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Research Article

Specific and rapid visual detection of organophosphorus and carbamate pesticides in agricultural products by gold nanoparticles conjugated with aptamer

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Abstract: Designing a fast, inexpensive, and easy method for on-site detection of pesticide residues is very important. In the present research, a sensitive nanobiosensor has been designed based on gold colloidal nanoparticles that could detect organophosphorus and carbamate pesticides. The biosensor was synthesized using gold plasmonic nanoparticles chemically grown on grain particles and was optimized in the presence of different concentrations and volumes of aptamer, salt, etc. To detect pesticides, this nanobiosensor was used to detect Trichlorfon and diazinon (OP) and carbofuran and pirimicarb (Carb) pesticides were used. Upon interaction with the pesticides, the nanobiosensor changed markedly in appearance and color, which was visible to the naked eye. The results show that the sensitivity of this nanobiosensor is lowest to diazinon and highest to carbofuran over time. In the presence of Trichlorfon, the nanobiosensor initially designed shows significant morphological changes in the nanostructures. The incubation time for pesticide samples with the nanobiosensor is about 10-15 minutes. Another interesting potential of colorimetric nanobiosensors is the extreme sensitivity of surface plasmon resonance in gold nanostructures to the surrounding media, which can be functionalized with specific biomolecules for targeted detection. Due to the ease of synthesis, indigenous production, ease of functionalization, maintenance of biomolecule stability on the surface, and the ability to detect pesticides quickly and visually at the lowest concentrations of analytes, there is strong potential to replace this new method with conventional methods.

Keywords: Nanobiosensor, Gold colloidal nanoparticles, Pesticides, Organophosphates, Carbamates

Introduction

In recent years, several problems related to food safety and security have emerged worldwide. Exposure to pesticides may cause acute or chronic toxicity and harm human health (Damalas and Eleftherohorinos, 2011). These health impacts may include numerous disorders such as neurological diseases like Parkinson's, various types of cancers,

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miscarriage, congenital disabilities, and pathological lesions in various tissues and organs of the body (Morowati 2022; Morowati *et al.*, 2024). Therefore, determining the residue levels of pesticides in agricultural products and comparing them with the maximum residue limits is very important regarding human health and safety. To solve such problems, regular monitoring of food production from farm to fork is conducted, including controls across production, processing, distribution, and marketing (Tritscher *et al*. 2013). Therefore, to do this, there is an urgent need for fast, accurate, sensitive, and low-cost analytical methods to trace contaminants in food, water, and soil. In recent years, nanotechnology has leveraged the physical properties of nanoparticles to develop improved methods for chemical analysis (Thakur, *et al*., 2022, Jain *et al*., 2008; Katz and Willner, 2004; Song *et al*., 2010; Liu *et al*., 2010). For example, carbon nanotubes have shown strong catalytic activity and high sensitivity for detecting organophosphate pesticides (Asensio-Ramos *et al*., 2009). Recently, the use of gold nanoparticles to produce color has been used in several chemical reactions without the use of advanced devices using molecular modifications (Sadiq *et al*., 2023; Weerathunge, *et al*., 2014; Liu *et al*., 2010; Wang *et al*., 2006; Huang *et al*., 2005; Nam *et al*., 2005; Liu and Lu, 2003). In general, solutions containing well-dispersed gold nanoparticles turn red, while those containing nanoparticle aggregates turn purple or blue (Weerathunge, *et al.*, 2014; Liu *et al*., 2010; Wang *et al*., 2006; Nam *et al*., 2005; Huang *et al*., 2005; Liu and Lu 2003). However, in the last decade, different methods for analysis using gold nanoparticles have been developed (Sun *et al*., 2011; Virel *et al*., 2009; Li *et al*., 2011; Xu *et al*., 2011) and gold nanoparticles has been used effectively in identifying various pollutants like mercury and copper in water samples (Rex *et al*. 2006; Kim *et al*. 2001; Zhou *et al*. 2017) and also, endosulfan, paraxon, carbofuran, monocrotophos, methyl parathion, carbaryl and malathion (Nair *et al*., 2003; Lin *et al*., 2006; Shulga and Kirchho, 2007, Du *et al*., 2007; Du *et al*., 2008; Dasary *et al*., 2008). Analysis of pesticide residues using gold nanoparticles is straightforward and can be performed without any training. The advantages of using these nanobiosensors include high sensitivity, reliability, energy efficiency, time efficiency, cost efficiency, and reduced analyte consumption, and they do not require labeling. Nanobiosensors, due to their nanometer-scale dimensions, enable easier, faster, and more sensitive measurements in biological environments. They usually have three main components: the biological element, the converter, and the reading system. The biological part must have high selectivity for biological interactions and analyte detection. The physical transducer converts the detected phenomenon into a measurable effect, such as an electrical signal, light emission, or mechanical motion, and ultimately measures it with a reading system. Recently, the unique optoelectronic properties of these nanoparticles have been used in advanced research and technology, including photovoltaics, sensors, probes, therapeutic agents, drug delivery, electronics, and catalysts. Changes in size, shape, chemical surface properties, or aggregation state can adjust the optical and electronic properties of gold nanoparticles. The interaction between gold nanoparticles and light is highly dependent on their size; in fact, it is the nanoparticles' intrinsic properties that determine their optical properties. Oscillations in electric fields near colloidal nanoparticles interact with free electrons, causing oscillations corresponding to the electron's charge and thereby intensifying the frequency of visible light. These unique properties have made gold nanoparticles among the most widely used nanomaterials in research and an integral part of medicine and industry (Chen *et al*., 2007).

Organophosphorus and Carbamate pesticides can enter the body through three pathways, including inhalation, dermal, and oral routes

(Apilux *et al*., 2015; Dasary *et al*., 2008). These two groups of pesticides have the highest consumption rate in Iranian agriculture. The purpose of this study is to design and manufacture plasmonic nanobiosensors for the rapid detection of these two common pesticide groups. The research was conducted in two phases: phase 1, including the design and synthesis of a nanobiosensor using gold spherical nanoparticles and the determination of the optimal nanoparticle stability limit; and phase 2, the identification and quantification of various concentrations of pesticides using the nanobiosensor produced.

