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# DESIGN OF AN AUTOMATED SYNTHESIS SYSTEM FOR GOLD NANOPARTICLES FROM THAUMATOCOCCUS DANIELLII (SWEET PRAYER LEAF)

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**Abstract:** Intelligent systems are designed to assist humans in performing their regular chores, such as making routine decisions, faster and tirelessly. This research focused on the designing of an inference system to control the synthesis and extraction of gold nanoparticles from leaves, specifically the *Thaumatococcus Daniellii* (ewe eran) plant, for the benefit of mankind. It employed forward chaining mechanism in neuro fuzzy adaptive inference system (ANFIS) to build a rule-based system that can be supervised to learn the routine of leaf preparation, characterization, synthesis, extraction, and infra-red spectroscopy. MATLAB and Python are the choice development environment and programming language, respectively, chosen for coding because of their scalability and upgradability.

**Keywords:** forward chaining, fuzzy, synthesis, nano particles, leaf.

## Introduction

Technological advancements in the twenty-first century have impacted every facet of life. Medicine, commerce, academia, construction, agriculture, food, and nutrition. In accordance with the United Nations Millenium Development Goals (MDGs), scientists and researchers are pressing harder with innovations and rolling out new systems to ease human existence, and daily chores are not excluded. Yerokun et al. (2022) stated that food is second to security in MDGs and that intelligent systems are necessary in the control of food processing industries to ensure easy and smart production.

Food is mainly obtained from plants and animals. Recently, agriculturists have collaborated with technology experts to produce intelligent systems that will push food production to higher quality and quantity. Researchers are naming new plants and discovering higher phytonutrient levels in common plants around the world. Many plants hitherto categorized as weeds or labelled as useful for insignificant things, such as wrapping nuts, are being rediscovered as highly rich in major phytonutrients. One such plant is *Thaumatococcus Daniellii*, which can be synthesized for its gold nanoparticles.

## **Original Article**

A nanoparticle is an invisible natural polymetric particle with a spherical shape that affords it a high surface area-to-volume ratio and subsequently has several potential applications. It has a diameter of 1-100 nm (Paz et al., 2014). Nanoparticles of most elements are unknowingly transferred, imparted, or transmitted into food through cooking objects such as pots, plates, wraps, and leaves. This chemical action makes many caterers carefully choose their cooking utensils knowing that the cooking vessels can greatly affect the taste and quality of the foods.

Cooking is done using several kinds of vessels. The type of food often determines the vessel or crockery that will be used. Cooking vessels found in many homes are made of metals, stainless steel, clay, wood, and foils. In Nigeria, especially in the Southwest (Yoruba land), some delicacies are best prepared wrapped in leaves. Foods such as iyan (pounded yam), ekuru (plain beans pudding), moi-moi (beans pudding), eko (pap), adalu (corn and beans), and ofada (locally grown rice) are best enjoyed when cooked and/or served in leaves, even at big ceremonies and festivities. Some nuts and snacks are also wrapped in leaves, some of them are: iru/ogiri (local seasonings), aadun (dry corn pudding), obi (kolanut), and orogbo (bitter kola).

### **Definition of the problem**

Nanoparticles from *Thaumatococcus Daniellii* seep into food unwittingly and have been discovered to be of high nutritional value, thereby deriving its categorization as gold nanoparticles. It is considered one of the miracle plants God blessed Nigeria with because it has richer components and food value in every part of its body, from top to bottom, from leaves to roots. The synthesis and application of nanoparticles is essential for promoting balanced and affordable meals for all (Yerokun & Onyesolu, 2021). Therefore, special efforts are being made to deliberately extract as much of the nanoparticles as possible from main foods. Technological systems make life easier, and even basic domestic issues such as food and nutrition can be made pleasurable with technological inventions.

### **Aim and Objectives:**

The aim of this work is to develop a computer-based system that can safely control the synthesis of gold nanoparticles and characterize their biomedical applications for consumption. The objectives are to:

1. Arrange the chemical constituents and procedures for the extraction of gold nanoparticles from the *Thaumatococcus Daniellii* plant.
2. Synthesize the gold nanoparticles and characterize the extract's bioactive compounds.
3. Design an automated system that can control the extraction of gold nanoparticles from the *Thaumatococcus Daniellii* plant.

