EC_{0.5}$).

Synthesis and characterization of gold nanoparticles (AuNPs). For nanoparticles synthesis, different sample volumes (0.05, 0.1, 0.2 ml) were mixed with 2 ml of 0.07% $HAuCl_4$ (Sigma-Aldrich). The reaction mixtures were incubated in a water bath (Micromed VB-20) at 50 °C for 20 minutes. The formation of nanoparticles was confirmed by analyzing the spectra in the range of 300–700 nm using a Fluorat-02 Panorama spectrophotometer and Panorama Pro software. The size and morphology of the synthesized nanoparticles were characterized by transmission electron microscopy (TEM) on a JEM-1400 microscope (Jeol, Japan) with an accelerating voltage of 80 kV. The sizes of the nanoparticles were determined using ImageJ software (https://imagej.net/ij/download.html), measuring at least 200 nanoparticles in each variant.

Statistical analysis. The results were calculated and expressed as the mean ± standard deviation, estimated in three independent replicates. The data were checked for normality using the Shapiro-Wilk test. To assess the presence of a statistically significant difference in the results of studies of different

extracts, ANOVA was used, followed by a Tukey test.

Results and Discussion

The study was conducted using the roots of *B. pilosa* transgenic line No. 4 and the roots of nontransformed plants from the collection of the Institute of Cell Biology and Genetic Engineering of the NAS of Ukraine.

It is known that the presence of reducing activity in the extracts used in the "green" synthesis of metal nanoparticles is one of the most important factors affecting the process of nanosynthesis. Since flavonoids are compounds with high reducing activity [29], the analysis of extracts obtained from the roots of the control and transgenic roots for the presence of these compounds was carried out. It revealed differences in the flavonoid content of the studied samples. In particular, the content of flavonoids in the extract from control roots was equal to 2.03±0.03 mg RE/g fresh weight, and in the extract from transgenic roots – 4.87±0.06 mg RE/g fresh weight. The obtained extracts were diluted to the same rutin equivalent concentration, 0.5 mg RE/ml, and used to analyse reducing activity (Fig. 2). It was found that the reducing activity of the ethanol extracts differed significantly among the studied variants. The extracts of the roots of control plants (CR) were characterized by a significantly lower reducing capacity (the higher the equivalent concentration $EC_{0.5}$, the lower the reducing activity is considered), reaching $EC_{0.5}$ = 11.98±2.38 mg fresh weight, while the corresponding figure for the hairy roots (HR) was about 3.78±0.14 mg fresh weight. Thus, the reducing activity of the extracts of the control roots was approximately 3.2 times lower than that of the transgenic roots. The difference between the variants was statistically significant ($P < 0.05$).

The results indicate that the transformation induced by *R. rhizogenes* is accompanied by a significant reprogramming of *B. pilosa*'s secondary metabolism, leading to an increase in the reducing capacity of ethanolic root extracts. Since the reducing activity of plant extracts is largely determined by the content of polyphenolic compounds and other antioxidants, the data obtained may indicate qualitative changes in their composition in transgenic roots compared with non-transformed roots. Such changes may affect the ability of extracts to synthesize metal nanoparticles biogenically, since the efficiency of reducing metal ions depends directly on their reducing power.

Fig. 3 presents the visual appearance and UV-visible absorption spectra of gold nanoparticle solutions synthesized using ethanolic extracts of hairy roots (HR) and untransformed control roots (CR) of *B. pilosa*. Visual analysis revealed a clear color change of the reaction mixtures from colorless to ruby red upon addition of the plant extracts to the $HAuCl_4$ solution (Fig. 3), confirming the reduction of Au^{3+} ions and the formation of colloidal gold nanoparticles. In NPs solutions obtained from both HR and CR, increasing the extract volume from 50 to 200 µL gradually intensified the characteristic ruby-red color, indicating an increase in nanoparticle concentration. The most intense coloration was observed with the extract at the highest concentration (200 µL/2 mL), whereas only a faint pink coloration was observed in samples containing 50 µL of extract.

UV-Vis spectra recorded immediately after synthesis confirmed the formation of nanoparticles (Fig. 3). Samples prepared using extracts at concentrations of 100 µL/2 mL (curve 2) and 200 µL/2 mL



Fig. 2. **Transgenic roots of line 4, control non-transformed** *Bidens pilosa* **L. plants, and results of analysis of the reducing activity of ethanol extracts from these samples**

(curve 3) of extract showed a pronounced surface plasmon resonance (SPR) band centered at approximately 540–555 nm, which is characteristic of gold nanoparticles. In contrast, solutions obtained using only 50 µL of extract (curve 1) showed no clear SPR maximum (HR extracts) or only a weak, poorly defined absorption peak (CR extracts), indicating incomplete reduction of Au^{3+} ions and formation of nanoparticles at a much lower concentration.