In this research, only nanoparticles coated with citrate ions, which are negatively charged, are used. Such a sensor, in the presence of many oppositely charged molecules, can exhibit significant changes in the intensity and position of the surface plasmon resonance. Under such conditions, as the molecule's concentration increases, the sensor moves towards nonspecific aggregation, to the point that accumulation becomes visible to the naked eye. Considering these points, in addition to designing a highly sensitive sensor, strong specificity to the target agent has also been considered. Therefore, to achieve this, biosensing elements such as whole cells, antibodies, aptamers, and complementary nucleic acid sequences must be used. So far, aptamers have been designed and reported for the specific detection of pesticides. Although the biosensors mentioned above use biosensing agents (Sassolas *et al*. 2012), there is a lack of new technologies that use plasmonic nanoparticles with high diagnostic sensitivity.

Materials and Methods

Chemicals and equipment

Gold salt, sodium citrate, Dithiothreitol (DTT), sterile distilled water, ethyl acetate, ordered specific oligonucleotides (Fazapajooh Co., I. R. Iran), gold nanoparticles (US-NANO Co. and FINE NANO Co.), microtubes, beaker, sampler and free DNase/RNase sampler tips, volumetric flasks, Pesticide standards (diazinon, trichlorfon, pirimicarb, carbofuran) purchased from Sigma-Aldrich: perkinElmer-Lambda25 spectro-photometer, centrifuge, spin vortex, heater-magnetic stirrer.

Design and synthesis of plasmonic nanobiosensor

For the synthesis of gold nanoparticles, the Turkevich method, a bottom-up approach, was used. To produce nanoparticles with a size of about 50 nm, 0.6 ml of sodium citrate was added as a reducing agent with a concentration of 34 mM to 50 ml of gold salt ($HAuCl_4$ $3H_2O$) with a concentration of 0.25 mM in water, and completely dissolved. In this process, sodium citrate acts as a reducing agent and stabilizing agent through adsorption on the surface.

To functionalize the synthesized nanoparticles for detecting the desired pesticides, an oligonucleotide was designed (Shintaro *et al*., 2014) and ordered for synthesis from Fazapajooh Company, I. R. Iran. The oligonucleotide designed and used in this research is as follows:

5′_AAGCTTGCTTTATAGCCTGCAGCGAT TCTTGATCGGAAAAGGCTGAGAGCTACG C_3′

It should be noted that the 5′ end of this oligonucleotide is tiled.

Characterization of nanoparticles

One of the most powerful and widely used methods for measuring a broad range of analytes is spectroscopy. UV-Visible spectroscopy (PerkinElmer Lambda 25) was used to characterize the nanoparticles in this study.

Functionalization of gold nanoparticles

To covalently bind the oligonucleotide to the gold nanoparticle, DTT was first used to break the oligonucleotide disulfide bonds. It was then washed with ethyl acetate to remove this reducing agent. The purification process was performed in two stages: nanoparticle synthesis and functionalization with a specific target-detection aptamer. After centrifugation of the samples, the supernatant solution containing the excess material and gold ions (which did not react) was carefully removed. The sediment collected during

this process was carefully diluted to the desired concentration with a suitable buffer/water. The concentration of purified nanoparticles at this stage was analyzed using ICP-AAS. To prevent nonspecific nanoparticle aggregation and improve sensor efficiency, the prepared sample was placed in a sonicator bath containing water for a few minutes.

Results

The first phase: Synthesis and functionalization of gold nanoparticles were performed. 10 µM of the active oligonucleotide was prepared and added to a solution of gold nanoparticles with an OD of ~1. The spectra were then obtained at different intervals and in different salt concentrations. Due to the good stability of the samples under different conditions (salt and sonication) and the special importance of nanoprobe stability over time, the selected probe-nanoparticle complex was analyzed after 24 hours of incubation. However, due to surface plasmon resonance, the GNPs + Oligo + NaCl combination aggregated completely after 24 hours and was unstable (Fig. 1).

Then a stock of active oligonucleotide with a higher concentration was prepared, and its stability in the presence of gold nanoparticles was evaluated, provided that the spectrum was taken without the addition of NaCl (Fig. 2).

In another sample, spectroscopy was first performed without salt, then NaCl (1 M) was added at different concentrations and for different time intervals, and spectroscopy was performed again. Two days after the last prepared sample was treated with salt, spectroscopy was performed to measure the stability of the GNPs /Oligo composition in the presence of salt. The results were summarized as follows (Figs. 3 & 4):

According to the results, the best and most stable state (GNPs + Oligo (50 µM) + 4 µl NaCl (1 mM) + 10″ sonication after 30′) was selected and used in this investigation (Fig. 4). To study the stability of the functionalized nanoparticles after the purification process, the nanoparticles were diluted with methanol and water. Based on the results, the nanoprobe designed in the presence of methanol was unstable and was destroyed due to changes in the nanoparticles' surface charge (zeta potential). Therefore, methanol cannot be used for sample purification or dilution.

The second phase

Identification of different concentrations of pesticides under test by the nanobiosensor produced

Assessing the capability of detection of pesticides by nanobiosensors

After complete optimization of the designed nanobiosensor in the presence of various agents, used to functionalize the nanoparticles with a specific aptamer, detection of various concentrations of the pesticides under test was performed. The capability of the nanobiosensor for detecting pesticides was tested using two organophosphate (trichlorfon and diazinon) and two carbamate (carbofuran and pirimicarb) pesticides. Five concentrations (0.1, 0.5, 1, 5, 10, 25 mg/kg) were considered for each pesticide. Because methanol destabilizes the designed nanoprobe, the pesticide samples were diluted to the required concentrations in Phosphate-Buffer saline (PBS).

The appearance of the synthesized gold nanoparticles (Fig. 5A) and purified functionalized nanobiosensor in the required dilution before the detection of pesticides (Fig. 5B) is as follows:

The performance of the designed nanobiosensor in the qualitative detection of four types of pesticides is shown in Fig. 6. As observed, in the presence of the pesticides, the color of the functionalized nanobiosensor changes completely. The appearance of this color is an obvious sign of a change in the distance between nanoparticles and severe morphological changes in them, which have occurred in the presence of the target molecule. The stability of the designed nanobiosensor and its lack of accumulation in the absence of the target molecule were fully determined in the first phase of the research.