### **Significance of the Study**

Research exploring the biomedical applications from various parts of the TD plant are ongoing in various universities and research institutes globally. Some reports show that this plant has biomedical properties because of its effectiveness against bacteriocin-producing microorganisms and its richness in phytochemicals (Ojekale et al., 2010; Ajayi et al., 2016).

These antifungal, anticoagulant, and thrombolytic activities can be best optimized by employing technology in the synthesis and characterization of nanoparticles. This system will make the entire processes and procedures easier, faster, and more efficient, thereby making it more readily available and affordable.

## Original Article

### Theoretical Background

#### a) **Thaumatococcus Danielli (Ewe Eran) - The Local Wrapping Leaf**

*Thaumatococcus danielli* (ewe eran) TD (ewe eran) is mostly grown for wrapping foods, and most people in this generation know only this purpose for **ewe eran**, but the plant has many other purposes.



**Plates 1–4: *Thaumatococcus danielli* (Ewe Eran) - 1: In its growing habitat; 2: The seeds found in roots of old stock; 3: Used to wrap moi-moi (Beans Pudding); 5: The seeds and the roots.**

TD is a monocotyledonous herb found in the rain forests and coastal areas of West and Central Africa (Noda et al., 2000). This plant is a large rhizomatous flowering herb that grows to about 3-4 m in height with large papery leaves. It bears pale purple flowers and soft, crimson fruits containing a few shiny black seeds. It is commonly referred to as miraculous fruit, miraculous berry, serendipity berry, and katamfe/katempfe. In Southwest Nigeria, it is commonly referred to as soft cane. One of the underutilized and neglected plant species in Nigeria, it grows wild in cocoa-growing areas (Yerokun & Onyesolu, 2021). It is categorized as a non-woody fibre (NWF) plant used to supplement wood fibre in paper manufacturing. TD is a popular natural source of thaumatin, a globally traded protein sweetener. This low-calorie sweetener is approximately 3000 times sweeter than sucrose on a weight basis and is suitable for patients with diabetes. Thaumatin is found in the arils located at the top of the seeds (Van der Wel & Loeve, 1972). The seeds are black, hard, and impervious, wrapped around by a transparent, sticky, gel-like sac. The seed is used by locals in ethnomedicine as an emetic and in treating pulmonary problems (Arowosoge & Popoola, 2006) and for sweetening drinks and foods (fruits). Researchers, farmers, and industrialists in the West African region are currently interested in the economic prospects of the fruits (Yeboah et al., 2003).

### Review of Related Studies

Abhinav and Deshpande (2016) designed a fuzzy logic irrigation controller and a data mining system for farmers' information flow and smart decisions. It comprises a sensor interface, valve controller, microcontroller, and key control units to facilitate smooth information flow and informed smart decisions. Basic electronic devices were programmed with Python to produce an expert system that made farming much easier in NARs.

Wijaya, et al. (2019) used the back propagation technique in an artificial neural network (ANN) to develop a system based on image processing techniques for monitoring the growth of red spinach. The analysis/prediction was designed to run on MATLAB as a component of a plant growth monitoring program created with Borland Delphi 7 software and DS Pack version 2.3.4. The system reduced the complexity of image extraction from plants and increased the accuracy of the results obtained from the growth monitoring exercises. The evaluation of the system confirmed a 98% accuracy in predicting fresh plant weights.

Yerokun and Onyesolu (2021) developed the Neuro-Fuzzy expert system for the detection of leghaemoglobin (NFESDL) in leguminous plants. The system featured a combination of neural networks and fuzzified weighted

## Original Article

values, mapped with MATLAB, in the design of an expert system that could detect the presence of LH in plants, especially legumes. It was a one of its kind and a motivating stride in the research for TAFC systems.

