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REVIEW

Advances and strategies in biosensor-based diagnostics for parasitic infections: a comprehensive scoping review

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Abstract
Parasitic diseases are among the most widespread infections worldwide, causing millions of deaths and illnesses each year. So rapid and accurate diagnosis is essential, requiring highly sensitive and specific tests. Biosensors can provide significant advantages over traditional diagnostic methods because of their specificity, sensitivity, speed, simplicity, ease of use, repeatability, and capacity for early-stage disease detection. Recent advances in modern diagnostic tools for detecting parasitic infections use nanomaterials such as gold nanoparticles, carbon nanofibers, and carbon nanotubes. These developments have significantly lowered detection limits to the picogram and femtogram levels. This review will cover recent advancements in biosensor-based diagnostic techniques in parasitology.

Keywords Biosensor · Diagnosis · Parasitic diseases · Early-stage evaluation

Introduction

Parasitic diseases can cause global health problems, especially in developing countries. The growth of international travel has helped spread these infections to new regions (Ricciardi et al. 2015). Accurate diagnosis is essential for proper treatment; however, traditional methods often cannot tell the difference between latent, recurrent, and acute infections (Davis et al. 1983). This highlights the urgent need for new diagnostic tools that offer better accuracy and sensitivity (Ahmadpour et al. 2019; Yu et al. 2021).

Biosensor technology offers a solution to these diagnostic challenges. These technologies are devices that combine biological components with transducers to quickly and

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accurately detect specific analytes. Their technology allows for easier, faster, and more sensitive measurements in various samples (Rateni et al. 2017). The concept of biosensors was first introduced by Clark and Lyon, who used enzyme-containing membranes to detect glucose and urea through pH and oxygen electrodes (Clark Jr et al. 1962). These innovative approaches can have more sensitivity, selectivity, reaction time, reproducibility, detection range, half-life, and stability than other diagnostic tools (Mehrvar et al. 2004).

A typical biosensor consists of three main components: the biological recognition element, the transducer, and the signal processor, which converts a biological response into an electrical signal. Leyland C. Clark introduced the main concepts of biosensors in 1969 (Abid et al. 2021). The biosensor components include bio-receptors like monoclonal antibodies, enzymes, nucleic acids, glycans, lectins, tissues, whole cells (Ejeian et al. 2018; Bhalinge et al. 2016), and microorganisms (Ejeian et al. 2018). The interactions among these components are transformed into measurable signals by a transducer, allowing pathogen detection (Abid et al. 2021). As shown in Fig. 1, novel sensing tools are categorized into five types based on their transducer mechanisms: thermal, electrochemical, acoustic, mass, and optical (Thévenot et al. 2001).

The development of diagnostic systems is a leading field in next-generation medical innovations (Kawamura et al. 2016). Different types include enzyme-based, tissue-based, immunosensors, DNA biosensors, and thermal and piezoelectric biosensors (Mehrotra et al. 2016). Enzymatic biosensors use immobilized oxidoreductases and other enzymes, focusing on substrates or inhibitors (Wang et al. 2008; Akyilmaz et al. 2010). Immunosensors take advantage of the high affinity of antibodies for specific antigens (Pohanka et al. 2018; Bahadır et al. 2016). DNA biosensors identify complementary sequences through hybridization (Teles et al. 2008; Kavita et al. 2017). Temperature-sensitive biosensors typically immobilize biological elements on a transducer, and methods such as quartz crystal microbalance and surface acoustic wave are mass-sensitive and piezoelectric biosensors, measuring changes in oscillation caused by mass binding (Mehrotra et al. 2016; Ramanathan et al. 2001).

These devices detect specific compounds or pathogens in complex mixtures, including liquids like water and serum (Sin et al. 2014). These devices are more stable and sensitive than traditional methods and are rapidly expanding across various fields (Haleem et al. 2021). These technologies are particularly valuable in parasitology (Baryeh et al. 2017; Turner et al. 2013). They are expected to become common in biomedical laboratories and personalized medicine. For example, diagnosing Chagas disease could greatly benefit from these tools (Rocha-Gaso et al. 2017). This review will

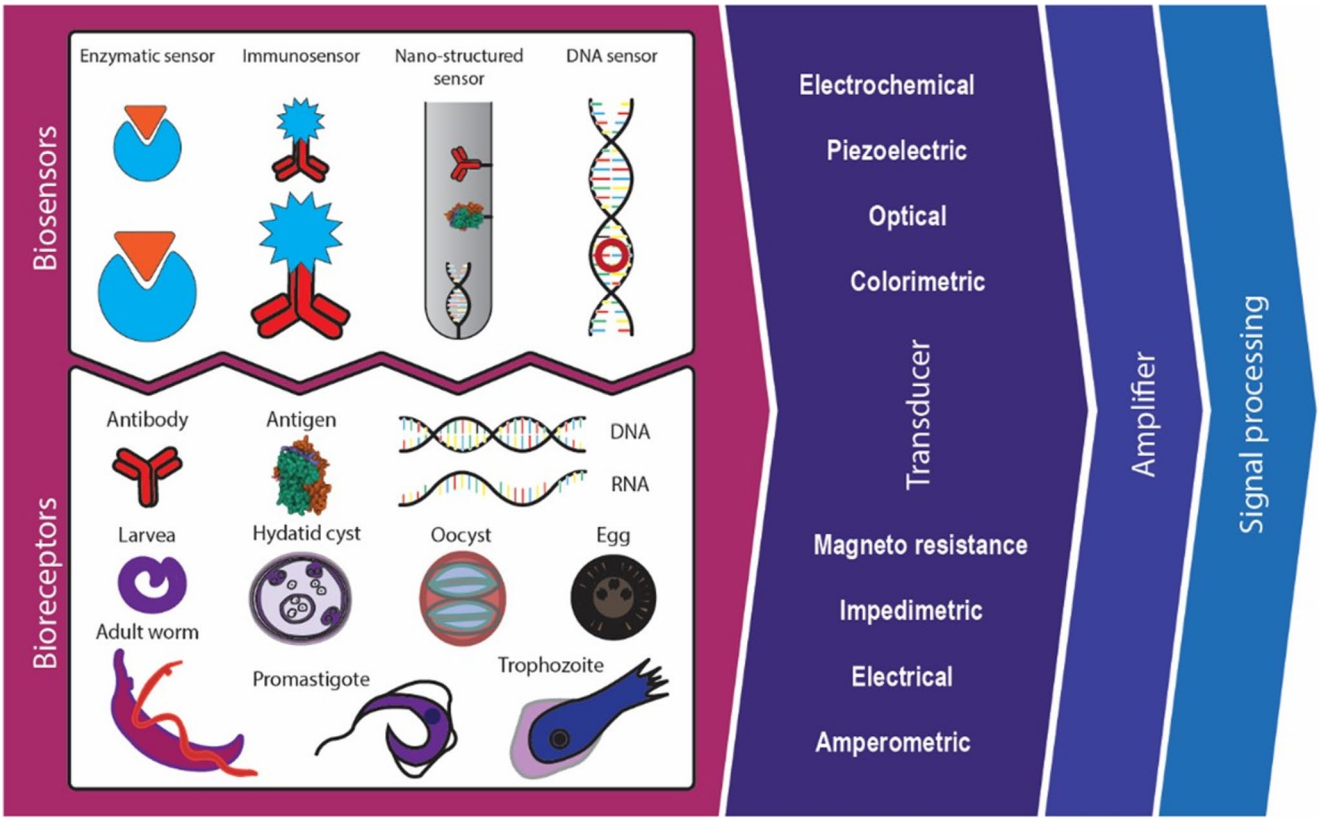

Fig. 1 A sample biosensor can be used to detect parasites

cover recent advancements in biosensor-based diagnostic techniques in parasitology.

Methods

Search strategy

To assess the sensory methods for diagnosing parasitic infections, a systematic search was conducted across major English-language databases, including PubMed, Scopus, ProQuest, and Google Scholar. The search targeted publications related to parasite diagnosis using biosensors from January 2000 to June 2025. This review was limited to original papers published in English and used keywords such as "biosensor" and "parasite" or "parasites" (Table 1).

Study selection

The inclusion criteria for this scoping review were as follows: (i) Studies that diagnosed parasitic infections using a diagnostic approach; (ii) Journal articles published with full text or abstracts in English were eligible for inclusion; (iii) No geographic limitations were imposed on the studies. Exclusions included conference papers, posters, and studies with ambiguous or unclear content. All studies extracted from the databases were independently reviewed. Figure 2 illustrates the scoping review methodology.

Data extraction

Data were extracted from 136 selected articles. Each included paper was examined for relevant details, including the year of publication, sensor types used, materials, target parasites, frequency range, and detection limits. To evaluate the quality of the selected articles, two independent reviewers evaluated both data extraction and quality assessment.

Results

In this review, 136 full texts were retrieved based on the selection criteria described above. Of these, 136 articles were identified: 110 focused on using biosensors for protozoan detection, while 26 focused on helminth detection (Tables 2 and 3).

These tools used for detecting protozoan parasites include immunosensors, DNA biosensors, electrochemical biosensors, SPR biosensors, phosphatidylinositol 3-phosphate biosensors, nanostructured biosensors, piezoelectric-excited millimeter-sized cantilever (PEMC) sensors, optical biosensors, aptasensors, impedimetric sensors, lateral flow biosensors, flexible chemoreceptive biosensors, protein-based biosensors, magnetoresistance sensors, lipid biosensors, inductive-based sensitive and reusable sensors, label-free interdigitated capacitive biosensors, and density-based biosensors.

On the other hand, the 26 articles related to helminthology discussed various biosensors, including GloSensor

Table 1 The table identifies the search keywords for each database, along with the corresponding number of articles

Database & Search engine	Search terms	Search results 11/06/2025
PubMed	biosensor OR "biosensing" OR "electrochemical biosensor" OR immunosensor OR genosensor OR aptasensor OR "DNA biosensor" nanoparticle biosensor" OR "carbon nanotube biosensor" OR "gold nanoparticle biosensor" AND"parasitic infection" OR parasite OR protozoa OR helminth OR malaria OR *Plasmodium*OR schistosomiasis OR leishmaniasis AND sensitivity OR specificity diagnosis OR detection OR "early detection" OR "rapid detection"	1,007
ProQuest	biosensor OR "biosensing" OR "electrochemical biosensor" OR immunosensor OR genosensor OR aptasensor OR "DNA biosensor" nanoparticle biosensor" OR "carbon nanotube biosensor" OR "gold nanoparticle biosensor"AND"parasitic infection" OR parasite OR protozoa OR helminth OR malaria OR *Plasmodium*OR schistosomiasis OR leishmaniasis AND sensitivity OR specificity diagnosis OR detection OR "early detection" OR "rapid detection"	450
Scopus	biosensor OR "biosensing" OR "electrochemical biosensor" OR immunosensor OR genosensor OR aptasensor OR "DNA biosensor" nanoparticle biosensor" OR "carbon nanotube biosensor" OR "gold nanoparticle biosensor"AND"parasitic infection" OR parasite OR protozoa OR helminth OR malaria OR *PlasmodiumOR* schistosomiasis OR leishmaniasis AND sensitivity OR specificity diagnosis OR detection OR "early detection" OR "rapid detection"	429
Google Scholar	biosensor OR "biosensing" OR "electrochemical biosensor" OR immunosensor OR genosensor OR aptasensor OR "DNA biosensor" nanoparticle biosensor" OR "carbon nanotube biosensor" OR "gold nanoparticle biosensor"AND"parasitic infection" OR parasite OR protozoa OR helminth OR malaria OR *Plasmodium*OR schistosomiasis OR leishmaniasis AND sensitivity OR specificity diagnosis OR detection OR "early detection" OR "rapid detection"	2,421
Total after deduplication		2,542