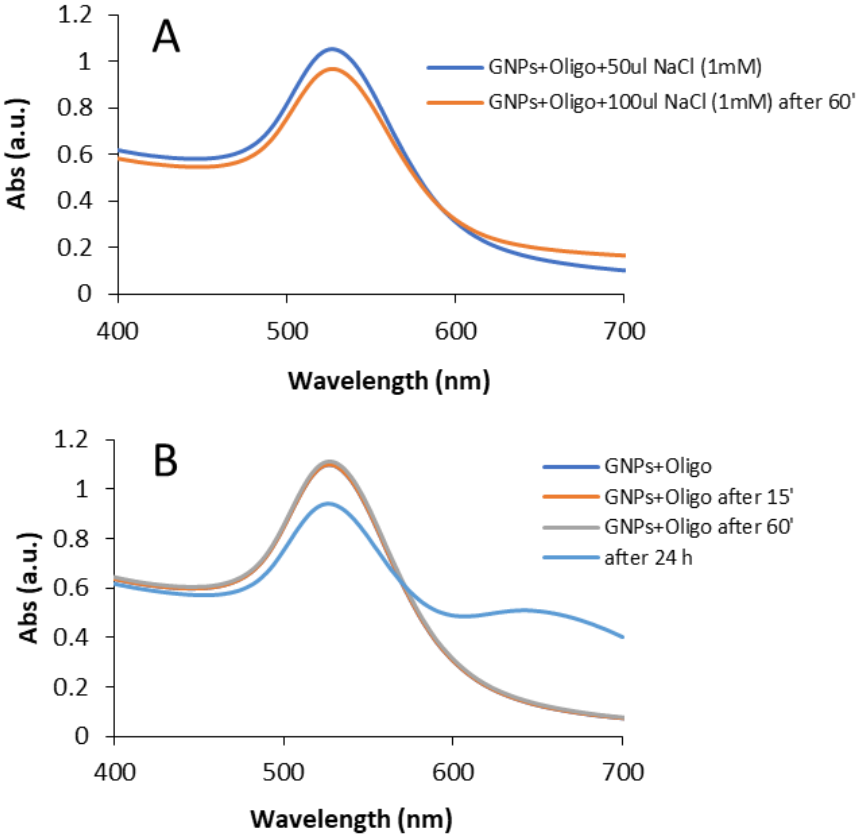

Figure 1 Measurement of stability of functionalized nanoparticles in two different states A) salt concentration, B) different time intervals, no salt.

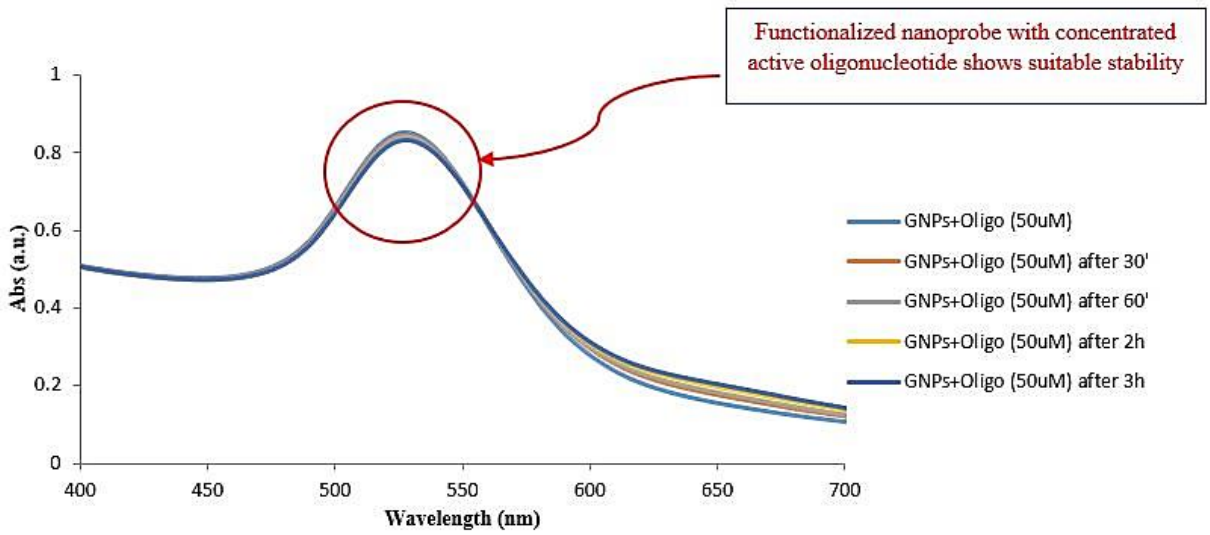

Figure 2 Monitoring the surface plasmon resonance of gold nanoparticles after functionalization with 50 µM active oligonucleotide.

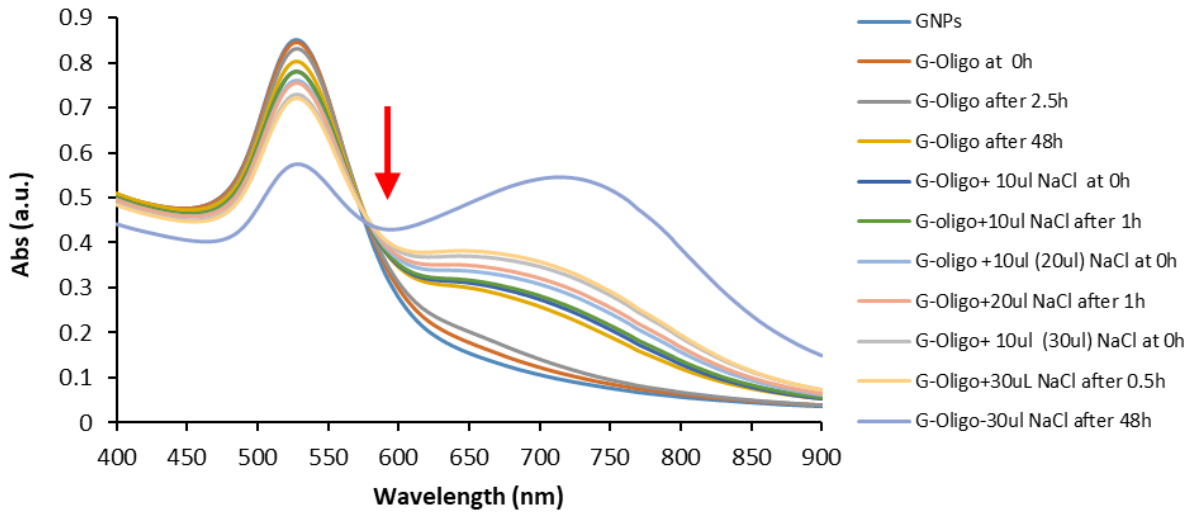

Figure 3 Summary of surface plasmon oscillation monitoring of gold nanoparticles (functionalized) under salt conditions (1mM) at different times.