### **Synthesis methods:**

1. Top-down protocols: Usually physical-chemical processes are usually used to degrade a bulk material into smaller pieces, achieving the nanometric scale. Also called bottom-up protocols because they are the most abundant protocols for nanomaterials, where nanoparticles are synthesized from smaller precursors, such as metallic salts or molecular seeds that nucleate and form nanostructures (Alibert et al., 2012). They are mainly based on the energy transfer that occurs in a material when irradiated by ionizing or non-ionizing radiation, which may trigger the reduction reactions that lead to the nucleation of metallic particles. These methods include photochemical processes (Wang et al., 2008), ionizing radiation (Misra et al., 2012), and microwave radiation (Gangapuram et al., 2018).
2. Chemical routes are the most common and require strong and/or mild reducing agents, such as sodium borohydride (NaBH<sub>4</sub>), hydrazine, and citrate (Jang and Choi 2012), to initiate the synthetic process and promote nanoparticle nucleation. It is worth highlighting that chemical agents also function as nanoparticle stabilizers to avoid precipitation or particle agglomeration.
3. Green approaches are also becoming common in nanomaterial applications. The microwave-induced plasma-in-liquid process (MWPLP) is a good example of the green synthesis of nanoparticles because it does not require the use of toxic reducing agents and the energy consumed in the process is quite low.
4. Radiolysis by gamma radiation or X-rays (MWPLP) is based on the breakage of water molecules by microwaves, leading to the generation of reducing agents responsible for the nucleation of metallic particles (Cempel et al., 2018).
5. Laser sources can also be applied to the synthesis of gold nanoparticles (Corread et al., 2014).
6. Electrochemical or seed-mediated methods are used for the synthesis of gold nanorods. The first is conducted in a two-electrode cell with a gold layer as the anode and a platinum layer as the cathode, both immersed in an electrolyte solution containing a mixture of surfactants, such as hexadecyltrimethylammonium bromide (CTAB) and tetra-dodecyl ammonium bromide (TCAB). The reduction occurs at the interface between the cathode and the electrolytic solution (Tornblom & Eriksson, 1997; Sunand Xia, 2004).

### **Nanostructures: Morphology of gold nanoparticles**

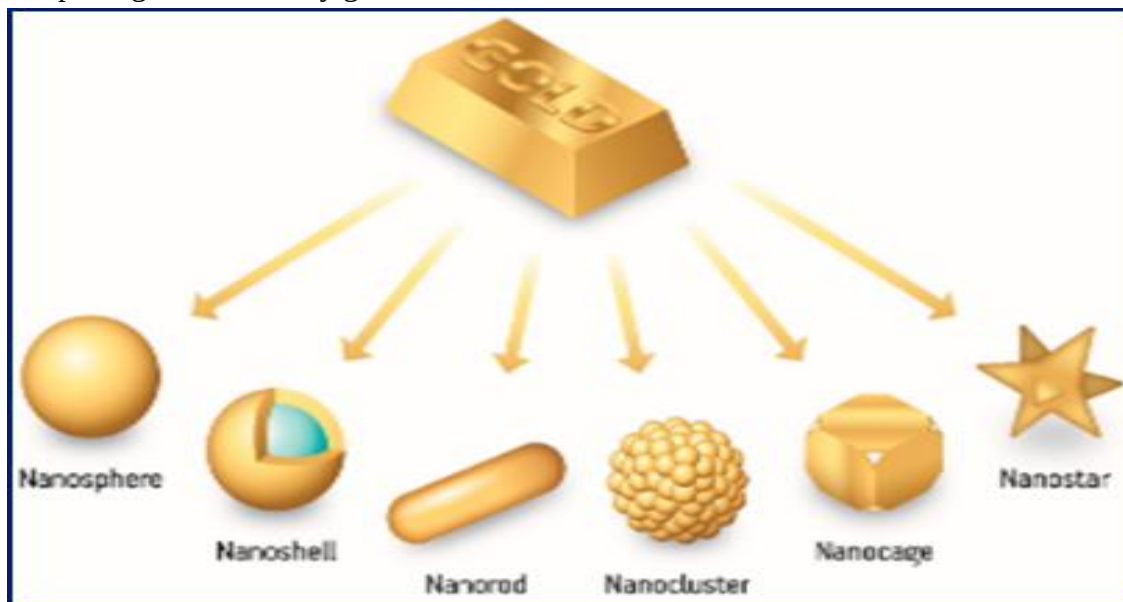
Nanostructures that may be designed and synthesized by radiation include metal nanoparticles, organic nanoparticles (such as proteins and enzymes), hybrid nanoparticles, nanocomposites, and nanogels. Yamaguchi et al. (2016) and Kadlubowski (2013).