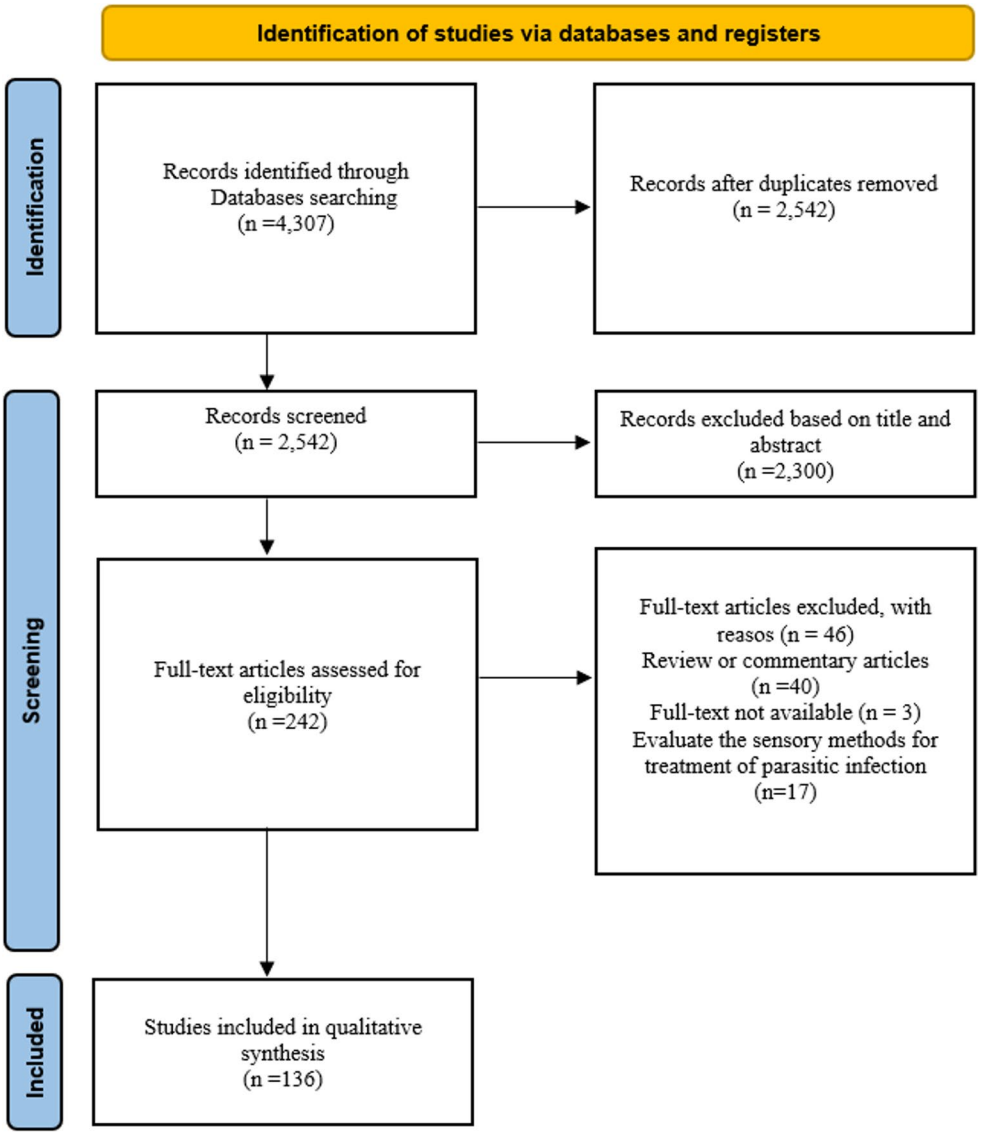

Fig. 2 Flowchart describing the study design process

(cyclic adenosine monophosphate bioluminescent sensors), protease-based biosensors, amperometric immunosensors, in vitro biosensor systems, piezoelectric immunosensors, electrochemical biosensors, DNA biosensors, genosensors, label-free nanostructured biosensors, cAMP biosensors, nucleic acid-based biosensors, point-of-care biosensors, porous silicon resonant microcavity biosensors, Dot-Lab biosensors, and optical biosensors, as well as nanoparticle biosensors.

Among the listed biosensors, immunosensors are the most commonly used in parasitology, with 49 articles focusing on protozoa and 14 on helminths. These sensors are especially valuable because of their rapid response times (results within two hours), accuracy, stability, low interference, minimal detection limits, and the lack of need for markers, making them suitable for monitoring in endemic areas. Leishmania species among protozoa and *Schistosoma* species among helminths are identified as the most important parasites studied for diagnostic approaches.

In biosensor design, different materials are used based on their specific functions. These include antigens, antibodies, nanoparticles, DNA ligands, magnetic beads, various proteins, and peptides. The targets a biosensor can detect vary depending on the biosensor type. Each biological tool has been employed not only for diagnosis but also to support other diagnostic methods, and in some cases, to replace serological and molecular techniques. These innovative approaches are highly valued for their high specificity and sensitivity, excellent selectivity, fast response times, simplicity, ease of use, and consistency. They can detect very low levels of substances, enable early diagnosis, and help prevent the incorrect use of toxic drugs. Additionally, they offer easy access without requiring expensive diagnostic equipment.

Table 2 Comprehensive records of biosensor applications for protozoan parasites, organized by publication year