The resonance of the nanobiosensor surface plasmon in the presence of four types of pesticides with the same concentration (25 ppm) is shown in Fig. 7. Comparison of four SPR spectra of a nanobiosensor with nanoparticles before and after functionalization with a biosensing agent shows significant changes in morphology and the distance between gold nanoparticles in the nanobiosensor in the presence of pesticides.

Because the aptamer specifically detects all four types of pesticides, the nanobiosensor response to each is positive and similar. It is worth noting that so far, no aptamer has been reported to differentiate these pesticides. Considering similar diagnostic conditions of the nanobiosensor, the ability of functionalized gold nanoparticles to accumulate in the presence of different concentrations of a pesticide (Carbofuran) is shown in Fig. 8. The intensity of the color produced decreases with increasing pesticide concentration.

The detection of carbofuran at different concentrations, monitored by surface plasmon resonance, is shown in Fig. 9. According to this figure, within the concentration range shown, the nanobiosensor can detect carbofuran well, and the specific resonance of the nanoparticles' surface plasmon in the presence of this pesticide has been drastically altered.

Effect of different volumes of pesticides in the presence of nanobiosensor

The performance of the nanobiosensor in different volumes of pesticides is shown in Fig. 10. An overview of the specific resonance of nanoparticles' surface plasmons improves the sensor's diagnostic performance at higher volumes of the pesticides under test. According to the figure, the nanobiosensor achieved the best performance at a sample volume of 50 microliters. Therefore, it can be concluded that the nanobiosensor designed in this study can quickly detect specific pesticides at very low sample volumes, which is a significant advantage for sample preparation and analysis.

Effect of time on the detection speed of nanobiosensor

The detection ability of the nanobiosensor for diazinon at 10 and 25 ppm, at 0 and 20 minutes, is shown in Fig. 11. It is observed that the surface plasmon resonance of the nanostructures in the designed nanobiosensor enables rapid detection immediately after the addition of the pesticide. A longer time period has no significant effect on the sensor's detection speed.

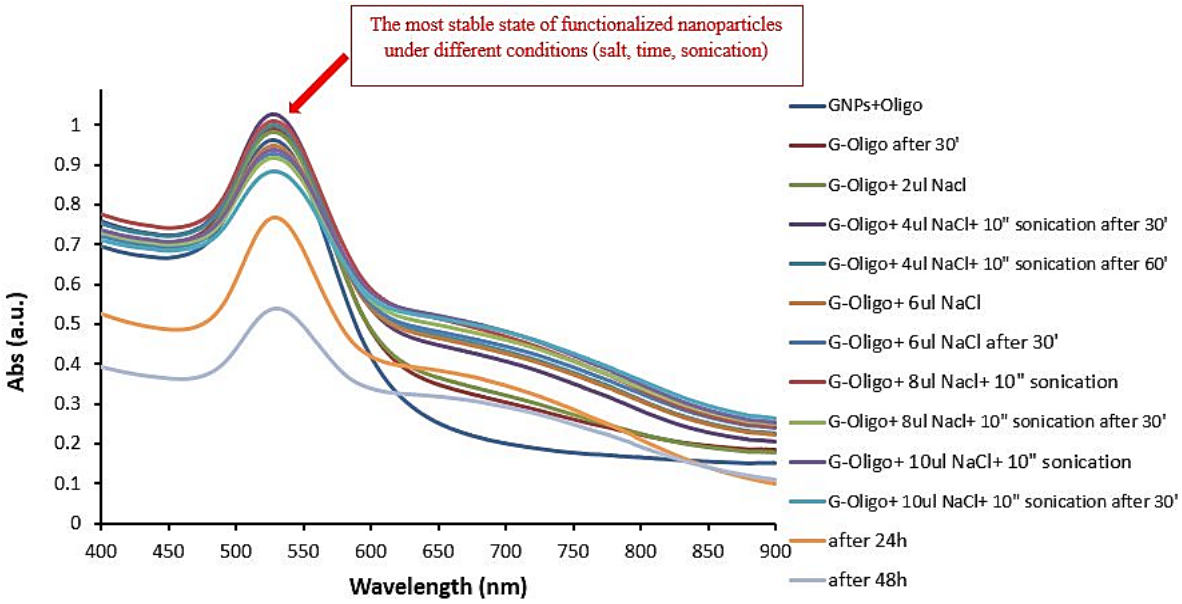

Figure 4 Monitoring the surface plasmon resonance of functionalized nanoparticles (50 µM) under salt condition (1mM), sonication and different times and determination of the most stable state.

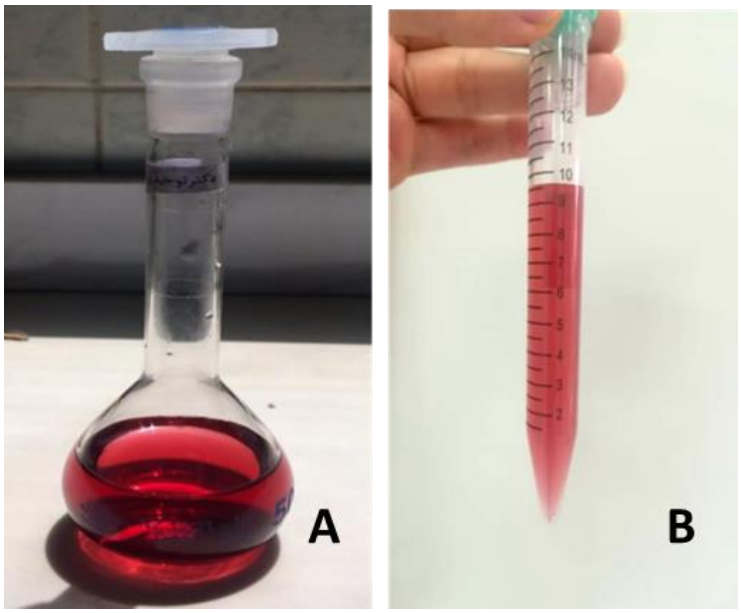

Figure 5 Synthesized gold nanoparticles (A), Ready to use functionalized nanobiosensor (B).