Gold Nanoparticles Noble metals such as gold, when applied for the synthesis of nanostructured materials, present all the properties and others, such as relatively low toxicity to biological systems and conformational flexibility (Zhao and Li 2016). Colloidal gold has been empirically used for millennia for various applications. Gold nanoparticles can assume several morphologies, from bulk gold nanospheres to composites of a polymeric nucleus covered by a gold layer or capping. They can also be assembled in short or long chains of spherical nanoparticles with the desired optical properties depending on the chain size (Vieaud et al., 2018).

Nanoparticles synthesized by the reduction of gold in the aqueous phase tend to have a quasi-sphere morphology because this shape presents the smallest surface area compared to other morphologies. Typically, the suspension of spherical gold nanoparticles presents a ruby red colour due to the scattering of light by the

## Original Article

nanomaterial. However, the optical properties of the colloid may be modified by the increase in size and a change in the environment surrounding the nanoparticles (Khan et al., 2012). Plate 5 illustrates some morphologies featured by gold nanomaterials.



**Plate 5: Representative scheme of the most common AuNP assemblies and morphologies.**

### Applications of TD

The TD leaf is rich in gold nanoparticles, which are used in the following ways:

1. **Biomedical uses in diagnosis and therapeutics:** Gold, being inert and relatively less cytotoxic, is mostly appropriate for drug and gene delivery (Connor et al., 2005). This is due to their unique properties of small size, large surface area to volume ratio, high reactivity to the living cells, stability at very high temperatures, and translocation into the cells.
2. **Antifungal activities:** By incorporating graded concentrations (150  $\mu\text{l/ml}$ ) of the synthesized gold nanoparticles into potato dextrose agar plates, which were then inoculated with agar plug of 6mm of 48 h old cultures of *Aspergillus nigrigensis*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Fusarium solani*, and *Candida albicans*, no fungal activities were found in the cultures, whereas the control plates with no gold nanoparticles were found to have heavy fungal growth. The antifungal activities of gold nanoparticles were evaluated using the Mycelial Inhibition Method (Khatami et al., 2015; Agbaje et al., 2016).
3. **Anticoagulant Activities:** Azeez et al. (2007) investigated the anticoagulation activity of 150 m of gold nanoparticles prepared at 100 g/ml, added to 0.5 ml of blood (freely provided by a healthy donor) treated with clove seed extract and aqueous gold chloride solution, held at room temperature for 30 min. The gold nanoparticles restricted the coagulation in the blood sample.
4. **Thrombolytic Activities:** The methods of Devi et al. (2016) and Lateref et al. (2017) were used. Eppendorf tubes containing 0.5 mL of blood are held at 37°C for 30 min to allow the blood to clot. The weight of the clean tube (W1) was subtracted from the weight of the tube and blood clot (W2) to obtain the weight of the blood clot (W3). Thereafter, 100 $\mu\text{l}$  of the gold nanoparticles, gold chloride solutions, and clove seed extract were added to each tube containing the blood clot. These were incubated at 37°C for 90 min and then inverted

## Original Article

to check for clot lysis. The lysed clot was drained, and the weight of the tube with the remaining clot (W4) was taken to obtain the weight of the clot that was not lysed (W5) (Ojo et al., 2016; Lateef et al., 2017).

5. Conventional chemotherapy: This includes treatment agents for acquired immunodeficiency syndrome (AIDS), bronchial asthma, cancer, and malaria (Shaw 1999), as well as sensors for the detection of heavy metals in blood (Priyadahshini and Pradan 2017). The irradiation of nanoparticles using near-infrared (NIR) light provides heat and may thus be applied in heat-sensitive carrier systems for controlled drug release, such as hydrogels and other “intelligent materials” (Kawano et al., 2010).