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Immunosensor									
Amperometric bioelectrode (detects immunoglobulin G (IgG antibodies)	*Trypanosoma cruzi*	FcMe as the soluble mediator	NOT REPORTED	Epimastigotes	Electrophoresis, SDS-PAGE, and ELISA	12.4 ng mL-1 IgG	"This technique may successfully detect anti-T. cruzi IgG, both in terms of sensitivity and specificity".	2006	(Ribone et al. 2006)
Automated fiber optic-based biosensor	*Cryptosporidium parvum*	Anti-Cryptosporidium oocyst polyclonal and monoclonal antibodies	NOT REPORTED	Oocyst	"Anti-Cryptosporidium oocyst polyclonal and monoclonal antibodies were tested to capture and detect Cryptosporidium oocysts using a fiber optic biosensor assay."	Polyclonal antibody: boiled oocysts: 10 5 oocysts/mlControl oocysts (not boiled) were detected at 106 oocysts/ml. Monoclonal antibody:10 6 oocyst/ml	"To be detected by a biosensor assay, oocysts would have to be concentrated from water samples and heat-treated, according to preliminary procedures in the construction of an in-line biosensor assay system".	2007	(Kramer et al. 2007)
Nanostructured biosensor	*Leishmania amazonensis*	"Nanostructured biomaterials".[PAMAM (Polyamidoamine) and proteoliposomes],"nanostructured films containing specific Leishmania amazonensis and T. cruzi antigens"	10 Hz to 1 MHz	Anti-L. amazonensis antibodies	"1 and 0.7 mg/mLThis biosensor is made with nanostructured films containing specific Leishmania amazonensis and T. cruzi antigens and employs impedance spectroscopy as the detection method.	10 -5mg ml-1	"A low-cost biosensor device can effectively distinguish between cutaneous leishmaniasis and Chagas disease.The methods described here are general and may be used for any type of biosensor, which is critical for the accurate diagnosis of a wide range of illnesses".	2010	(Perinoto et al. 2010)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Piezoelectric immunosensor	*Plasmodiumfalciparum*	"Screen-printed electrodes (SPEs), alumina sol-gel (Al2O3sol-gel, film, and gold nanoparticles	NOT REPORTED	Antibodies to Plasmodium falciparum histidine-rich protein-2 (PfHRP-2)	"Formation of a thin film by dropping Al2O3 sol on SPE, causing sedimentation of electrochemical AuNPs. The reformed SPEs were monitored by "scanning electron microscopy/energy dispersive X-ray analysis (SEM-EDAX), Raman spectra, and voltammetric experiments".	NOT REPORTED	"For the detection of rabbit anti-PfHRP-2, the developed disposable immunosensor "AuNPs/Al2O-3sol–gel/ SPE" outperformed the Dot ELISA test in terms of analytical performance and sensitivity".	2010	(Sharma et al. 2010)
Piezoelectric-excited millimeter-sized cantilever (PEMC) sensor	*Cryptosporidium parvum*	Protein G,"goat polyclonal IgG anti-C. parvum"PZT layer (lead zirconate titanate, Piezo Systems, Woburn, MA) and a quartz layer (SPI, West Chester, PA)	920–950kHz	Oocysts	50–10,000Oocysts/ mL"Piezoelectric-excited millimeter-sized cantilever (PEMC) sensor can detect five Cryptosporidium parvum oocysts in 25% milk in PBS background in a flow format (1mLmin−1)".	5 oocysts/ mL	"In a flow device, identification of C. Parvum in PBS or milk background is possible at concentrations as low as 5oo cystsmL1".	2010	(Xu et al. 2010b)
Piezoelectric immunosensor	*Leishmania chagasi*	"Recombinant antigen of Leishmania chagasi" (rLci2B-NH6)Quartz crystal	9 MHz	Antibodies	3 µg/mL A quartz crystal microbalance immunosensor for the diagnosis of canine visceral leishmaniasis using a recombinant antigen of Leishmania chagasi (rLci2B-NH6) was developed. The rLci2B-NH6 was strongly immobilized on a quartz crystal gold electrode by self-assembled monolayer based on short-chain length thiol."	NOT REPORTED	"This immunosensor measures anti-L. Chagasi antibodies directly, without the need for a marker, making the test quicker and easier than traditional techniques. This immunosensor may be used to monitor canine visceral leishmaniasis and is portable and convenient for screening tests in endemic locations across the world."	2011	(Ramos-Jesus et al. 2011)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical-based sandwich enzyme-linked immunosensor	*Cryptosporidium parvum*	"dual-labeled gold nanoparticles" (alkaline phosphatase and anti-oocysts monoclonal antibody) or "gold nanoparticle functionalized ITO electrode, AuNP probe"	0 to 0.4 V	Oocyst	1 * 105"oocysts/ mL and anti-oocysts monoclonal antibody of 1/20–1//2000 unit / Synthesis of AuNP, Fabrication of ITO electrode, immobilization of anti-oocysts McAb"	3 oocysts/ mL	"Using a dual-tagged AuNP probe, a novel improved electrochemical immunosensor test was designed to detect the parasite C. parvum at very low concentration levels".	2011	(Thirupathiraja et al. 2011)
Immunosensor	*Plasmodium falciparum*	Magnetic Nanoparticles	NOT REPORTED	Plasmodium falciparum Histidine-Rich Protein 2(PfHRP-2)	0 to 250 ng/ mL Low concentration:35 ng/ mL/A successful covalent immobilization of "anti-HRP2 IgM monoclonal antibody" was first done on 300 nm magnetic nanoparticles and tosyl-modified magnetic beads, causing an excellent coupling efficiency achievement.	0.36 ng/ mL	With little pretreatment, this biosensor may provide a quantifiable result for the Plasmodium falciparum HRP2 linked to malaria in blood samples. Furthermore, this approach might be used to screen at-risk blood samples for the prevention of malaria transmitted by transfusion.	2011	(de Souza Castilho et al. 2011)
Optical microfluidic biosensors	*Cryptosporidium parvum*	Anti-C. parvum was covalently conjugated to 920 nm highly carboxylated polystyrene beads.	NOT REPORTED	Oocyst	"10 0 to 10 4 oocysts/ mL An immune agglutination assay using "Mie scatter intensity" changes for detection of different Cryptosporidium concentrations."	10 0-10 1 oocysts/mL	"This approach might identify low levels of Cryptosporidium parvum in-field water, saving thousands of gallons of water in swimming pools each year, as well as saving the lives of young children and immunosuppressive patients who are more susceptible to cryptosporidiosis."	2012	(Angus et al. 2012)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Immunosensor	*Cryptosporidium parvum*	IgG antibody IgMProtein G	NOT REPORTED	Oocyst	"100 oocyst/ Among 4 tested methods under static and convective conditions, G linkage. The protein G linkage protocol presented the highest recovery rates in both conditions".	NOT REPORTED	"These findings may be beneficial in the development of future Cryptosporidium biosensor systems that employ antibodies as the detection tools".	2012	(Gavriilidou et al. 2012)
Label-free immunosensor(surface plasmon resonance (SPR))	*Leishmania infantum*	11-mercaptoundecanoic acid (11-MUA) modified gold Surface plasmon resonance sensorchip	NOT REPORTED	anti-Leishmania infantum antibodies	"10, 18, 30, 40 and 50 µg. mL-1/A SPR immunosensor protocol was suggested for the detection of anti-Leishmania infantum antibodies. Leishmania infantum antigens were immobilized on the SAM of 11-MUA on gold substrate. SECM was applied for 2-D electrochemical imaging of Leishmania infantum antigens.	NOT REPORTED	"Anti-L. Infantum antibodies are detected using an Immunosensor with high specificity. As a result, this study reveals the effective creation of an SPR sensor for anti-L. infantum. Antibody detection in a short period, indicating a promising future as a Visceral Leishmaniasis sensing device in endemic areas".	2013	(Souto et al. 2013)
Novel electrochemical immunosensor	*Toxoplasma gondii*	Goldman (Au–Fe3O4) nanoparticles, graphene sheets (GS), and gold nanoparticles (AuNPs)	1 to 105 Hz	Toxoplasma gondii-specific IgM	0.0375 to 1.2 AU mL-1 and from 2.0 to 18 AU mL-1/ TEM and SEM system	0.016 AU mL-1	"The immunosensor's repeatability, stability, and selectivity were all excellent."	2013	(Jiang et al. 2013)
Electrochemical sensor	*Plasmodium falciparum*	PfHRP-II specific antibodies,Gold electrodes were fabricated on glass substrates	NOT REPORTED	PfHRP2	(4-1,024 ng/mL) "A compact mobile phone platform was offered for rapid, quantitative bio-molecular detection. This system consists of an embedded circuit for signal processing and data analysis, and disposable microfluidic chips for fluidic handling and biosensing.	16 ng/mL	"This device has enormous promise as a widely reachable, point-of-care diagnostic tool, especially in distant and rural regions, due to its small size and excellent performance".	2013	(Lillehoj et al. 2013)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Label-Free Plasmonic Immunosensing	Plasmodium spp.	Plasmon nanostructures,Protein A,Monoclonal antibodies against Plasmodium lactate dehydrogenase	NOT REPORTED	PLDH	"A highly site-directed and stable antibody immobilization process on the nanostructure's surface was used for detection of malaria pathogen".Changes in the excitation condition of a surface plasmon wave (SP) were detected by the SPR sensor.	NOT REPORTED	"Among many portable biosensing Plasmon sensor is a highly sensitive, small, cost-effective, and selective diagnostic tool".	2013	(Cho et al. 2013)
Piezoelectric-Based Immunosensors	*Leishmania infantum*	Anti–L. infantum monoclonal antibodies (aLimAbs)	Relative frequency shit:0.99994-1.00000%	Amastigote	A 100 µg protein/ml/ aLimAbs immunosensor-based assay was developed to detect Leishmania spp.	1.8×104 Amastigotes/g	"Based on the detection of parasite products, cheap, high sensitivity and specificity may represent a significant achievement in improving the clinical treatment of suspected AVL cases".	2014	(Cabral-Miranda et al. 2014)
Immunosensor	*Plasmodium falciparum*	Carbon Nanofibers Grown on Glass Microballoons	NOT REPORTED	Plasmodium falciparum histidine-rich protein-2 (PfHRP-2) antigen	0.01 ng/mL and 10 ng/ mL/"Direct detection of PfHRP-2 antigen using carbon nanofiber (CNF) forests grown on glass micro balloons (NMBs)".	0.025 ng/ mL	"NMBs are a potential technique for early detection of malaria and other infectious illnesses due to their fast, sensitive, and strong signal amplification capabilities".	2014	(Gikunoo et al. 2014)
Surface plasmon resonance biosensor	*Plasmodium falciparum*	4-mercaptobenzoic acid,MoabPf and PoabPf	NOT REPORTED	PfHRP-2	"4-mercapto benzoic acid (4-MBA) modified gold SPR chip was applied for immobilizing the Ag, and then Ab interacted".	MoabPf:5.6 pg·mL−1	"This sensing approach might potentially be used in pathology laboratories equipped with SPR systems to provide effective and timely screening of malaria patients."	2014	(Sikarwar et al. 2014)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Surface plasmon resonance Immunosensor	*Leishmania infantum*	Hypothetical C1 protein or C1antigen,	NOT REPORTED	IgGs anti-C1	(0.1–80 mg mL1 or 2.44×103 –1.95 mmol L1)"The application of SPR immunosensor for elucidating the reaction kinetics between a protein of unknown function in Leishmania infantum (hypothetical C1 protein) and specific antibodies."‥	7.37nmol/L	"The strong antigenic character of a hypothetical protein was quantitatively shown in this work, indicating its potential application in the immunodiagnosis of the VL".	2015	(Souto et al. 2015)
Immunosensor	*Trypanosoma cruzi*	Surface plasmon resonance (SPR)	NOT REPORTED	Epimastigotes	ELISA, SPR immunoassay	NOT REPORTED	"The suggested immunosensor was successfully constructed, and the immunoassay enabled the detection of anti-T. cruzi antibodies in a simple, effective, quicker, and more specific manner, which is a promising development in the field of Chagas disease diagnostics".	2015	(Luz et al. 2015)
Gold nanoparticle piezoelectric immunosensor	*Leishmania infantum*	Gold nanoparticle piezoelectric immunosensor	rLci2Brecombinant antigen,Gold nanoparticle, AuNP cysteamine	590-650 HZ	Leishmania infantum antibodies	3 µg/mL	"A sensitive piezoelectric immunosensor for anti-Leishmania antibodies based on rLci2 B recombinant antigens immobilized on quartz crystal electrode".	2016	(Ramos-Jesus et al. 2016)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical immunosensor	*Trypanosoma cruzi*	"Screen-printed carbon electrode" (SPCE), "shed acute. phase antigen" (SAPA)	NOT REPORTED	Epimastigotes	"10 to 200 ng mL-1/ Recombinant antigen, Modification of SPCE electrode, ELISA"	3.03 ng mL-1	"Instead of utilizing a serological test, this electrochemical immunosensor can be utilized to identify congenital Chagas disease".	2016	(Regiart et al. 2016)
Enzyme-free electrochemical immunosensor	*Plasmodium falciparum*	Methylene blue and the electro-oxidation of hydrazine on Pt nanoparticles	NOT REPORTED	Plasmodium falciparum lactate dehydrogenase (PfLDH)	10 -12 to 10 -7 g/ mL /"A new enzyme-free electrochemical immunosensor based on a unique competitive detection scheme using methylene blue (MB), hydrazine and platinum nanoparticles (Pt NPs)".	2.2 pg/ ml	"Fast measurement and high sensitivity without limitation related to enzyme reporters are the features of Enzyme-free electrochemical sensors".	2017	(Dutta and Lillehoj 2018)