The effect of time on the biosensor's detection ability for all four pesticides at a constant concentration of 10 ppm, at 0 and 20 minutes, is shown in Fig. 12. As observed, the time-dependent response of the nanobiosensor surface plasmon resonance varies across the four pesticides. The sensitivity of this nanobiosensor to diazinon is the lowest over time, whereas that to carbofuran is the highest possible. It seems that in the presence of trichlorfon, the designed nanobiosensor initially shows significant changes in morphology and inter-nanostructure distances.

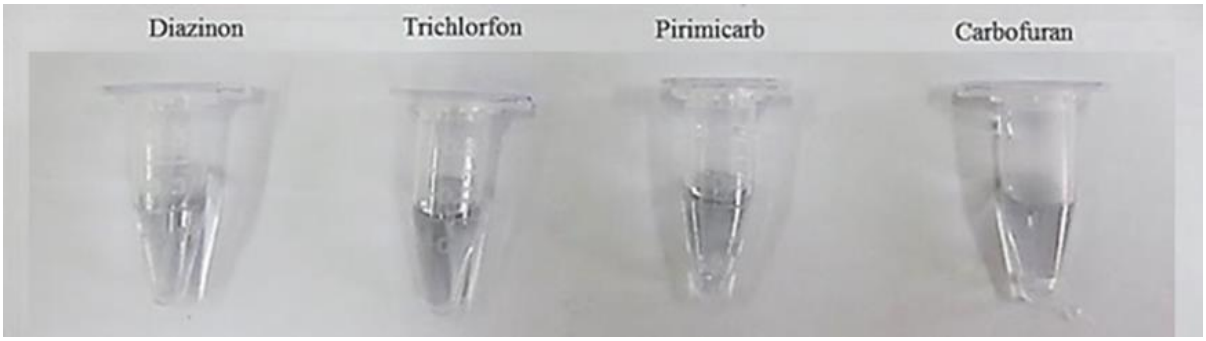

Figure 6 Structural aggregation and morphological changes of nanobiosensor in the presence of 25 ppm of each pesticide under investigation.

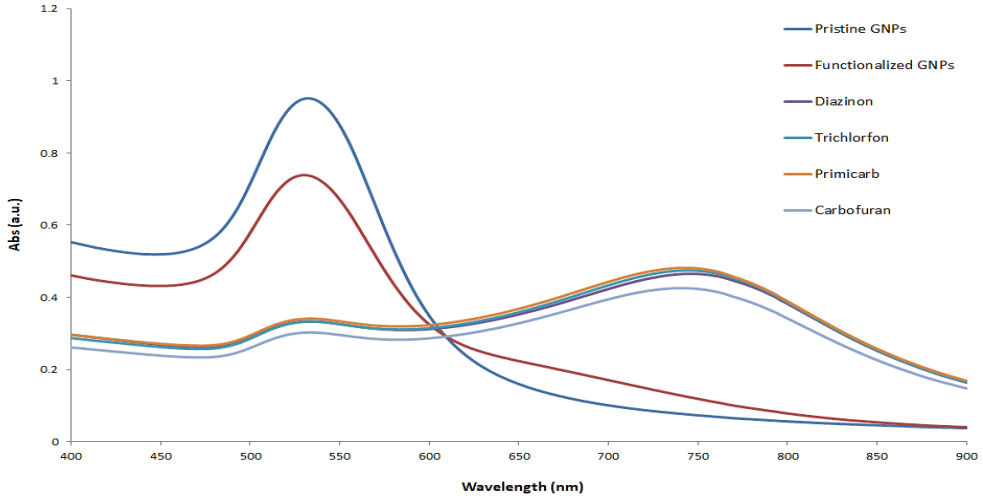

Figure 7 Detection of different pesticides with a constant concentration of 25 ppm by nanobiosensor in the presence of PBS buffer and NaCl.

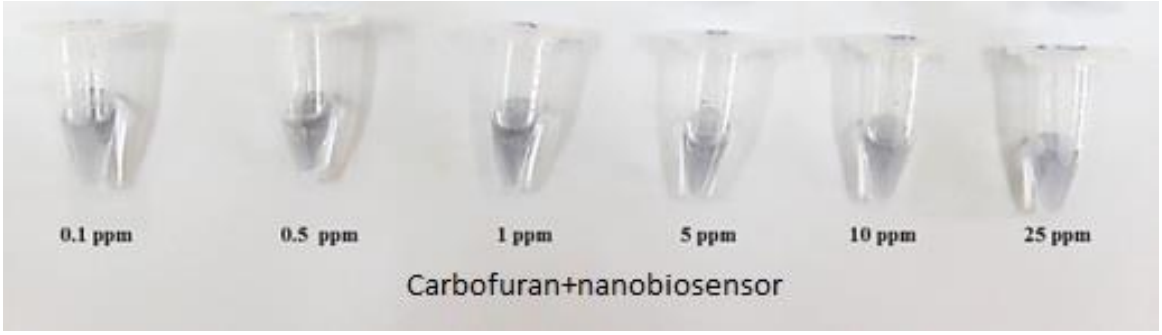

Figure 8 Specific accumulation of nanobiosensors in the presence of different concentrations of carbofuran**.**

Discussion

Designing a quick, relatively inexpensive test without sophisticated chromatographic devices is essential for detecting pesticides. In this study, a sensitive and rapid nanobiosensor was designed using gold nanoparticles, enabling detection of organophosphorus and carbamate pesticides via a specific bioassay sequence. At present, the production of these nanoparticles is

indigenously feasible at a cost comparable to other analytical methods, with specific functionalization targeting the targets, enabling a new generation of nanobiosensors for quick and easy detection of various pesticides on agricultural products at production sites and markets.