### Process and Synthesis Procedures

#### 1. Materials and Methods

a) Sample Collection: Fresh sweet prayer leaves were obtained from local markets in Ogbomoso, Oyo State, and then transported in sterile polythene bags to the laboratory. Two experts in Botany in the Department of Pure and Applied Biology, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, and a consulting professor of Olusegun Agagu University of Science and Technology, Okitipupa, Ondo state, validated and authenticated the manuscript during a working visit to the LAUTECH laboratory.

b) Preparation of the Sample: The Sweet Prayer leaves were washed with sterilized distilled water, aseptically drained, air-dried under ambient temperature, and aseptically blended after drying for 2 weeks. 1g of the powder was weighed, suspended in 100 ml of distilled water, and heated in water bath at 60°C for 1 h. The extract was filtered using Whatman No. 1 filter paper and centrifuged at 4000 rpm for 15 min.

c) Preparation of gold chloride (AuCl<sub>3</sub>) solution: The gold chloride solution was prepared by dissolving 1 mM of gold chloride salt in 1000 mL of distilled water and stored in an amber bottle in a dark cupboard at ambient temperature.

2. **Synthesis of gold nanoparticles:** Two millilitres (2 ml) of each sample supernatant was drawn into three different slant bottles using a sterile hypodermal syringe and labelled accordingly. Then, 20 ml of gold chloride (AuCl<sub>3</sub>) was added to each bottle containing 2 ml of the supernatants in a ratio of 2:20 and labelled. The solution containing the aqueous salt solution (AuCl<sub>3</sub>) and the sample supernatant were then photoactivated by exposure to direct sunlight to enhance the formation of the gold nanoparticles. As an experimental control, an aqueous solution alone was also maintained. The formation of AUNPs was visually observed by checking the change in colour.

#### 3. Characterization of Gold Nanoparticles:

a. Fourier transform infrared (FTIR) spectroscopy: FTIR spectroscopic analysis of the powdered form of the sample was performed using an IR Affinity -IS Spectrometer according to the method of Bhat et al. (2016). 5 ml of gold nanoparticle solution was poured into a glass Petri dish and transferred into an oven at a temperature of 40°C for 4hours to change from the liquid to solid state. The obtained solid residue was cooled down at room temperature, while the obtained powder was used for FTIR measurements using KBr pellets.

b. UV-Vis spectrum analysis: For the structural characterization of gold nanoparticles using the CCECIL CE model. It uses visible light and adjacent near-UV and near-infrared (NIR) ranges. The absorption or reflectance in the visible range directly affects the perceived colour slant of the chemicals. Then, on a 4 ml4 ml spectrophotometer, the synthesized gold nanoparticles were bottled, and readings were taken using a wavelength of 650 nm and bandwidth of 2.0 nm.

## Original Article

c. Energy Dispersive X-ray (EDX) Analysis: The elemental composition of each gold nanoparticle was determined using Espirit 1.8.5 software to determine the most prevalent element in the gold nanoparticle. A droplet of gold nanoparticle is placed onto a clean silicon water surface. The droplet was allowed to dry by evaporation at ambient temperature, and a thin carbon film was placed on the dry gold nanoparticles to prevent them from charging. The compositions of the elements present in the samples were then achieved.

d. Scanning Electron Microscopy (SEM): The morphology of the gold nanoparticles was studied using SEM using a Leo 912 AB high-resolution transmission electron microscope operating at an accelerating voltage of 120 kV. Powdered leaves (1 g) were dissolved in 100 ml of distilled water and heated in a water bath at 60 C for 1 h. The extract was then centrifuged.

### Results

The results of the entire process are summarized in Plate 6.