Immunosensor	*Leishmania infantum*	Recombinant protein - CPX2	0,1–100 KHz	Antibody of Leishmania	"A potentiostat (Metrohm), model Auto lab PGSTAT10 and was controlled by GPES 4.9.005 software. For these measurements, screen-printed carbon electrodes were used. For electrochemical assays, the SPEs inserted in the microfluidic platform were placed in a switch box (DROPSENS), and the electrical connections were introduced to the potentiostat.	NOT REPORTED	"Low detection limits, high sensitivity, low interference levels, non-destructive sample method, and stability are the features of immunosensors".	2017	(Esteves et al. 2017)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Immunosensor	*Plasmodium falciparum*	Graphite–epoxy composite magneto electrode,gold nanoparticles (AuNPs)	NOT REPORTED	PfHRP 2	(0, 2, 16, 20, 64, 80, and 100 ng·mL−1)"PfHRP 2" was used as the biomarker for the detection and diagnosis of malaria. The sensor was applied to immobilize the anti-PfHRP 2 monoclonal antibodies as the capturing receptor	Optimized:2.95 ng/ mLAmplified:40 pg/ mL	"This sensor type is excellent for malaria detection and on-site analysis as a point-of-care device (POC) in resource-constrained areas where malaria diagnostics are critical to malaria control and elimination efforts".	2017	(Hemben et al. 2017)
"Multi-walled carbon nanotubes - zinc oxide nanofiber" basedflexible chemiresistive biosensor	*Plasmodium falciparum*	Multi-walled carbon nanotubes (MWCNTs), zinc oxide nanofibers	NOT REPORTED	PfHRP-2	"10 fg/mL to 10 ng/Ml /A flexible, lightweight, and disposable multi-walled carbon nanotubes (MWCNTs)-zinc oxide (ZnO) nanofiber-based chemiresistive biosensor for detection of malaria biomarker, histidine-rich protein II (HRP2).	0.97 fg/ mL	"This is the first study on a flexible chemiresistive biosensor that has been investigated for the detection of a malaria biomarker and may be expanded to many additional biomarker detection systems in the future for smart point-of-care (POC) diagnostics".	2017	(Panigrahi et al. 2017)
Surface Plasmon Resonance Biosensor(SPR biosensor)	*Leishmania spp*	A highly specific and sensitive constrained synthetic peptide (LC2) derived from a mimotope of Leishmania chagasi antigen.	NOT REPORTED	Anti-Leishmania antibodies	"A highly specific and sensitive-constrained synthetic peptide (LC2) derived from a mimotope of Leishmania chagasi antigen, selected by phage display (is a selection technique in which a library of peptide or protein variants is expressed as a genetic fusion to a bacteriophage coat protein), was used as probe for IgG detection".	NOT REPORTED	"This method for leishmaniasis detection using disposable biochips implies that this biosensor might be used to diagnose other infectious and chronic illnesses in the future".	2017	(Ferreira et al. 2017)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Photoelectrochemical immunosensor	*Leishmania infantum*	NanoparticlesAuNP, CdS, ITO	10 -1 Hz – 10 5 Hz	Anti-Leishmania infantum antibodies	"The cadmium sulfide films and gold nanoparticles placed on an indium tin oxide-coated glass slide"	0.41 nmol L-1	"The suggested photo electrochemical immunosensor is a cheap, easy-to-use option for high-sensitivity detection of anti-L.infantum antibodies."	2018	(Neto et al. 2018)
Density-basedbiosensor	*Trypanosoma cruzi*	Magnetic levitating microbeads (MLμBs), SiO2 microcrystals,	NOT REPORTED	Epimastigotes	"ELISA, Preparation of MLμBs and SiO2 microcrystals, MLμBs immunoassays."	5 μgmL-1	"Applying magnetically floating micro beads, the study describes a simple, cheap, transferable, and accurate method for detecting and quantifying anti-T. cruzi antibodies in whole blood."	2018	(Castro et al. 2018)
Immunosensor	*Plasmodium falciparum*	Colloidal gold nanoparticlesCommercial AuNPanti-pLDH	NOT REPORTED	PFLDH	0.1 ng /mL to 100 μg/ ml"Affinity sensor was one of the biomarkers developed to detect Plasmodium falciparum parasite Lactate dehydrogenase (pLDH)".	In buffer: 1.80 ng/ mLIn serum: 0.70 ng/ mL	"The sensor demonstrated great sensitivity and repeatability, as well as being a cost-effective point-of-care immunoassay that can be completed in under two hours."	2018	(Hemben et al. 2018)
Immunosensor/Optical	*Leishmania infantum*	Gold nanoparticles(GNPs)	NOT REPORTED	Amastigote(Chimeric recombinant antigens)	"Lateral flow immunoassay (LFIA) technology as a rapid and portable tool was used for VL diagnosis".	NOT REPORTED	"Because the LFIA uses the widely specific protein A, it may easily be modified to detect VL in dogs, the major reservoir for human infection, and other animals, aiding attempts to restrict the spread of the disease".	2018	(Anfossi et al. 2018)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Novel peptide-based sensor platform/ electrochemical immunosensor	*Toxoplasma gondii*	Silico predicted peptide (PepB3),Modifies graphite electrodes with Poly (3-hydrobenzoic acid), polymer filmsSurface Antigen 1(SAG1)	NOT REPORTED	Anti-T. gondii immunoglobulins	10µl ml -1 /"A new electrochemical immunosensor based on immobilization of an in silico predicted peptide (PepB3), obtained from the membrane protein of T. gondii , on the graphite electrode modified with poly (3-hydroxybenzoic acid) was used for detecting anti-T. gondii immunoglobulins"	NOT REPORTED	Electrochemical immunosensor could distinguish among various infection phases.	2019	(Alves et al. 2019)
Novel electrochemical sensing platform	*Toxoplasma gondii*	screen-printed carbon electrode (SPCE),"poly-vinyl alcohol" (PVA), poly-vinyl pyrrolidone (PVP), graphene oxide (GO)T. gondii antigens	NOT REPORTED	Anti-Toxoplasma gondii antibodies	100 µg/ mL"A novel nanocomposite based on PVP, PVA, and graphene method was used. Electrochemical quantitation of anti-T. gondii IgG antibodies in serum samples".	0.012 U/mL	"For toxoplasmosis serological diagnosis, the electrochemical platform has been shown to be a sensitive and easy-to-use instrument. As a result, the nanocomposite developed is an excellent choice for the manufacture of electrochemical biosensors".	2019	(Takara et al. 2019)
Label-free electrochemical impedance immunosensor	*Leishmania infantum*	(SPEs)"screen-printed electrodes" 3-mercapto Propionic acid monolayer (MPA) Antigens of L. infantum	100 kHz to 10 mHz	Anti-Leishmania infantumantibodies	12.5, 25,50, and 100 µg/mL "The soluble antigens of L. infantum were immobilized on an SPE by a3-mercaptopropionic acid monolayer. Electrochemical impedance spectroscopy (EIS) was used for detecting bimolecular interactions occurring at the electrode surface."	NOT REPORTED	"A sensitive, quick, specific, and simple immunosensor was successfully created, which potentially can be applied for the serological detection of leishmaniasis."	2019	(Cordeiro et al. 2019)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical Immunosensor(carbon immunosensor)	*Leishmania infantum*	Screen-printed carbon electrode,gold nanoparticles,Leishmania infantum antigens	NOT REPORTED	anti-Leishmania antibodies	"Leishmania infantum antigen was immobilized on the gold nanoparticle-modified surface, the antibodies were coupled (real sample/serum); and at the end, the electro-analytical solution was inserted and the process of transduction was initiated."	200 ng mL−1	"Without cross-reactivity with Chagas disease, a specific diagnosis of visceral leishmaniasis may be made".	2020	(Martins et al. 2020)
Enzyme-free dual electrochemical immunosensor	*Plasmodium falciparum*	Gold electrode,Ab-PFHRP-2,Dihexadecylphosphate (DHP)	10 mHz to 100 kHz	"Plasmodium falciparum histidine-rich protein 2"(Ag-PFHRP2)	EIS: 10 to 400 ng mL -1DPV:10 to500 ng ml -1/"The applied analytical method is based on a novel one-step enzyme-free dual electrochemical immunosensor performed by the simple Ab-PfHRP2 immobilization on a gold electrode surface using dihexadecyl phosphate polymer as an immobilization platform."	EIS:3.3 ngmL−1 and-DPV:2.8 ng mL−1	"The electrochemical immunosensor can be a beneficial and modest tool for biomedical sensing and therapeutic applications for in situ diagnosis of a malaria biomarker detection in human serum samples."	2021	(Gandarilla et al. 2021)
immunoassay	*Toxoplasma gondii*	dot blot immunoassay using colorimetric biosensor	NOT REPORTED	anti-Toxoplasma IgG and anti-Toxoplasma IgM antibodies.	Formation of a sandwich complex between a gold nanoprobe (chitosan gold nanoparticles-anti-human IgG or anti-IgM) and anti-Toxoplasma lysate antigen (TLA), containing anti-TLA antibodies, either IgG or IgM	0.5 mg/mL, 2 IU/mL, 10 IU/mL, and 20 µg/mL	A simple diagnostic technique that does not require expensive equipment for the detection of IgM and IgG antibodies against Toxoplasma gondii in pregnant women and immunocompromised patients	2021	(Safarpour et al. 2021b)
Gold-immobilized photonic crystal fiber-based SPR biosensor	*malaria*	Surface plasmon polarisation (SPP) mode coupled to the core in phase-matched conditions	NOT REPORTED	ring phase, trophozoite phase, and Schizont phase	In the proposed PCF, two layers of air holes and a thin layer of gold coating are formed on the PCF.	0.029 nm/RIU	SPR biosensor with (low detection limit and high sensitivity) is suitable for the early detection of malaria disease.	2021	(Chaudhary et al. 2021)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
one-dimensional photonic crystal	*malaria*	A simple one-dimensional photonic crystal with a defect layer is presented	NOT REPORTED	Diagnose malaria.	The defect layer is taken as a patient's blood sample, in which the concentration change causes a significant change compared to a normal blood sample.	495.73 nm/RIU, 2.03 × 105, 8.07 × 10−6 RIU, and 73.8 fs.	This change in refractive index can be used to diagnose malaria.	2021	(Ankita et al. 2021)
Immunoassay	*Toxoplasma gondii*	gold nanoparticles	NOT REPORTED	Toxoplasma gondii serotyping	Gold nanoparticles modified with a synthetic polymorphic peptide derived from the GRA6 antigen specific for Toxoplasma gondii type II.	NOT REPORTED	Biosensor-based immunoassay using gold nanoparticles (AuNPs) attached to polymorphic synthetic peptides can be used as a serotyping device.	2021	(Sousa et al. 2021)
Dimensional Distributed Bragg Reflector Biosensor	*malaria*	Bragg Reflector (DBR) with a central micro cavity to sense	NOT REPORTED	The detection of the P. falciparum parasite in its various stages in the analyte.	N=3 layers are selected for initial analysis, and finally, 8 layers are selected to increase the Q factor. The length of the central defect cavity is varied until a suitable defect length is selected, which improves the sensitivity of the sensor.	4500nm/RIU and 8333nm/RIU	The sensor could be used to detect malaria in its early stages.	2021	(Gowda et al. 2021)
Immunosensors	*malaria*	specific proteins	NOT REPORTED	PfHRP-2,pLDH, Aldose, Hemozoin	Specific proteins within the parasite	NOT REPORTED	Biosensors and immunosensors are the best diagnostic devices for specific proteins within the parasite, compared to other diagnostic tests such as RDTs.	2022	(Wambani et al. 2022)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical impedance biosensor	*Trypanosoma cruzi*	An electrochemical impedance biosensor for the detection of CD was developed for the first time using a cruzipain-based sensor surface.	NOT REPORTED	Chagas disease	The protein, highly immunogenic and isolated from Trypanosoma cruzi, was immobilized over the surface of gold disc electrodes modified with 11-mercaptoundecanoic (MUA) and 6-mercapto-1-hexanol (MCH) self-assembled monolayers (SAMs).	120 µg/mL	The amplimetric immunosensor detected specific interactions of anti-T. cruzi antibodies in human serum samples diluted to a concentration of 1/800. The charge transfer resistance of the biosensors increased by about 100% in the presence of positive samples, while negative samples produced a negligible increase of about 6%. The difference in signal for positive and negative clinical samples highlights the application of the sensors for point-of-care diagnosis of celiac disease.	2022	(Cisneros et al. 2022)
Photonic crystal-based biosensor	*malaria*	A biosensor based on a two-dimensional photonic crystal (2D PhC) waveguide including a ring resonator is designed and simulated based on refractive index changes of red blood cells.	NOT REPORTED	Stages of the Plasmodium falciparum cycle in red blood cells	Gold bars and the finite difference time domain (FDTD) method have been used to simulate and investigate this device.	0.514 and 1.55 µm	Highly sensitive differentiation between normal red blood cells and Plasmodium falciparum-infected cells	2022	(Rashidnia et al. 2022)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
plasmonic biosensor	*malaria*	photonic crystal fiber-based plasmonic biosensor	NOT REPORTED	three different stages (ring, trophozoite, and schizont phases) of malaria infection	A highly sensitive solid-core photonic crystal fiber sensor with gold nanowires is suggested for an analyte range of 1.36–1.40	438.41 and 522.25RIU-1	The arrangement of the holes and the use of gold nanowires enhance the performance of the biosensor and show increased sensitivity (for three phases). The performance of this sensor (high sensitivity and resolution along with appropriate figures of merit) is suitable for the early detection of malaria disease.	2022	(Meshgin-qalam et al. 2022)
photonic crystal fiber biosensor	*malaria*	A simple quasi-D-shaped photonic crystal fiber (PCF)-based surface plasmon	NOT REPORTED	ring, trophozoite, and schizont	The flat surface of the D-shaped PCF is covered with a thin layer of TiO2 along with a gold layer. The finite element method (FEM) is used to numerically investigate the characteristics of the sensor.	42857.14 nm/RIU, 22105.26 nm/RIU, and 16206.90 nm/RIU with resolutions of 2.33 × 10−06 RIU, 4.52 × 10−06 RIU, and 6.17 × 10−06 RIU	This type of sensor could be an excellent candidate for detecting Plasmodium falciparum phases in red blood cells for malaria diagnosis.	2023	(Nijhum et al. 2023)