In this study, plasmonic gold nanoparticles were fabricated by the chemical growth method on grain particles. After chemical reduction of tetrachloroauric acid by sodium citrate at a specific temperature, gold plasmonic nanoparticles were formed, which were characterized by color changes in the colloidal solution, the location and intensity of the surface plasmon resonance, hydrodynamic radius, heterogeneity index, and transmission electron microscopy images.

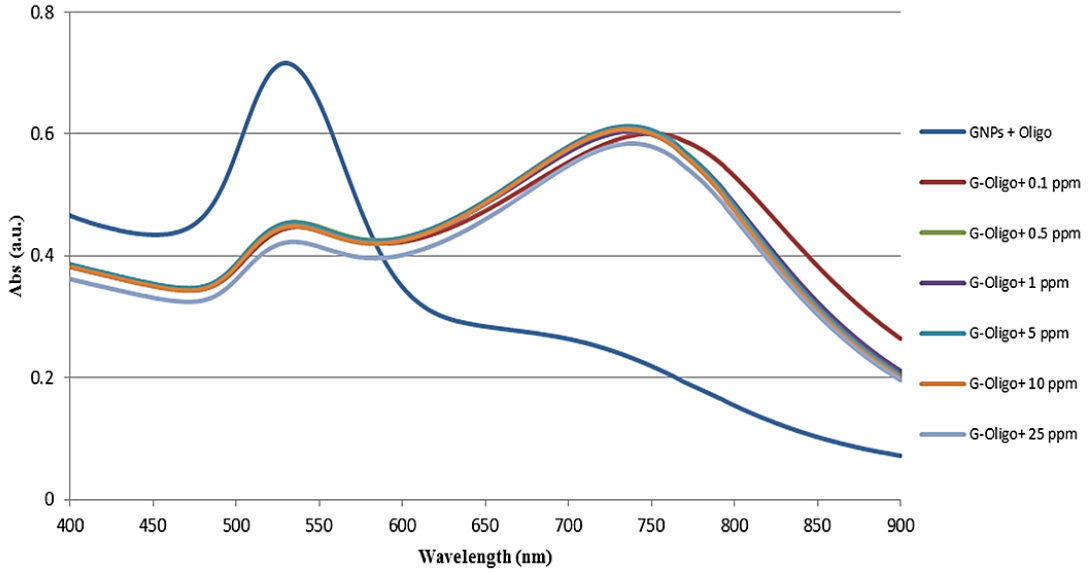

Figure 9 Detection of carbofuran with different concentrations of 0.1, 0.5, 1, 5, 10 and 25 ppm.

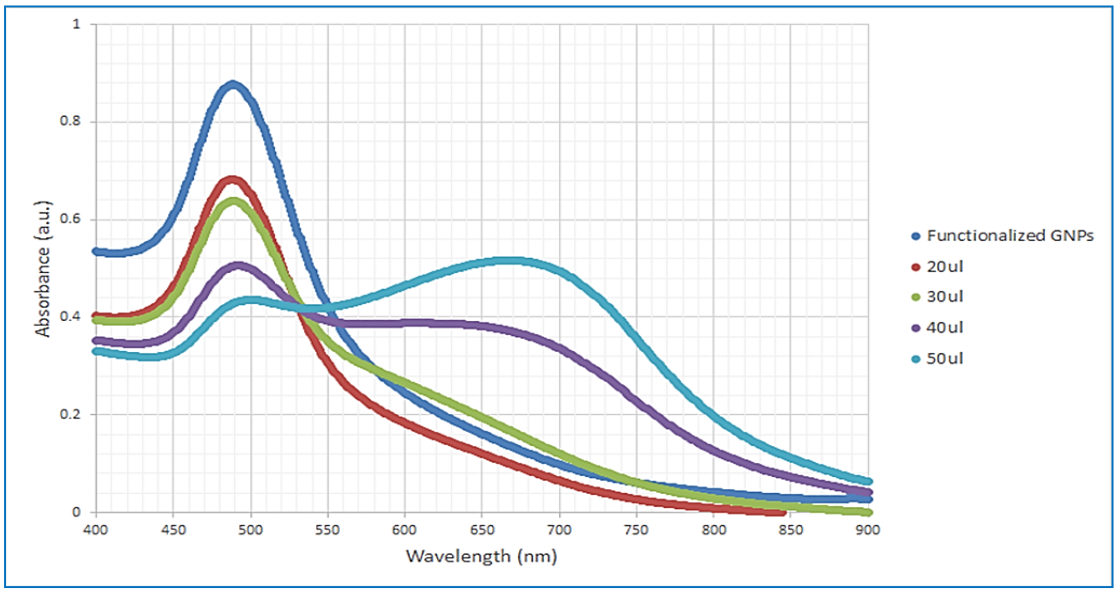

Figure 10 Resonance of the nanobiosensor surface plasmon in the presence of different volumes of pesticide.

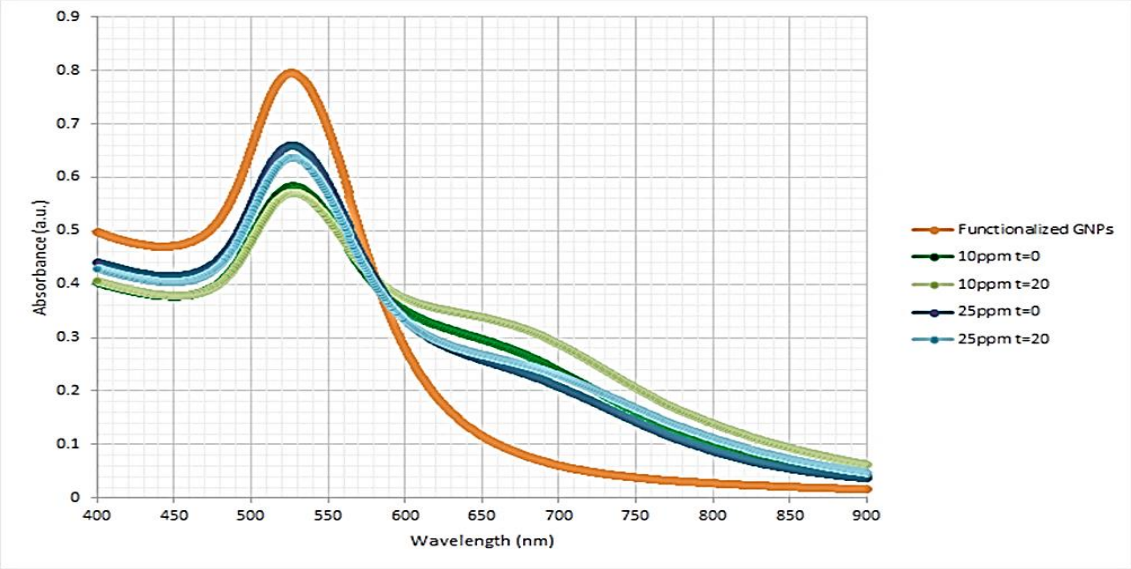

Figure 11 Effect of time on the detection of diazinon at two concentrations of 10 and 25 ppm at zero and 20 minutes by the nanobiosensor.