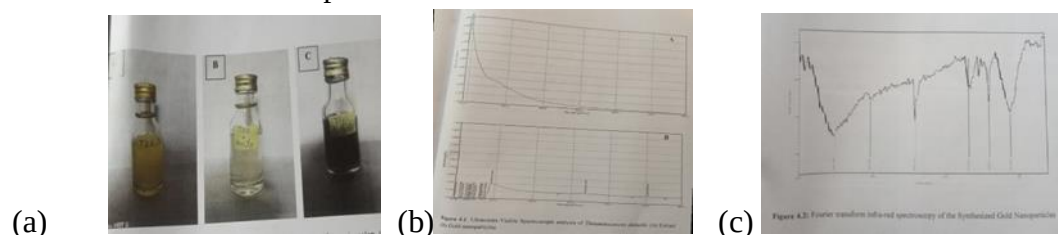


Plate 6: Results: (a) After heating and centrifugation of the leaves extract. (b) Visible colour changes of nanoparticles from the leaf extract after photo-action. (c) UV- visible spectrum of the sweet prayer plant extract

**(a) Visibility of AuNPs:** The formation of AuNPs was visually observed by checking the colour change. When exposed to direct sunlight, the nanoparticles synthesized from sweet prayer leaf extract changed from orange to lilac after 5 min to light purple after 7 min then to dark purple after about 11 min (Plate 6a). The control (gold chloride solution without any sample) remained colourless throughout the photoactivation stage.

**(b) UV-Vis Scanning:** The UV-visible spectrum of the AuNPs synthesized from sweet prayer leaf extract displayed maximum absorbance at 290 nm (Plate 6b).

**(c) Fourier Transform Infra-Red (FTIR) Spectroscopy:** The FTIR absorption spectrum of the synthesized AuNP showed distinct strong peak at 3040.1535, 2422.2141, 1677.3818, 1398.5212 and prominent peaks at 1677.3818, 3531.0949 other minor peaks at 1102.1818 (Figure 4.4) an infrared spectrum typically shows absorption bands related to the bending or stretching of unique bonds and can be considered a sample fingerprint.

### Discussion of the Findings

The biosynthesis of AuNPs was mediated by the extract of *T. Danielli* within 15 min of exposure to direct sunlight. The deep purple colour indicates the formation of Au nanoparticles (Ladeef et al., 2016; Shah et al., 2016).

Characterization was performed to monitor the process of the formation of gold nanoparticles through UV-Visible spectroscopy analysis and Fourier transform infrared spectroscopy (FTIR). The UV-visible spectral analysis confirmed the formation and stability of AuNPs biosynthesized using leaves. At a wavelength of 390 nm, the optimum AuNP production was determined at 60°C, pH 7 with 1 mM HAuCl<sub>4</sub>, and a 45-min incubation period.

## Original Article

### Design of an Intelligent Control System

**a. Knowledge Acquisition:** Experts in Botany and Biochemistry were consulted at the Ogbomosho Ladoké Akintola University of Technology. They provided technical data on the subject domain through oral interviews, and laboratory observations were made. All gathered information was collated and arranged into usable datasets. Several journals accessed from various platforms were scoured for information regarding the research domain for further confirmation of the processes. All these forms the knowledge base content and working memory.

**b. Knowledge Engineering:** The entire process and laboratory procedures can be summarized in four steps: extract collection and preparation, gold chloride ( $\text{AuCl}_3$ ) solution preparation, gold nanoparticle synthesis and gold nanoparticle characterization. These are further subdivided, and the weights are shown in Table 1.

**Table 1: Organization of activities and procedures**

| S/No | Main Activity                                             | Procedures                                     | Weights |
|------|-----------------------------------------------------------|------------------------------------------------|---------|
| 1.   | Collection and preparation of the extract                 | Wash leaves and air dry                        | 1       |
|      |                                                           | Blend aseptically after 2 weeks                | 1       |
|      |                                                           | Suspend in water                               | 1       |
|      |                                                           | Heat in a water bath for 1 hr.                 | 1       |
|      |                                                           | Filter and centrifugation                      | 1       |
| 2.   | Preparation of gold chloride ( $\text{AuCl}_3$ ) solution | Dissolve the salt in distilled water           | 2       |
|      |                                                           | Store in an amber bottle                       | 0       |
|      |                                                           | Keep in a dark cupboard at ambient temperature | 1       |
| 3.   | Synthesis of gold nanoparticles                           | Draw the sample into slant bottles             | 0       |
|      |                                                           | Add 20 mL of $\text{AuCl}_3$                   | 2       |
|      |                                                           | Photoactivation by direct sunlight exposure    | 2       |
|      |                                                           | Watch color change after a few days            | 0       |
| 4.   | Characterization of gold nanoparticles                    | Fourier Transform Infrared (FTIR) Spectroscopy | 2       |
|      |                                                           | UV-Vis spectrum analysis                       | 2       |