For nanoparticles synthesized using extracts from transgenic roots (Fig. 3, *A*), increasing the extract volume from 100 to 200 µL caused only minor changes in the position of the SPR peak but resulted in a significant increase in the absorption intensity, indicating enhanced nanoparticle formation without significant changes in particle size distribution. Similarly, extracts from control roots (Fig. 3, *B*) generated nanoparticles with SPR peaks in the same wavelength range.

The SPR peaks of all efficiently synthesized samples remained in the range typical of AuNPs, with no significant shift observed above 560 nm. This indicates the absence of extensive nanoparticle aggregation or the formation of large nanoparticles immediately after synthesis.

Thus, the results of this study showed that the volume of plant extract at a constant $HAuCl_4$ volume is an important factor controlling the efficiency of gold nanoparticles synthesis. Increasing the amount of added extract provides a greater amount of reducing and stabilizing chemical compounds, which leads to a greater reduction of Au^{3+} ions and the formation of stable colloidal solutions of AuNPs.

Even though the two analyzed extracts showed different reducing activities, both types of extracts allowed for the efficient synthesis of gold nanoparticles when used in a ratio of 100–200 µl per 2 ml of precursor solution ($HAuCl_4$), indicating that even extracts with reduced reducing capacity contain sufficient amounts of bioactive metabolites for the formation of NPs.

TEM analysis confirmed the presence of nanoparticles formed using both transgenic and control root extracts (Fig. 4). This analysis showed that regardless of the type of plant extract used to initiate nanosynthesis, predominantly spherical or nearly spherical AuNPs were formed. At the same time, nanoparticles synthesized using transgenic root extracts were characterized by greater size heterogeneity and the presence of individual larger NPs, while extracts from non-transformed roots provided the formation of a more homogeneous population of nanoparticles.

The size distribution of gold nanoparticles synthesized using ethanol extracts from hairy roots (HR) and untransformed control roots (CR) of *B. pilosa* is presented in Fig. 5.

The gold nanoparticles synthesized using the extract from transgenic roots (Fig. 5, *A*) exhibited a relatively broad size distribution. The predominant fractions consisted of nanoparticles with diameters

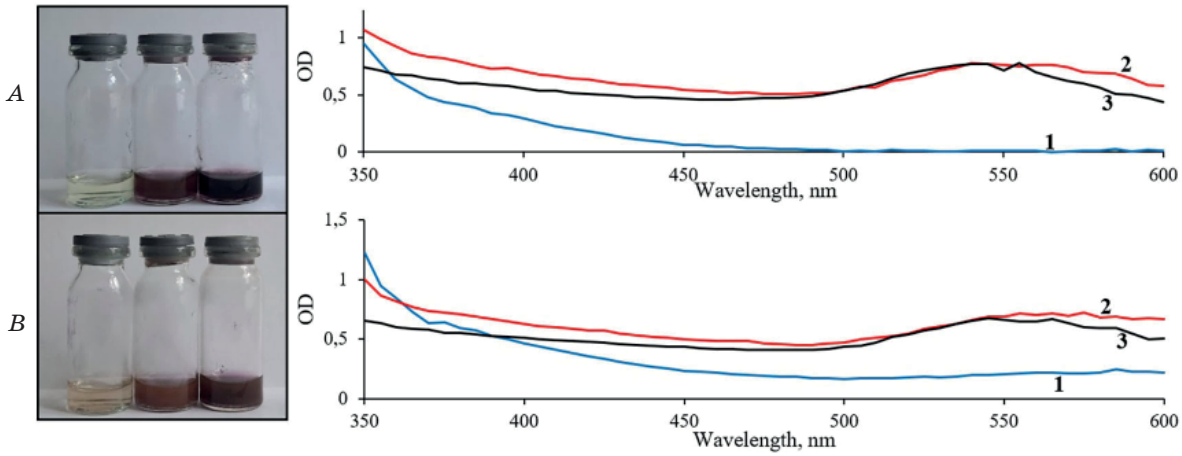


Fig. 3. **Solutions of AuNPs, made using *B. pilosa* hairy root (*A*) and control root (*B*) extracts with the incubation temperature 50 °C and their UV-Vis spectra after the synthesis**
line *1* — 50 µl of extract, line *2* — 100 µl (colloid solution was diluted two times), line *3* — 200 µl (colloid solution was diluted four times)

of 10–20 nm (32%) and smaller than 10 nm (31%). Nanoparticles with a size of 20–30 nm constituted about 19% of the population, while NPs with a size of 30–40 nm constituted 15%. Only a small fraction of nanoparticles (3%) exceeded 40 nm in diameter. Thus, more than 60% of the synthesized nanoparticles were smaller than 20 nm, although the overall population remained relatively heterogeneous.