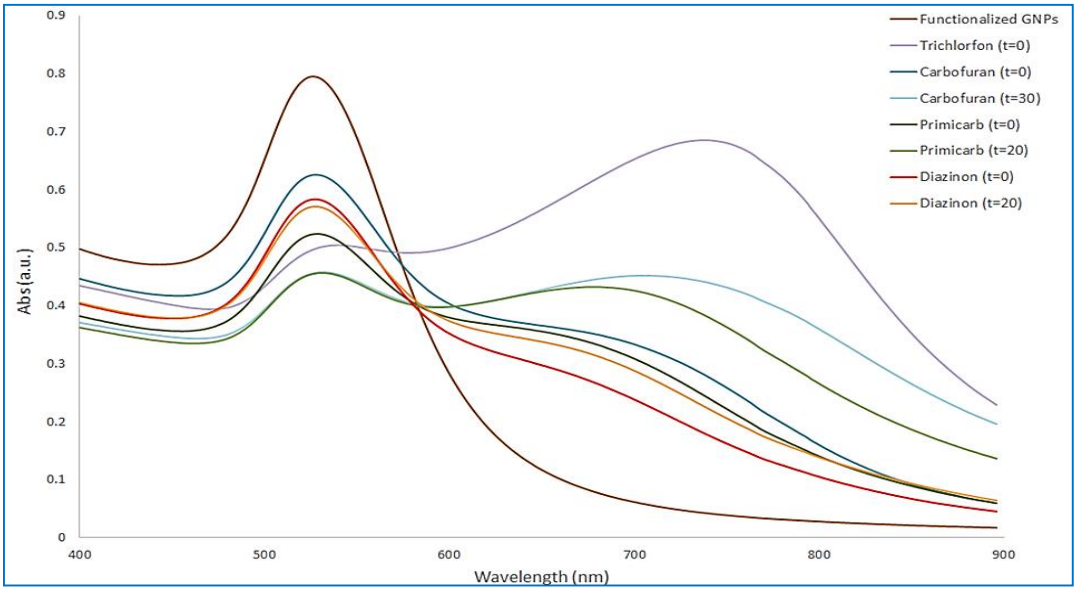

Figure 12 Effect of time on the detection ability of all four types of pesticides at a constant concentration of 10 ppm at zero and after 20 minutes by the biosensor.

In the functionalization of gold nanoparticles with biosensing agents, specific sequences of oligonucleotides, aptamers, and antibodies were used, which were attached to the nanoparticles' surfaces by adsorption or chemical bonding (depending on the experimental design). Due to the high cost of antibodies and the special conditions required for their maintenance, the aptamer was considered and designed to detect the pesticides under test, which has better stability than antibodies. They are more cost-effective and are (structurally) reversible after tolerating denaturation conditions. At the same time,

they are quite similar to antibodies in terms of specificity and the strength/affinity with which they bind to the target molecule. Also, these oligonucleotide sequences are easily functionalized, without losing their efficiency in finding the target molecule. Such properties make these biomolecules superior to alternatives such as enzymes and antibodies. Determination of the sensitivity and specificity of the designed nanobiosensor is important; hence, the appropriate concentration ranges of nanoparticles and the specific identification agent for the target molecule should be well defined, and the nanobiosensor should exhibit good stability. The temporal stability of the sensor, assessed by monitoring the surface plasmon resonance of nanoparticles at different time intervals, is also crucial. Therefore, to produce a stable diagnostic kit, the nanobiosensor was optimized in the presence of different concentrations and volumes of aptamer, salt, etc. Failure to optimize these conditions can lead to severe instability and nonspecific aggregation of nanostructures. According to the results, the best and most stable state (GNPs + Oligo (50 µM) + 4 µl NaCl (1 mM) + 10″ sonication after 30′) was selected and used in the experiment (Fig. 4).

To identify the target molecule, standard solutions of organophosphorus and carbamate pesticides were used. According to the results, the designed nanoprobe was not stable in the presence of methanol; therefore, various concentrations of standard solutions of organophosphorus pesticides (trichlorfon and diazinon) and carbamates (carbofuran and pirimicarb) were prepared in PBS buffer. The color change observed in the presence of the pesticide sample indicated the performance of the designed nanobiosensor. Monitoring the intensity of surface plasmon resonance in nanoparticles, as well as the location of these oscillations, provides useful information about the presence or absence of pesticides. This valuable qualitative information resulted from morphological changes in the nanoparticles and the distance between them, which can be readily observed by the naked eye, confirming the ease of use of this type of nanobiosensor.

In this study, the nanobiosensor designed based on the specific sensitivity of surface plasmon resonance of gold nanoparticles to the smallest changes in the medium was tested to detect pesticides; in the particular exploitation of this feature, the surface of gold nanoparticles was functionalized through a strong and stable covalent bond with a specific aptamer for the pesticides. Upon interaction with the nanobiosensor, in the presence of all four pesticides, the appearance and color of the nanobiosensor changed markedly, and, as expected, it was visible to the naked eye. As seen in Fig. 10, the nanobiosensor achieved the best performance at a sample volume of 50 µl. Therefore, it can be stated that the nanobiosensor designed in this study can quickly detect specific pesticides at very low sample volumes, which is a significant advantage for the preparation and analysis of the target.