colorimetric biosensor	*leishmania*	gold nanoparticle (AuNP)	NOT REPORTED	Leishmania major surface protease (Gp63) antibody (anti-gp63)	Kinetoplastid membrane protein-11 (KMP-11) was labeled with AuNPs directly. After that, Gp63 antibody was added to the KMP-11@AuNP solution, and a color change from red/pink to purple/violet was observed.	NOT REPORTED	The anti-gp63 solution diluted 1:640 was able to detect developed Leishmania with the colorimetric biosensor.	2024	(Can et al. 2024)
optical biosensor	*malaria*	A novel ohm-shaped index of refraction biosensor is presented for early diagnosis of malaria-infected red blood cells with beneficial sensitivity and accuracy	NOT REPORTED	The schizont step of malaria	Parametric variation to achieve the performance of vital sensor parameters	0.0007 RIU	Sensors lead to the detection of malaria-infected cells.	2024	(Kamani et al. 2024)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Bragg mirror optical sensor	*malaria*	This research focuses on the construction and analysis of a one-dimensional (1D) Bragg mirror (BM) with a micro-cavity at the centre to identify the Plasmodium falciparum parasite, which is the primary cause of malaria.	NOT REPORTED	using 1D photonic crystal-based biosensors	A multilayer BM structure was fabricated to detect P. falciparum parasite at all its life stages in the test sample. To increase the Q factor, the proposed structure starts with N=3 and ends with N = 6 layers. The length of the central cavity was varied to select the ideal defect length that improves the sensor sensitivity.	4010 nm/RIU with a Q factor of 1800nm/RIU	Proposed sensor for detecting early stages of malaria	2024	(Gowda et al. 2024)
Synthetic peptide-based SPR biosensor	*Visceral-leishmaniasis*	Synthetic peptide-based SPR	NOT REPORTED	Serological diagnosis of Canine Visceral Leishmaniasis (CVL)	Between the two peptides tested, PEP13 was more sensitive when assessing its responses against antibodies purified in buffer solution (LOD = 1.05 nmol L-1) and had a better response when used on diluted serum samples from infected dogs compared to diluted samples from healthy dogs.	1.05 nmol L-1	Suitability of synthetic peptides for use in biosensors	2024	(Volpe et al. 2024)
Electrochemical biosensor	*Trypanosoma cruzi*	Gold and platinum electrodes	10 to 100 kHz	Epimastigotes	electrochemical impedancespectroscopy	NOT REPORTED	"The results, represented in terms of charge transfer resistance across the interface, show that employing impedance technique to build a biosensor for Chagas disease serological diagnosis is feasible".	2003	(Diniz et al. 2003)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
IgM-functionalized piezoelectric-excited millimeter-sized cantilever biosensor	*Cryptosporidium parvum*	Immunoglobulin M (IgM),a thin layer of both lead PZT and glass, a few millimeters in length	NOT REPORTED	Oocyst	100, 1000, and 10,000 oocysts/ mL/"Biosensors were fabricated and functionalized with immunoglobulin M (IgM) for the detection of Cryptosporidium parvum oocyst in a flow configuration at 1 mL/min".	1-10 oocyst	"Because IgM-functionalized PEMC sensors are extremely selective and sensitive to C. parvum oocyst, they might be used to reliably identify and quantify C. parvum oocyst in drinking water".	2008	(Campbell et al. 2008)
Amperometric biosensors	*Trypanosoma cruzi*	Gold electrodes, clean electrodes, hiol-modified electrodes, TRX-pL-Q1 biosensors, TPH	NOT REPORTED	Epimastigotes	0.015 and 0.060 mg ml-1/ ELISA,	62 ng ml-1	"The novel biosensor may be exposed to harsh chemical treatment to remove the analyte. Amperometric biosensors with a new interface that demonstrated to successfully exposed the bioreactive molecule have been constructed.	2011	(Belluzo et al. 2011)
Electrical impedance sensor	*Cryptosporidium parvum*	IMA (Interdigitated Microelectrode Arrays)	100 Hz to 1 MHz	Zoite and meront	"1 sporozoite per cell/ An electrical impedance-based device can get insights on Cryptosporidium development in a cell culture and quantify sample infectivity".	NOT REPORTED	"This biosensor can be utilized as a protozoan infectivity sensor that is faster than currently available methods".	2015	(Dibao-Dina et al. 2015)
Label-free interdigitated-based capacitivebiosensor	*Cryptosporidium parvum*	FITC-labeled anti-Cryptosporidium parvum oocyst antibody (Crypt-a-Glo), capacitive Immunosensor	5.5 to 8.5 GHz	Oocyst	"15 and 153 cells/mm2 in environmental water samples/ fluorescein isothiocyanate (FITC) immunofluorescence assay"	40 cells/mm2	"The proposed label-free capacitive biosensor offers a lot of potential for detecting Cryptosporidium in water samples".	2019	(Luka et al. 2019)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Optical biosensor	Trypanosomaevansi and Plasmodium berghei	NOT REPORTED	NOT REPORTED	Trophozoites and trypomastigotes	"Typical spectral intensity for the lamp, Photomicrographs of Giemsa stain blood film"	NOT REPORTED	"Corresponding stained slides of control and infected blood at each sampling date were taken, with related infected cell counts determined, and these correlate well for Plasmodium absorbance at 650 nm."	2019	(Theint et al. 2019)
Amperometric sensor	*Leishmania. infantum*	Gold nanoparticles(AuNPs)	NOT REPORTED	surface protease GP63	2 × 10 -2 and 2 × 106Parasites/mL/A rapid quantification assay to detect Leishmania parasites based on the combination of the electrocatalytic ability of gold nanoparticles (AuNPs) to act as a catalyst for the hydrogen formation reaction, along with the specificity of the interaction between casein and the major surface protease of the Leishmania parasite, GP63.	0.55 parasite/mL	"The technique has the potential to be useful in human and veterinary care, especially in low-resource situations".	2019	(Diouani et al. 2019)
Micro-cantilevered MEMS (micro-electro-mechanical systems) Biosensor	Plasmodium spp.	Au, Cu, Si, and Pt	NOT REPORTED	Protozoan biomolecules	"This biosensor model using microelectro-mechanical systems (MEMS) technology is presented. The studies were carried out for stress developed and displacement occurred due to the force applied through these protozoan biomolecules and varying beam length."	NOT REPORTED	"The given concept uses an array of cantilevers to detect protozoan parasites more accurately, simply, and efficiently, which is impossible to do with currently existing biosensors".	2019	(Rahul et al. 2019)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Functional sensor surfaces or surface plasmon resonance (SPR) biosensor	*Trypanosoma cruzi*	Farnesyl pyrophosphatesynthase (tcFPPS)	NOT REPORTED	Farnesyl pyrophosphate synthase from Trypanosoma cruzi	"SPR-biosensor assay, fragment screening"	NOT REPORTED	"This is the first research on FPPS as an FBLD target, and it has shown that it can be utilized for fragment library screening and hit validation with an unusual referencing method, which is useful when reference compounds are unavailable".	2020	(Opassi et al. 2020)
Inductive-Based Sensitive and Reusable Sensor	Plasmodium falciparum	PCB substrate(printed circuit board)	2.4 - 4 – 5 (GHz)	Hemozoin	12.7- 100- 650 (pg) / Hemozoin has been used as a biomarker for the detection of malaria. "An inductive sensing technique has been employed to detect the presence of hemozoin in PBS droplets, which mimics the blood".	No of parasites detected:At least 25 parasites.(25-50)	"The suggested sensor is a step toward quick, sensitive, low-cost, reusable, portable, and quantitative malaria detection in economically disadvantaged malaria-prone areas".	2020	(Hole et al. 2020)
Inductive-Based Sensitive and Reusable Sensor	Plasmodium vivax	PCB substrate(printed circuit board)	2.4 - 4 – 5 (GHz)	Hemozoin	12.7- 100- 650 (pg)/ Hemozoin has been used as a biomarker for the detection of malaria. An inductive sensing technique has been employed to detect the presence of hemozoin in a PBS droplet, which mimics the blood.	No of parasites detected:At least 25 parasites.(25-50)	The suggested sensor is a step toward quick, sensitive, low-cost, reusable, portable, and quantitative malaria detection in economically disadvantaged malaria-prone areas.	2020	(Hole et al. 2020)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Inductive-Based Sensitive and Reusable Sensor	Plasmodium ovale	PCB substrate(printed circuit board)	2.4 - 4 – 5 (GHz)	Hemozoin	12.7- 100- 650 (pg)/ Hemozoin has been used as a biomarker for the detection of malaria. An inductive sensing technique has been employed to detect the presence of hemozoin in PBS droplets, which mimics the blood.	No of parasites detected:At least 25 parasites.(25-50)	The suggested sensor is a step toward quick, sensitive, low-cost, reusable, portable, and quantitative malaria detection in economically disadvantaged malaria-prone areas.	2020	(Hole et al. 2020)
Inductive-Based Sensitive and Reusable Sensor	Plasmodium malariae	PCB substrate(printed circuit board)	2.4 - 4 – 5 (GHz)	Hemozoin	12.7- 100- 650 (pg)/ Hemozoin has been used as a biomarker for the detection of malaria. An inductive sensing technique has been employed to detect the presence of hemozoin in a PBS droplet, which mimics the blood.	No of parasites detected:At least 25 parasites(25-50)	The suggested sensor is a step toward quick, sensitive, low-cost, reusable, portable, and quantitative malaria detection in economically disadvantaged malaria-prone areas.	2020	(Hole et al. 2020)
Magneto resistance Sensor	Plasmodium spp.	Finite-element (FEM)CMOS analog front-end (AFE)	1-108 Hz	Paramagnetic hemozoin particles	100-108(N)/"This paper presents proof of principle of a miniature low noise, low power, and highly sensitive malaria detection method based on the magneto resistance (MR) sensor with a CMOS analog front-end(AFE) readout circuit for the detection of paramagnetic hemozoin particles".	150 pT/√Hz.	"This method responds quickly to samples containing hemozoin particles and can identify malaria parasites".	2021	(Li et al. 2021)
Smart SPR (surface plasmon resonance) Sensor	Leishmania spp.	PPBIO solution(Polymeric Prism for BIO logical applications)	NOT REPORTED	NOT REPORTED	"Surface plasmon resonance (SPR) based sensors allow evaluating liquid and gas solutions fromreal-time measurements of molecular interactions"	NOT REPORTED	"Surface plasmon resonance (SPR) sensors enable real-time molecular interaction data to be used to analyze liquid and gas solutions".	2021	(Gomes et al. 2021)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical aptamer-based biosensors	*Leishmania infantum*	Colloidal gold	NOT REPORTED	L. infantum Kinetoplastid membrane protein 11(KMP 11)	10 and 50 µg /well /"A novel SELEX methodology using colloidal gold to select high-affinity single-stranded DNA aptamers against Leishmania infantum KMP-11".	NOT REPORTED	"The SELEX method has been used to find RNA or ssDNA aptamers that can identify a variety of proteins from various origins and have a variety of structural and functional characteristics".	2003	(Moreno et al. 2003)
Digoxigenin-labeled SELH3 aptamer(ssDNA Aptamer)	*Leishmania infantum*	Anti-digoxigenin-POD antibody	NOT REPORTED	L. infantum H3 antigen	0–1.25mg/mL/We have successfully isolated a pool of DNA aptamers, named SELH3, which bind to Leishmania infantum H3 with high affinity and specificity.	50 ng	This new anti-H3 aptamer population has the potential as a leishmaniasis diagnostic method.	2010	(Ramos et al. 2010)
Aptamer-based Electrochemical impedance spectroscopy sensor	*Plasmodium vivax*	Magnetic beads	10KHz-100MHz	PvLDH	1, 10, 100, 277, and 2906parasites/L/"We identified versatile single-strand DNA aptamers for Plasmodium lactate dehydrogenase (pLDH), a biomarker for malaria, via the Systematic Evolution of Ligands by EXponential Endichment (SELEX)".	108.5 fM	"The pLDH aptasensor was able to identify malaria-positive blood samples from two main species (Plasmodium vivax and Plasmodium falciparum), and it might be beneficial for malaria diagnosis and monitoring".	2012	(Lee et al. 2012)
Aptamer-based Electrochemical impedance spectroscopy sensor	*Plasmodium falciparum*	magnetic beads	10KHz-100MHz	PfLDH	1, 10, 100, 200, and 2000 parasites/L /"We identified versatile single-strand DNA aptamers for Plasmodium lactate dehydrogenase (pLDH), a biomarker for malaria, via the Systematic Evolution of Ligands by EXponential endichment (SELEX)"	120.1 fM	"The pLDH aptasensor was able to identify malaria-positive blood samples from two main species (Plasmodium vivax and Plasmodium falciparum), and it might be beneficial for malaria diagnosis and monitoring".	2012	(Lee et al. 2012)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Carbon nanotube aptasensor	*Trypanosoma brucei*	glassycarbon cylindrical rod	NOT REPORTED	VSG proteins	Between 10-16 and 10-12/"The variable surface glycoprotein from African Trypanosomes was chosen as an ideal model system for a pathogenic exoantigen protein in a clinical sample".	NOT REPORTED	"This research might lead to real-time diagnostic tests for a variety of illnesses, as well as fast molecular detection of many proteins in completely configurable protein biosensing systems".	2013	(Zelada-Guillén et al. 2013)