In contrast, nanoparticles synthesized using extracts from untransformed roots (Fig. 5, *B*) exhibited a significantly narrower size distribution band. The dominant fraction consisted of nanoparticles with a diameter of 10–20 nm, which accounted for 54% of all measured particles. Nanoparticles smaller than 10 nm were 31%, while particles 20–30 nm and 30–40 nm were only 8% and 6%, respectively. Nanoparticles larger than 40 nm were rarely observed (only 1%).

Comparison of the two distributions shows that both extracts preferentially contributed to the formation of relatively small AuNPs (< 20 nm). However, using an extract from control roots led to a more homogeneous population of nanoparticles, with more than 50% of NPs measuring 10–20 nm. At the same time, extracts from transgenic roots showed a broader distribution, with a larger proportion of particles larger than 20 nm, indicating greater variability in nanoparticle formation and growth during synthesis.

These results show that the chemical composition of the plant extract influenced not only the efficiency of gold nanoparticle formation but also the kinetics of NP formation and growth, which likely determined the nanoparticle size distribution. The narrower size distribution observed in the colloidal solution of nanoparticles synthesized using extracts from control roots indicates a fairly balanced ratio of reducing and capping compounds. The broader nanoparticle size distribution observed with transgenic root extracts may reflect transformation-induced changes in secondary metabolism that alter the concentration or composition of metabolites involved in metal-ion reduction and nanoparticle stabilization. It should be noted that the studied extracts did not differ in total flavonoid content. However, their reducing power (as determined by the $EC_{0.5}$ parameter) differed significantly: the extract from transgenic roots showed a higher reducing activity. Therefore, it can be assumed that with greater reducing activity, the nanosynthesis process occurred faster, accompanied by the aggregation of small nanoparticles and a higher percentage of nanoparticles larger than 20 nm.

Plant extracts from various species can serve as reducing agents for metals, including gold, in the synthesis of nanoparticles. This is possible due to the presence of chemical compounds, including polyphenols, whose functional groups participate in nanosynthesis, ensuring the coating and stabilization of nanoparticles [30, 31]. Specifically, gold nanoparticles have previously been synthesized using extracts from numerous plants, such as *Mucuna pruriens* (L.) DC., *Saraca indica* L., *Trianthema decandra* L., *Antigonon leptopus* Hook. & Arn., *Nepenthes khasiana* Hook., *Cassia italica* Mill., *Camellia sinensis* (L.) Kuntze, *Curcuma spp.*, *Mangifera indica* L., *Musa paradisiaca* L., *Punica granatum* L., *Abutilon indicum* (L.) Sweet, *Artocarpus hirsutus* Lam., *Dracocephalum kotschyi* Boiss., *Hibiscus sabdariffa* L., *Mimosa pudica* L., *Platycodon grandiflorum* (Jacq.)

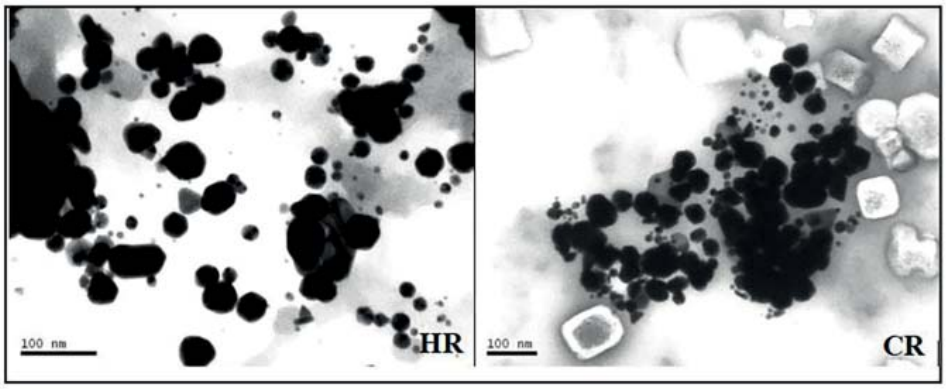


Fig. 4. **TEM images of gold nanoparticles synthesized using hairy root (HR) and control root (CR) ethanol extracts of *Bidens pilosa*. Scale bars: 100 nm**

A. DC., *Ricinus communis* L., and others. These nanoparticles exhibited differences in physical characteristics and their bioactivity [see reviews 32–34], which is linked to differences in the metabolism and synthesis of bioactive compounds.