**c. Database:** The system uses a relational database to map antecedents into the knowledge base. The use of media contents helps in interacting with a user in a more practical manner and eases the use of the system, increasing the accuracy of inferred reasoning presented to a user by the inference engine. Microsoft SQL Server 2012 (local DB) is used in the implementation and storage of the media contents of the system. Microsoft's ADO.NET and Linq are used in the mapping of the database contents to the knowledge base and the inference engine. The forward chaining technique of the Sugeno fuzzy inference model is employed with MATLAB's integrated development environment to design the inference engine operations. The entire process was reduced into four stages: collection and preparation of extract, preparation of gold chloride ( $\text{AuCl}_3$ ) solution, synthesis of gold nanoparticles, and characterization of gold nanoparticles. Each activity requires different materials: chemicals, water, sunlight, and heat. These materials are comprehensively captured with the procedures, compiled as rules, and stored in the knowledge base. They are modified to conveniently transform into expected

## Original Article

results and stored in the inference engine, which is directed through the rules in the knowledge base and eventually the working memory, to conclude called inference.

To control the processes, the production rules in the knowledge base are compared with the facts supplied by users to the system. The system only executes a consequent when a rule containing it is fired, and a rule is executed only when all its antecedents are satisfied by facts supplied to the inference engine by the user.

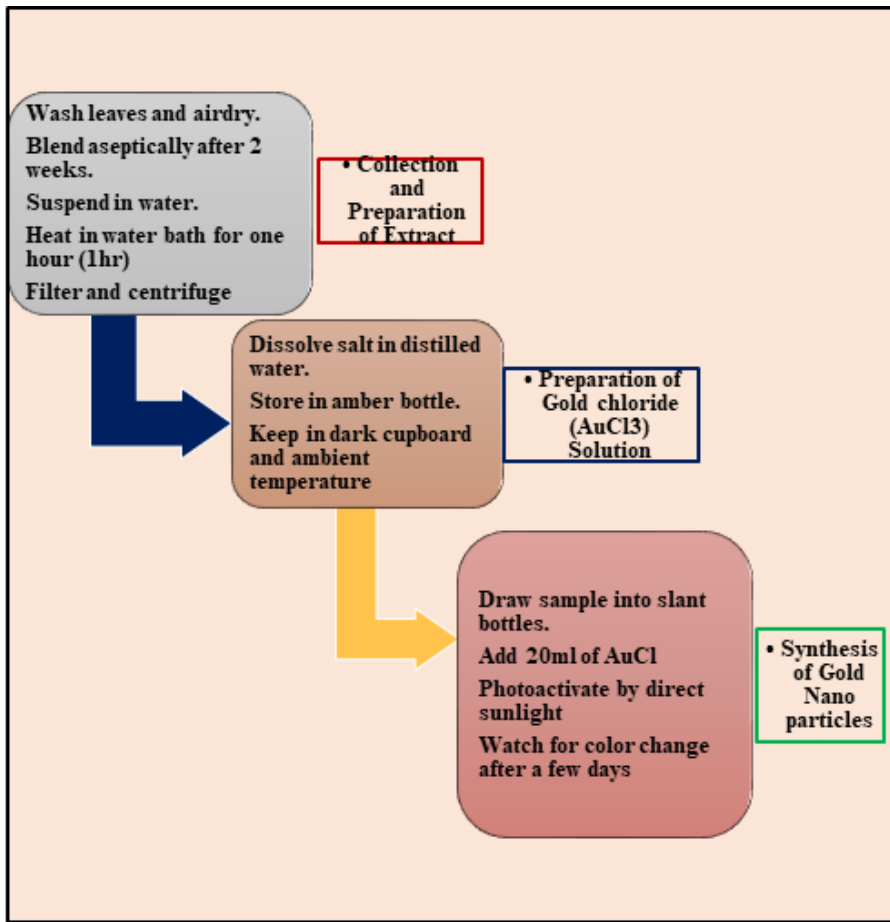
The MATLAB platform, an integrated development environment, made the analysis and use section easier. It allows a combination of both procedural and object-oriented approaches for representing most expert system models. All the rules elicited are saved using the specific object to the class rule. Some rules added contain media contents that are saved on the database. As supported by MATLAB and access control to the database, pointers are used to point to contents in the database. To model the identification of materials (chemicals, water, sunlight, and heat) processing, a rule instance is created for each identification. Then, a rule name is created so that antecedents are added to the rule created using the `addAntecedent()` object to ascertain the conditions to be met to lead to the `setConsequent` (conclusion) added using the `setConsequent()` object for each identification. The `Addfact()` object is used to query the inference engine to provide input data supplied by users to the inference engine for antecedent crossmatching. Python (Anaconda) is recommended for coding because more macros are needed to provide ample room for upgrading and expanding.