The effect of time on the detection ability of all four pesticides by the nanobiosensor, at a constant concentration, was also investigated: zero and 20 minutes. The time-dependent performance of the nanobiosensor surface plasmon resonance was detected for four different pesticides. According to the results, the sensitivity of this nanobiosensor to diazinon is the lowest over time, whereas that to carbofuran is the highest. It seems that in the presence of trichlorfon, the nanobiosensor designed shows significant changes in the distances between the nanostructures and their morphology right from the beginning, and it does not need to be examined 20 minutes later. In any case, the maximum time required for incubating samples containing pesticides and nanobiosensors was estimated to be 10-15 minutes. This is another interesting potential of colorimetric nanobiosensors, based on the extreme sensitivity of the surface plasmon resonance of gold nanostructures to their surrounding media, which can be detected by functionalization with specific biomolecules.

By reviewing the literature on colorimetric sensor-based methods for pesticide detection, a

clear lacuna emerges in the use of a specific biosensing agent to enhance the sensitivity and specificity of the detection process. However, in the present study, not only is the color change of the sample emphasized, but also the specific plasmonic resonance of conjugated nanoparticles with the biosensing agent, in the presence and absence of the target molecule, has been investigated. Another advantage of this study is the use of a conjugation strategy to bind the biosensing agent to plasmonic nanoparticles, whereas in other reports in this field, such a strategy is not used. For example, Kinattukara *et al*. (2009) used gold spherical nanoparticles to detect pesticides, food contaminants, and agricultural wastes. They reported a reduction in the nanoparticle distance and discoloration upon the addition of sodium sulfate, which can bind and react nonspecifically with molecules other than pesticides. As a result, color changes and other effects can occur in the presence of various other factors as well (Liu, *et al.*, 2022; Kinattukara *et al.*, 2009).

Other studies show that biosensors such as microbial, electrochemical (amperometric, potentiometric), microbial-optical, tissue-based, photosynthetic, fluorescence, piezoelectric, immunoassay, nucleic acid, etc., have been reported in this field and have used biosensing elements/agents. Still, the device and signal generation occasionally require more sophisticated equipment, more complex sample preparation, and more difficult information interpretation/processing. As a result, the time required to analyze the samples significantly increases. In addition to preparing samples under appropriate storage conditions, the need for expert personnel is also of great importance. In a review article, aptamers are considered a promising solution to replace conventional pesticide detection methods in the future (Pushparajah *et al*., 2025). These interesting oligonucleotide sequences are capable of specific binding to many target molecules of a protein, metal, and microorganism nature that do not require a living host to produce. Compared to antibodies, aptamers bind to target molecules with higher affinity, specificity, and stability (Pushparajah, *et al.*, 2025; Khosropour, *et al.*, 2022; Hayat and Marty, 2014). However, the biosensors mentioned above use a biosensing agent, but the gap in new technology —the use of plasmonic nanoparticles with high diagnostic sensitivity —is clearly evident (Kant *et al.*, 2024; Sassolas *et al*., 2012).

Conclusions

Therefore due to the ease of production of gold nanoparticles, high surface-to-volume ratio, indigenous production in the country, ease of functionalization with stable biomolecules, ability to place several biomolecules on the surface of nanoparticles, maintaining biostability of the molecules that can be used on the surface, ability to quickly and visually detect with the least amount of analytes, approves the ability to replace this new generation of biosensors which is easy to use, versatile and quick with conventional methods which are costly and time consuming.

Conflict of interest

The authors state that there is no conflict of interest.

Authors' contribution

M. Morowati and R. Berahman performed the experiment and prepared the manuscript along with T. Tohidi.

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تشخیص بصری سریع و اختصاصی آفتکش‌های ارگانوفسفره و کاربامات در محصولات کشاورزی با استفاده از نانوذرات طلای عامل‌دار شده به آپتامر

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چکیده: طراحی روشی سریع، ارزان و آسان که امکان تشخیص باقی‌مانده آفتکش‌ها را در محل فراهم کند، بسیار مهم است. در این تحقیق، یک نانوحسگر زیستی حساس بر پایه نانوذرات پلاسمونیک طلا طراحی شده است که می‌تواند آفتکش‌های ارگانوفسفره و کاربامات را تشخیص دهد. با استفاده از نانوذرات پلاسمونیک طلا به‌روش شیمیایی رشد روی ذرات دانه سنتز شد. این نانوحسگر زیستی در حضور غلظت‌ها و حجم‌های مختلف آپتامر، نمک و غیره بهینه شد. برای شناسایی و تشخیص آفتکش‌ها توسط این نانوحسگر زیستی، از تری‌کلروفون و دیازینون (OP) و کاربوفوران و پیریمیکارب (Carb) استفاده شد. در اثر برهم‌کنش آفتکش‌ها با نانوحسگر زیستی، ظاهر و رنگ این حسگر به‌طور قابل‌توجهی تغییر کرد که با چشم غیرمسلح قابل مشاهده بود. نتایج نشان می‌دهد که حساسیت این نانوحسگر زیستی بر اثر گذشت زمان نسبت به دیازینون کم‌ترین و نسبت به کاربوفوران بیش‌ترین است. به‌نظر می‌رسد که در حضور تری‌کلروفون، نانوبیوسنسور طراحی شده در ابتدا تغییرات مورفولوژیکی قابل‌توجهی در نانوساختارها نشان می‌دهد. زمان مورد نیاز برای برخوابش نمونه‌های آفتکش و نانوحسگر زیستی حدود ۱۰ تا ۱۵ دقیقه تعیین شده است. یکی دیگر از پتانسیل‌های جالب نانوحسگر زیستی رنگ‌سنجی، حساسیت شدید نوسان پلاسمون سطحی نانوساختارهای طلا به محیط اطراف است که می‌توان آن‌ها را با مولکول‌های زیستی خاص برای تشخیص خاص، عامل‌دار کرد. با توجه به سهولت سنتز، تولید بومی، سهولت عامل‌دار کردن، حفظ پایداری مولکول‌های زیستی روی سطح، توانایی تشخیص سریع و بصری آفتکش‌ها با کم‌ترین غلظت آنالیت، پتانسیل خوبی برای جایگزینی این روش جدید با روش‌های مرسوم وجود دارد.

واژگان کلیدی: نانوحسگر زیستی، نانوذرات کلوئیدی طلا، آفتکش‌ها، ارگانوفسفره‌ها، کاربامات‌ها