Nanoparticle bioactivity is influenced by both particle size and the chemical composition of the extract used during synthesis. The synthesis process itself also influences biocompatibility, as certain conditions can render nanoparticles toxic to living cells. These characteristics have been examined, particularly through in vitro studies using a range of cell lines. Findings indicate that, depending on factors such as surface layer properties, particle size, and NPs concentration, nanoparticles can promote inflammation, induce oxidative stress, suppress cell growth, and damage DNA [35–40]. However, other studies have found no such adverse effects [41–44]. Smaller nanoparticles may exhibit higher toxicity. In view of this, the nanoparticles synthesized by us using the extract of transgenic roots, which had larger sizes (only 32% of the nanoparticles had a size less than 20 nm) compared to those obtained from the extracts of the control plants (54% of NPs were in this size range), may be less toxic. However, such an assumption should be investigated to confirm it.

The results obtained in our study indicate that genetic transformation of *B. pilosa* using *Rhizobium rhizogenes* alters the metabolism of transgenic roots, which in turn affects bioactivity, particularly the level of reducing activity. Such features affect the process of "green" synthesis of gold nanoparticles. In particular, the analysis of reducing power showed that extracts from hairy roots were more effective at reducing Fe^{3+} in the test reaction than extracts from control plant roots. However, the total flavonoid content, measured spectrophotometrically, was the same in both extracts. This may indicate differences in the ratios of metabolites with reducing activity, or the synthesis of compounds not characteristic of untransformed plants, as observed earlier when studying the effect of genetic transformation on the synthesis of polyphenolic compounds in transgenic roots [20]. Such results require further analysis through an extended comparative study of the metabolite spectrum in the hairy roots.

Thus, extracts from both transgenic and non-transformed roots of *B. pilosa* can be used for the "green" synthesis of gold nanoparticles, since the presence of nanoparticles was visualized by TEM, and the SPR maximum was located around 540–555 nm for both variants, which is characteristic of gold nanoparticles. The concentration of the extract in the reaction

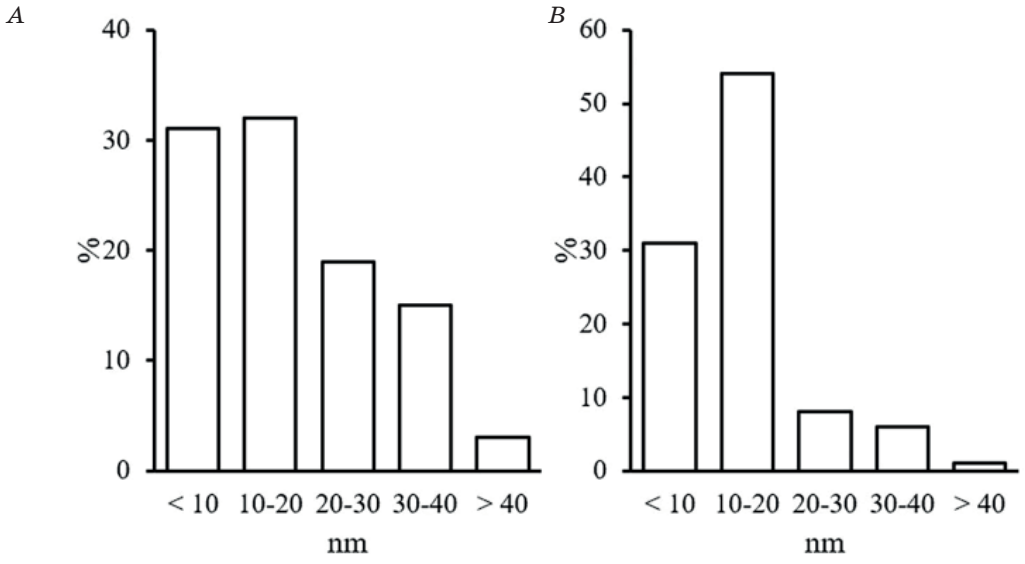


Fig. 5. **The size distribution of gold nanoparticles synthesized using ethanol extracts from hairy roots (*A*) and untransformed control roots (*B*) of *Bidens pilosa***