d. The user interface: Consist of graphical clickable controls that allow users to input queries easily and a natural language response control for easy use and understanding by expert and non-expert users.

The user interface was designed according to the instructions of the industrial supervisors and operators, following the antecedents in the working memory, database, and inference engine. The flow of the process is illustrated in Figure 1.

e. Design model and workflow: The system is designed to control the workflow of the processes and procedures as outlined by the chemists and laboratory technologists.

## Original Article



**Figure 1: Workflow diagram of the system.**

Membership Functions: Four membership functions—triangular, trapezoidal, Gaussian, and Gaussian combination—are applied to limit the fuzzification process. The Gaussian function is known for its conciseness and nonzero results return at all points. This characteristic is required to ensure an adaptively stable system. The general equations are given as follows:

1. The triangular membership function

$$\mu(x) = \begin{cases} 0 & \text{if } x < a \\ \frac{x-a}{b-a} & \text{if } a \leq x \leq b \\ \frac{b-x}{c-b} & \text{if } b \leq x \leq c \\ 0 & \text{if } x > c \end{cases}$$

where **a** is the start point, **b** represents the peak point, and **c** is the end point of the linguistic term of the linguistic variable *x* of input parameters (i.e., water, oil, and heat).

2. The trapezoidal membership function

## Original Article

$$\mu_{(x)} = \begin{cases} 0 & \text{if } x < a \\ \frac{x-a}{b-a} & \text{if } a \leq x \leq b \\ 1 & \text{if } b \leq x \leq c \\ \frac{d-a}{b-a} & \text{if } c \leq x \leq d \\ 0 & \text{if } x > d \end{cases}$$

where  $a$  is the start point,  $b$  represents the peak point, and  $d$  represents the end point of the linguistic term of the linguistic variable  $x$  of input parameters (Water, Oil, and Heat).

### 3. Gaussian combination membership function (gauss2 mf)

Gauss2mf is a combination of two of these two parameters namely  $sig_1$  and  $c_1$  as presented thus:

$$y = gauss2mf(x, [sig_1 c_1 sig_2 c_2])$$

The first function specified by  $sig_1 c_1$  determines the shape of the left- most curve, the second function specified by  $sig_2 c_2$  determines the shape of the right-most curve. Hence, when  $c_1 < c_2$ , the gauss2mf function reaches a maximum value of 1. Otherwise, the maximum value is less than one.

### Output

The result is an adaptive neuro-inference system with multiple layers and one output layer, which can control the flow of processes in the synthesis of gold nanoparticles from the *Thaumatococcus Daniellii* plant. The system simply prompts the user with options and stages of the procedures that the user intends to use. Then, it gives step-by-step instructions to complete the task. A nonexpert can run the system, whereas a general technologist with little or no knowledge about chemical synthesis can operate the system.

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