Aptamer-Based Concentration Method	*Trypanosoma cruzi*	Paramagnetic beads bound to the surface of the trypomastigote	NOT REPORTED	Live parasites in blood	2×107 trypomastigote /"A whole-cell SELEX strategy was utilized to develop serum-stable RNA aptamers that bind to live T. cruzi trypomastigotes. These aptamers bound to the parasite with high affinities (8–25 nM range)".	NOT REPORTED	"Aptamers can be utilized as pathogen-specific ligands to trap T. cruzi in blood and make PCR-based detection easier".	2012	(Nagarkatti et al. 2012)
Colorimetric aptasensor(GNPs based DIRK aptasensor)	*Plasmodium falciparum*	Polydiallyldimethyl ammonium chloride(PDDA) Polyallylamine hydrochloride (PAH)aggregate gold nanoparticles (AuNPs)	NOT REPORTED	PfLDH	"The proposed method is based on the interaction among the pLDH, which is a biomarker for malaria, and pL1 aptamer against Plasmodium falciparum lactate dehydrogenase "(PfLDH)	P. falciparum: 92 parasites/ µLPfLDH:10.3pM, for PDDA and 97 parasites/µL, PfLDH:12.5pM for PAH	"PLDH proteins were effectively identified with a low detection limit using this aptasensor. The specificity test revealed that the aptasensor is extremely particular in its targeting of proteins, even when additional interfering proteins are present".	2013	(Jeon et al. 2013)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Colorimetric aptasensor(GNPs based DIRK aptasensor)	*Plasmodium vivax*	Poly (diallyldimethyl ammonium chloride)(PDDA) Poly (allylamine hydrochloride) (PAH)aggregate gold nanoparticles (AuNPs)	NOT REPORTED	PvLDH	"The proposed method is based on the interaction among the Plasmodium lactate dehydrogenase (pLDH), which is a biomarker for malaria, and pL1 aptamer against Plasmodium vivax lactate dehydrogenase" (PvLDH)	"P.vivax: 80 parasites/µl PvLDH:8.7pM for PDDA and 74 parasites/µl PvLDH:8.3pM for PAH".	"PLDH proteins were effectively identified with a low detection limit using this aptasensor. The specificity test revealed that the aptasensor is extremely particular in its targeting of proteins, even when additional interfering proteins are present".	2013	(Jeon et al. 2013)
Aptamer-Based Detection	*Trypanosoma cruzi*	RNA ligand	NOT REPORTED	TESA	50 ml/well/"A selection-based method to isolate ligands that bind to these secreted proteins. These ligands, called aptamers, have been used to develop an assay that can detect the circulating parasite targets in the plasma or serum of an infected host".	NOT REPORTED	"Aptamer L44 may therefore be utilized in a qualitative ELA test to identify Chagas disease biomarkers".	2014	(Nagarkatti et al. 2014)
DNA Aptamers	*Cryptosporidium parvum*	Thiolated ssDNA primer and the anti- C. parvum aptamer	NOT REPORTED	Oocyst	DNA aptamers were selected against C. parvum oocysts using SELEX (Systematic Evolution of Ligands by EXponential enrichment).For detecting parasite-bound aptamers, a simple electrochemical sensor was employed, which used a gold nanoparticle-modified screen-printed carbon electrode.	100 oocysts	In comparison to established approaches such as microscopy and PCR, the created aptasensor has high sensitivity and specificity, indicating that this innovative technology is extremely promising for detecting and identifying C. parvum oocysts on spiked fresh fruits".	2015	(Iqbal et al. 2015)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
ssDNA Aptamers	*Leishmania infantum*	Gold nanoparticles,Gold screen-printed electrodes	NOT REPORTED	Recombinant 6xHIS–LiPABP protein (rLiPABP) Promastigote	2.5 µg/Ml/ "Aptamers are oligonucleotide ligands that are selected in vitro by their affinity and specificity for the target as a consequence of the particular tertiary structure that they can acquire depending on their sequence".	2500 parasites	"Aptamers have high specificity and affinity for the target, and they can detect a large quantity of endogenous LiPABP protein equivalent to 2500 L. infantum promastigotes".	2015	(Guerra-Pérez et al. 2015)
Electrochemical impedance spectroscopy (EIS) sensor	*Plasmodium falciparum*	ssDNA aptamer	NOT REPORTED	PfLDH	0.474mM/ " A sensitive, magnetic bead-based colorimetric assay for Plasmodium falciparum lactate dehydrogenase (PfLDH) in which the biomarker is extracted from parasitized whole blood and purified based on antigen-binding to antibody-functionalized magnetic particles. Antigen-bound particles are washed, and PfLDH activity is measured on-bead using an optimized colorimetric enzyme reaction.	LOD= 21.1±0.4 parasites/ml	"By replacing the capture antibody on the magnetic particles with a pan-specific Plasmodium LDH antibody, this technique may be broadened to detect all types of malaria".	2016	(Markwalter et al. 2016)
Genosensor/Optical	*Leishmania spp.*	Cadmium selenite quantum dots probes,magnetic beads	NOT REPORTED	genomic DNA,LPG and gp36 antigens	25 ng/µl/"A combination of magnetic bead and cadmium selenite quantum dot probes was applied for the detection of Leishmania specific surface antigens (proteins) and DNA".	3,125 ng/µl and 103 cells/ml	"The technique has a lot of potential for clinical use in human and veterinary medicine, especially in resource-constrained environments".	2016	(Andreadou et al. 2016)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Aptamer Tethered Enzyme Capture (APTEC) Biosensor	*Plasmodium falciparum*	Magnetic microbeads,microfluidic chambers,stop valves, mobile system	NOT REPORTED	Plasmodium falciparum lactate dehydrogenase (PfLDH)	(100 ng/mL)"A new concept for a malaria biosensor whereby aptamers are coated onto magnetic microbeads for magnet-guided capture, wash, and detection of the biomarker".	NOT REPORTED	"In endmic areas, a portable, equipment-free point-of-care aptamer-mediated biosensor might have a big impact on malaria detection".	2018	(Fraser et al. 2018)
Aptamer-Based Electrochemical Biosensor	*Plasmodium falciparum*	Ferri/ferro-cyanide as redox probe	10 kHz to 100 mHz	Plasmodium falciparum lactate dehydrogenase	0.1 pM to 10 nM/"A novel aptamer-based electrochemical biosensor (aptasensor) for malaria detection by impedance spectroscopy, through the specific recognition between a highly discriminatory DNA aptamer and its target Plasmodium falciparum lactate dehydrogenase.	Low detection limit:0.84 pM	"This aptasensor's design, along with its high sensitivity, can help identify malaria at various phases of infection with Plasmodium falciparum parasites or track medication therapy over time for probable drug resistance".	2018	(Figueroa-Miranda et al. 2018)
Aptamer	*Plasmodium falciparum*	rPfLDH-specific antibody fluorescence	NOT REPORTED	PfLDH	"Binding properties of selected aptamers to rPfLDH were investigated using ELONA, while in situ binding in P. falciparum parasites was demonstrated using fluorescently labeled aptamers and confocal microscopy".	NOT REPORTED	"For the first time, aptamers were selected against a conserved peptide epitope on P. falciparum lactate dehydrogenase, and they have selectivity for both the recombinant and native proteins".	2018	(Frith et al. 2018)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Aptasensor	*Plasmodium falciparum*	ThiolatedssDNA aptamer (NG3)	1 MHz - 100 MHzoptimized frequency:2 Hz	*P. falciparumglutamate dehydrogenase (PfGDH)*	100 fM - 100 nM/"A capacitive aptasensor for detecting the malaria biomarker, Plasmodium falciparum glutamate dehydrogenase (PfGDH), has been developed directly in human serum samples. A thiolated ssDNA aptamer (NG3) that binds specifically to PfGDH antigen with high affinity (Kd = 79 nM) was used to develop the aptasensor.	0.77 pM	"This PfGDH aptasensor has a lot of promise for detecting asymptotic malaria and monitoring malaria regression during antimalarial drug therapy because of its very sensitive and label-free detection capabilities".	2018	(Singh et al. 2018)
Aptamer-based BioFET sensor	*Plasmodium falciparum*	Extended gate field effect transistor (EGFET) with interdigitated gold microelectrodes (IDμE)	100 kHz to 100 MHz	Plasmodium falciparum glutamate dehydrogenase (PfGDH)	"A portable FET-based biosensor (BioFET) developed by using an extend gate field effect transistor with interdigitated gold microelectrodes and pseudo reference electrode for the detection of malaria biomarker Plasmodium falciparum glutamate dehydrogenase in serum samples".	16.7 pM	"The findings confirmed that the developed BioFET may be used to diagnose both asymptomatic and symptomatic malaria".	2019	(Singh et al. 2019)
Photonic biosensor	*Malaria*	photonic crystal sensor	NOT REPORTED	malaria in humans, and it is label label-free detection method.	The proposed photonic crystal sensor has a 10 μm × 10 μm dimension. The extracted sample is placed in the sensor holes, and a light beam with a wavelength of 1.85–1.95 μm is fed inside the biosensor.	225 nm/RIU	Photonic crystal sensors change wavelengths and detect malaria parasites.	2021	(Kumar et al. 2021)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
An electrochemical aptamer-based biosensor	*malaria*	The aptamer is modified with a methylene blue reporter and attached to a gold sensor surface for square-wave voltammetry interrogation.	NOT REPORTED	*P. falciparum histidine-rich protein II (PfHRP2)*	DNA aptamers that specifically bind to P. falciparum histidine-rich protein II (PfHRP2).	3.73 nM	Quantification of PfHRP2 in human serum with a LOD of 3.73 nM	2021	(Lo et al. 2021)
Aptamer-Based Electrochemical Microfluidic Biosensor	*Cryptosporidium parvum*	Herein, we propose a novel electrochemical microfluidic aptasensor based on hierarchical 3D gold nano-/microislands (NMIs), functionalized with aptamers specific to C. parvum.	NOT REPORTED	*C. parvum oocysts*	The 3D gold NMIs feature a large active surface area that provides high sensitivity and a low limit of detection (LOD), especially when they are combined with aptamers.	LOD of 5 oocysts mL–1 in buffer medium, as well as 10 oocysts mL–1 in stool and tap water media, over a wide linear range of 10–100,000 oocysts mL–1.	The NMI aptasensor was capable of detecting different concentrations of C. parvum oocysts present in different sample matrices, namely buffer, tap water, and feces.	2023	(Siavash Moakhar et al. 2023)
ssDNA aptameric electrochemical	*Giardia*	A thiolated aptamer was covalently immobilized onto a gold screen-printed electrode (SPGE), and the binding of the targeted protein was monitored using square wave voltammetry (SWV).	NOT REPORTED	G. intestinalis infection.	Two aptamers were selected, and the dissociation constants (Kd) were determined as 2.45 and 16.95 nM, which showed their high affinity for the G. intestinalis trophozoite protein.	The range of 0.1 pg/mL to 100 ng/mL	The developed aptasensor showed accurate detection of G. intestinalis recombinant protein with negligible cross-reactivity to other proteins such as bovine serum albumin, globulin, and G. intestinalis cyst protein.	2024	(Alhindawi et al. 2024)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
aptasensor	*Leishmania*	Green-synthesized chitosan-carbon dot nanocomposite	NOT REPORTED	detection and quantification Leishmania infantum parasite	Here, we have developed an ultra-selective turn-on fluorescent probe based on an aptamer and Chitosan-CD nanocomposite. The CDs used in this study were synthesized using Quercus cap extract and a microwave-assisted approach. The Chitosan-CD nanocomposite was optimized using several microscopic and spectroscopic techniques to possess a bright fluorescence emission before adding the aptamer, and a quenched fluorescence after the addition of the aptamer.	94 cells/mL	The use of chitosan-CD nanocomposite is an excellent strategy for developing selective probes for the detection of Leishmania infantum parasite in the early stages of the disease.	2024	(Rahmatian et al. 2024)
Plasmon resonance microstructure optical fiber	*Malaria*	The sensor uses a curved surface structure to bring the excitation layer close to the fiber core to achieve strong coupling.	NOT REPORTED	malaria parasitic cells.	The sensor uses a curved surface structure to bring the excitation layer close to the fiber core to achieve strong coupling.	142.857 μm/RIU, 123.684 μm/RIU and 120.687 μm/RIU	The malaria-infected cell sensor shows wavelength sensitivity values at the ring, trophozoite, and schizont stages, showing excellent sensitivity compared to previous malaria fiber sensors.	2025	(Wang et al. 2025)
photonic crystal fiber	*malaria*	a dual-core photonic crystal fiber (DC-PCF)	NOT REPORTED	Ring stage, Trophozoite stage, and Schizont stage	The proposed DC-PCF comprises four layers of a hexagonal lattice with circular air holes. In the proposed DC-PCF, we have used a central elliptical hole to infiltrate RBC samples.	10,50,000 nm/RIU for the ring stage, 10,54,736.84 nm/RIU for the trophozoite stage, and 10,32,758.62 nm/RIU for the schizont stage.	DC-PCF-based biosensors have low detection limits and superior sensing performance, making them very suitable for biological analysis and early detection of malaria.	2025	(Chaudhary et al. 2025)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
ssDNA aptamers	*Giardia*	SELEX process (systematic evolution of ligands by exponential enrichment)	NOT REPORTED	G. intestinalis cyst protein	The process is based on incubating a random DNA library with the targeted protein, and the bound sequences are recovered and amplified by polymerase chain reaction (PCR).	0.1 pg mL−1 to 1000 ng mL−1	The aptasensor showed good recovery rates with tap water samples contaminated with G. intestinalis.	2025	(Alhindawi et al. 2025)