mixture is a critical factor in the synthesis of AuNPs, since both a visual change in the intensity of the color of the solutions and an increase in the maximum of the SPR peaks were observed with increasing concentration of the extracts in the reaction mixtures. TEM analysis revealed that when using the extract from transgenic roots, a more heterogeneous population of nanoparticles is formed with the presence of a larger proportion of nanoparticles with a size of 20-40 nm than when using the extract from the roots of control plants, where large-sized nanoparticles (more than 40 nm) accounted for only 1% of the total number of analyzed NPs. It can be assumed that the qualitative composition of the extract is probably more important than its reducing activity.

Conclusions

Genetic transformation of *Bidens pilosa* with *Rhizobium rhizogenes* alters the metabolism of transgenic roots, as evidenced by increased reducing power, and affects the "green" synthesis of gold nanoparticles. Extracts from both transgenic and non-transformed roots effectively promoted the synthesis of AuNPs, and increasing their concentration in the reaction mixture improved the synthesis efficiency. TEM analysis showed that extracts of transgenic roots formed a more heterogeneous population of nanoparticles, while extracts of control roots provided the formation of more uniform-sized AuNPs. The results indicate that a possible determining factor in the "green" synthesis of gold nanoparticles is the qualitative composition of the plant extract, rather than its reducing activity alone.

Author Contributions

N. A. Matvieieva — conceptualization, supervision, research, analysis and interpretation of results, literature selection, drafting of the manuscript, and final approval of the manuscript. T. A. Bohdanovych — research, editing, language polishing, translation editing, literature selection, and critical revision of the manuscript. V. P. Duplij — data analysis, interpretation of results, critical revision of the manuscript. D. O. Klymchuk — research, approval of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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ПОРІВНЯЛЬНЕ ДОСЛІДЖЕННЯ УТВОРЕННЯ НАНОЧАСТОК ЗОЛОТА ЗА ВИКОРИСТАННЯ ЕКСТРАКТІВ З ТРАНСГЕННИХ ТА НЕТРАНСФОРМОВАНИХ КОРЕНІВ *Bidens pilosa* L.

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Мета. Метою дослідження було порівняти процес утворення наночасток золота (AuNPs) за використання екстрактів з трансгенних та нетрансформованих коренів *Bidens pilosa* L., зважаючи на можливі зміни у метаболізмі трансформованих клітин коренів після генетичної трансформації.

Матеріали й методи. Використовували трансгенні корені та рослини *Bidens pilosa* L. з колекції Інституту клітинної біології та генетичної інженерії НАН України. Визначали вміст флавоноїдів та відновлювальну активність етанольних екстрактів, які далі використовували для синтезу AuNPs з 0,07% $HAuCl_4$. Наночастки характеризували спектрофотометрично у діапазоні λ = 300–700 нм (SPR) та методом трансмісійної електронної мікроскопії (TEM); розподіл за розмірами наночасток вираховували шляхом вимірювання 200 наночасток у кожному варіанті (*ImageJ*).

Результати. Екстракти з трансгенних коренів проявляли більшу відновлювальну активність, ніж екстракти з контрольних коренів, незважаючи на однакову концентрацію флавоноїдів після стандартизації екстрактів. Додавання екстрактів як з трансгенних, так і контрольних коренів до розчину $HAuCl_4$ проводило до характерної зміни кольору розчину. Методом TEM візуалізовано присутність наночасток, максимум SPR знаходився близько 540–555 нм. Спостерігали підвищення максимуму піків SPR при збільшенні концентрації екстрактів у реакційній суміші. За використання екстракту з трансгенних коренів формувалася більш неоднорідна популяція наночасток з наявністю більшої частки AuNPs розміром 20–40 нм.

Висновки. Трансформація *B. pilosa* змінює метаболізм коренів, що проявляється у підвищенні їх відновлювальної активності та впливає на процес «зеленого» синтезу наночасток золота. Екстракти як трансгенних, так і нетрансформованих коренів ефективно забезпечували синтез AuNPs, а збільшення їх концентрації у реакційній суміші підвищувало ефективність синтезу.

Ключові слова: *Bidens pilosa* L., генетична трансформація, «бородаті» корені, відновлювальна активність, наночастки золота, «зелений» синтез.

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