Genosensors (the recognition element is DNA sequences)									
MagneticFluorescent Nanoparticles Biosensor	*Toxoplasma gondii*	Magnetic-fluorescent CdTe/Fe3O4 core-shell quantum dots (mQDs) and commercial quencher (BHQ-2)	NOT REPORTED	Toxoplasma gondii DNA	"The synthesized CdTe/Fe3O4 mQDs were nearly monodisperse and uniform with a diameter of ca 20 nm/ fluorescence energy transfer (FRET),and a magnetic-fluorescent CdTe/Fe3O4 core-shell quantum dots (mQDs) and a commercial quencher" (BHQ-2)	NOT REPORTED	"Compared to standard methods such as centrifugation, filtering, electrophoresis, and so on, an intriguing finding was discovered: the mMBP can be more easily separated from the unhybridized stem-loop DNA and target DNA using a simple magnet in about 10 minutes".	2009	(Liang et al. 2009)
DNA biosensor	*Leishmania donovani*	(Sol–gel synthesized nickel oxide (NiO) film deposited onto indium tin oxide (ITO) coated glass plate)	NOT REPORTED	Genomic DNA	"Leishmania-specific sensor is developed by immobilizing a 23mer DNA sequence (oligonucleotide) identified from 18S rRNA gene sequences from Leishmania donovani".	Detection level: 2 fg µl-1Detection range:2 pg/ml to 2 mg/µl	"This test might be a potential new technique for detecting Kala-azar and other leishmanial illnesses at the molecular level".	2011	(Mohan et al. 2011)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
DNA biosensor	*Plasmodium falciparum*	Quartz crystal microbalance (QCM)The 12 MHz AT-cut quartz crystals with 4 mm gold electrode	12 MHz	Merozoite surface protein 2(msp2)	0–250 ng/mL/"A label-free DNA biosensor based on quartz crystal microbalance (QCM) to diagnose and genotype P. falciparum was developed".	Detection sensitivity:≤0.025 ng/ml25 parasites in 10 mL of DNA solution	"This biosensor was sub-nanogram sensitive, selective for P. falciparum detection with no cross-reaction with P. vivax, and stable for up to 6 months at room temperature".	2011	(Potipitak et al. 2011)
Nanosensors	*Trypanosoma cruzi*	239–341 kHz	Epimastigotes DNA	Epimastigotes DNA	20–80 N m-1/ "chronoamperometry, Construction of Gold Electrodes (CDtrodes), Amperometric Monitoring of Enzymatic Reaction"	0.949 µA	"This approach was shown to be faster and less expensive than using a screen-printed electrode (SPE) modified with cysteamine and glutaraldehyde to produce the identical immunosensor".	2011	(Vinicius Foguel et al. 2011)
DNA biosensor	*Plasmodium falciparum*	Quartz crystal microbalance	133.69±3.72 Hz	Genomic DNA	10 µl of 50 µg/ml /"This study applied the biosensor technology based on quartz crystal microbalance (QCM) to differentially diagnose the most common and severe malaria, Plasmodium falciparum and Plasmodium vivax".	NOT REPORTED	"The malaria QCM was created with sensitivity, stability, specificity, and cost-effectiveness. It can be used in the field in malaria-endmic areas and might be a viable point-of-care test".	2013	(Ittarat et al. 2013)
DNA biosensor	*Plasmodium vivax*	Quartz crystal microbalance	(249.55±7.98 Hz).	Genomic DNA	10µl of 50 µg/ml/"This study applied the biosensor technology based on quartz crystal microbalance (QCM) to differentially diagnose the most common and severe malaria, Plasmodium falciparum and Plasmodium vivax".	NOT REPORTED	"The malaria QCM was created with sensitivity, stability, specificity, and cost-effectiveness. It can be used in the field in malaria-endemic areas and might be a viable point-of-care test".	2013	(Ittarat et al. 2013)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Genosensor/Optical	*Leishmania spp*	Functionalized gold nanoparticles(AuNPs)	NOT REPORTED	Kinetoplast DNA	3500 parasitic cells/ µl"The design and construction of functionalized gold nanoparticles (AuNPs) that would be incorporated into an easily applicable DNA detection methodology for the identification of Leishmania spp. in clinical samples".	11.5 ng/µL	"An attractive diagnostic approach, particularly for screening in enzootic settings where detection of very tiny quantities of the targeted analyte is not a major priority".	2014	(Andreadou et al. 2014)
MagneticFluorescent Nanoparticles Biosensor	*Toxoplasma gondii*	Fe3O4 magnetic particles and CdTe quantum dots	NOT REPORTED	Toxoplasma gondii DNA	MPA CdTe QDs, of which the average size was 2.5 nm and the concentration was 1.724×10 supported by UV-Vis's absorption, fluorescence spectroscopy and TEM images, bound with Fe3O4-KH550, which can be judged from IR spectrum, XRD pattern, and TEM image/ fluorescence spectrum (FS), PCR, coprecipitation method and 3-mercaptopropionic (MPA)	8.339 nM	"Based on the FRET process, a novel technique for the identification of particular DNA sequences linked to Toxoplasma gondii has been developed using the quenching of fluorescence of Fe3O4/CdTe".	2015	(He et al. 2015)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Platform nanostructured bio-detection (electro-chemical biosensor)	*Leishmania infantum*	Polyaniline-gold nanopar-ticles hybrid composite (PANIAuNp).	100 MHz to100 kHz	*Leishmania infantumgenome*	0.01 pg mL-1, 0.1 pg mL-1, 0.01 ng mL-1, 0.1 ng mL-1, 1 ng mL-1 and 10 ng mL-1/"Electrochemical measurements were performed on an Auto lab PGSTAT128N Potentiostat/galvanostat in a conventional three-electrode cell, working electrode modified with gold and polyaniline nanoparticles, gold electrode as counter electrode, and Ag / AgCl (saturated KCl) electrode used through-out the work".	Lower detection limit:0.01 pg/mL	"Due to the prospect of a rapid, sensitive, and low-cost analysis, the development of electrochemi-cal biosensors for the detection and identification of Leishmania infan-tum is critical".	2015	(Garcia et al. 2015)
Impedimetric sensor	*Leishmania infantum*	Gold nanoparticles (PANIAuNP)dispersed in a polyaniline matrix	100 mHz–100 kHz	Genomic DNA	0.0001, 0.001, 0.01, 0.1 ,1.0, 10.0 (ngmL−1)"The senso-rial system is based on the immobilization of a DNA probe onto a gold electrode surface previ-ously covered with a simple and effective layer of a SH-terminal group on polyaniline matrix containing gold nanoparticles" (PANIAuNp).	0.01 pg/ mL	"Biosensors have been shown to be a strategic option with a wide range of applications in the development of novel nucleotide sequence analysis techniques".	2016	(Garcia et al. 2016)
Lateral flow biosensor	*Leishmania spp*	Gold nanoparticle	NOT REPORTED	Promastigote (kineto-plast gene)	(5-200 ng/mL of DNA) Lateral flow biosensors (LFBs) are diagnos-tic devices based on single-use paper carrier material, where dry reagents are activated by applying a fluid sample.	100 fmol of target DNA3 parasites/ µL of sample	"LFBs are useful for diagnostic applications since they are fast, inexpensive, sensitive, specific, user-friendly, and require no special equipment".	2016	(Toubanaki et al. 2016)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
DNA biosensing	*Leishmania infantum.*	Gold nanoparticle (AuNP) Magnetic beads (MBs)	NOT REPORTED	Leishmania kinetoplast minicircle DNA	105 to 102 promastigotes mL –1/500 to 0.5 parasites per mL of blood (from 5 to 5 × 10 −3 parasites per isothermal amplification reaction in a tenfold dilution) "A novel methodology for the isothermal amplification of Leishmania DNA using labeled primers combined with the advantages of magnetic purification/ preconcentration and the use of gold nanoparticle (AuNP) tags for the sensitive electrochemical detection of such amplified DNA is developed".	0.8 parasites per mL of blood(8 × 10 −3 parasites per DNA amplification reaction)	"This technology is significantly more sensitive than standard real-time polymerase chain reaction (PCR) methods, as well as being faster, cheaper, and easier to use".	2016	(de la Escosura-Muñiz 2016)
Electrochemical genosensor	*Leishmania major*	Magnetic cobalt-zinc ferrite quantum dot (Co 0.5 Zn 0.5 Fe2o4)	NOT REPORTED	KinetoplastDNA	1×10 7 ml-1 parasite/ Parasite DNA concentration: 7.31×10-14 to 7.31×10-6 ng/µl"Quantum dots of magnetic cobalt-zinc ferrite (Co0.5Zn0.5Fe2O4) were synthesized and characterized by physicochemical methods".	Genomic DNA: 1.80× 10 14 ng/ µlSingle strand DNA: 2.0×10-19 mol/L	"The results showed that our label-free, PCR-free, signal-on genosensor can identify Leishmania major without amplification in patient samples".	2016	(Heli et al. 2016)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical Genosensing	*Leishmania major*	Gold hierarchical nanoleaflets	NOT REPORTED	Oligonucleotide, tDNA(promastigote)	1×10 7 mL-1 parasite, DNA concentration: 5 ng µL-1 /"Gold hierarchical nanoleaflets were synthesized by electrodeposition in the presence of spermidine in the deposition solution. A Leishmania major-specific single-stranded DNA probe was immobilized on the surface of nanoleaflets, and ferrocyanide was employed as a hybridization marker."	Synthetic DNA target:2.98×10 -21 mol / Lgenomic DNA:0.11 ng/µL	"Electrochemical biosensors have the potential to provide sequence-specific information in a faster, simpler, and less expensive way than conventional assays".	2016	(Moradi et al. 2016)
DNA biosensor	*Leishmania major*	Gold nanoparticles(AuNPs)	NOT REPORTED	Minicircle kinetoplast DNA(kDNA genome)	6.2, 10.4, 11.4, 13.2, 15.6, 18.2 ,20.7 ng/"An AuNPs-probe based on a sequence from non-protein coding region (AB678349.1) of Leishmania major minicircle kDNA was employed as a DNA biosensor for visual and spectrophotometrically detection of Leishmania major".	7.0 pg µL-1	"This technique offers a good specificity and sensitivity for detecting Leishmania major in clinical samples, according to the findings. For epidemiological, taxonomic, and clinical applications, the current test provides a quick, reliable, and cost-effective technique".	2016	(Sattarahmady et al. 2016)
Electrochemical DNA biosensor	*Leishmania major*	Gold nanoleaves,polyamine spermidine	NOT REPORTED	DNA	1×10 7 ml-1 parasite/"A simple green electrode position method was developed for the synthesis of gold nanoleaves at a surface using the biogenic polyamine spermidine.	Synthetic DNA (1.8× 10 -20 mol /L), genomic DNA (0.07 ng µL1)	"Nanomaterial-based sensors and biosensors are gaining popularity due to their benefits such as low cost, simple design, tiny size, and low power consumption".	2016	(Moradi et al. 2016)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Genetically encoded biosensor	*Plasmodium falciparum*	Cyan and yellow fluorescent proteins (ECFP and EYFP),PFLDH	0-1	Labile heme	"A protein-based sensor that undergoes fluorescence quenching upon heme bianing. By genetically encoding this sensor in the human malarial parasite, P. falciparum, we have quantified cytosolic labile heme levels in intact, blood-stage parasites".	NOT REPORTED	"P. falciparum may be used to get quantitative insights into fundamental heme biology by using diverse environmental perturbations".	2017	(Abshire et al. 2017)
Label-FreeImpedimetric Genosensor (Electrical Impedance Spectroscopy)	Leishmania spp.	Thiolated Carbon Nanotubes	(1×10 6–0.1) Hz	DNA	10 ng/µL/"Development of a thiolated carbon nanotube (ThNT) transducer for femtomolar detection of Leishmania spp".	LOD:0.1 fg/µL (15 fM)	"The use of these genosensors might be a straightforward and accurate way to diagnose canine leishmaniasis quickly at the molecular level".	2017	(Frias et al. 2017)
Electrochemical genosensor biosensor	*Trichomonas vaginalis*	Anisotropic-shaped gold nanostructure (Au/AAuN),	NOT REPORTED	DNA of the Trophozoite	1.0×10-19 to 1.0×10-12 mol L-1/PCR, Cell culture and genomic DNA extraction	3.1×10-20 mol L-1	"Genosensor can be used to detect Trichomonas vaginalis without the need for PCR amplification".	2018	(Delshadi-Jahromi et al. 2018)
Genosensor/ Electrochemical	*Leishmania. infantum*	Non-spherical gold nanoparticles(AuNPs)	NOT REPORTED	KDNA genome	DNA sequence: 1×10 -7 parasite ml-1Genome: 10 to 50 ng/µl/"DNA sensor was designed and developed based on the hybridization of a single-stranded DNA of L. Infantum immobilized on the gold nanostructures and toluidine blue as a redox indicator".	Target sequence:0.2 amol/LGenome:29 ng/µl	"The DNA sensor created in this work has greater sensitivity, enhanced selectivity, a quicker analysis time, and is easier to fabricate and apply".	2018	(Nazari-Vanani et al. 2018)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Electrochemical DNA biosensor	*Cryptosporidium spp*	3D µTAS	10-1 to 105 Hz	Oocyst	2.5 ng/mL to 0.1 µg/mL of DNA/3D micro total analysis systems (3D µTAS)	1.8 ng/mL	"The specificity of the produced DNA sensor was tested using non-complementary, single, three, and five mismatched strands, and the biosensor's ability to detect single mismatches was evaluated experimentally".	2019	(Ilkhani et al. 2019)
Genosensor	Leishmania spp	Citrate-capped Ag nanoparticles(Git-AgNPs)	NOT REPORTED	Leishmania single-stranded DNA	The concentration of cDNA (10 -6 M, 10-9 M, 10-12 M, 10 -17 M, 10-21 M)/"Biosensing Leishmania spp using novel optical probe (citrate capped silver nanoparticles) was conducted. Based on the optical properties of this nano probe, aggregation of Cit-AgNPs causes variations in absorption spectra and significant color changes in solutions. Hence, in the presence of analytes, the aggregation of these nanoparticles can occur, and an alteration in solution color will be caused.	"Low limit of quantification":1ZM	"The advantage of this technology is that it makes biosensors that can detect leishmania single-stranded DNA"..	2020	(Mehri et al. 2020)

Table 2 (continued)

Type of sensors	Protozoan parasite	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	year	Ref
Genosensor/ Electrochemical	Leishmania spp.	Gold nanoparticlesAuNP,thiolated probe	10.0 Hz	Leishmania-specific DNA	(10−6, 10 −9, 10 −12, 10 −15, 10 −17, and 10−21 M)"A novel ultra-sensitive DNA-based biosensor was prepared for the detection of Leishmania spp. For the first time, the specific and thiolated sequences of the Leishmania spp genome (50-SH-[CH2]6 ATCT CGTAAGCAGATCGC TGTGTCAC-30) were recognized by electrochemical methods.	1ZM (LLOQ)	"The experimental results point to a rapid and easy technique for detecting kala-azar patients, with the nanocomposite-based probe holding enormous promise for the creation of perfect biosensors".	2020	(Mobed et al. 2020)
Genosensor	*Leishmania infantum*	Electrode posited cadmium sulfide nanosheets	50kHz–100mHz	Genomic DNA	"A promastigotes parasite count of 1 × 10 7 mL−1/The genosensor was fabricated based on the transduction of cadmium sulfide nanosheets and recognition of a particular single-stranded DNA sequence, and worked in the label-, marker-, tag, and PCR-free manners.	0.81 fmol/L(6.5fgm/L)	"The genosensor exhibited a high selectivity, manufacturing repeatability, and stability, and it could be used in practical applications".	2020	(Nazari-Vanani et al. 2020)
DNA biosensor	*Trichomonas vaginalis*	ultrasensitive label-free electrochemical	NOT REPORTED	*Trichomonas vaginalis (TV)quantitation*	A novel label-free electrochemical DNA biosensor for TV quantitation was constructed based on an electropolymerized poly(ortho-aminophenol) thin film, simultaneously acting as a transducer as well as a redox indicator.	1.0 pg µL−1	The biosensor recognized a synthetic TV target sequence and was able to distinguish between complementary sequences and mismatched and non-complementary sequences. The designed biosensor was also capable of detecting the TV genome at a level of 1.0 picogram/µL.	2022	(Vais et al. 2022)

Table 3 Comprehensive records of biosensor applications for helminth parasites, organized by publication year

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Immunosensor									
Immunosensor	Trichinella spiralis	Polyvinylchloride (PVC),	NOT REPORTED	Larvae	ELISA, RPHA	NOT REPORTED	"The working principle of the biosensor is based on the measurement of the electrochemical potential difference between two electrodes immersed in the serum to be tested. By comparing the potential between the control serum (specific antibody negative) and the experimental serumto check the presence of antibodies in the serum and the determination of its titer"	2004	(Petkova et al. 2004)
Silica Sol-gel Amperometric Immunosensor	*Schistosoma Japonicum*	"saturated calomel reference electrode" (SCE), platinum plate auxiliary electrode,	–250 mV	adult worm antigen (AWA)	4.5 mg/ml Renewal of the immunosensor surface, Preparation of HRP-SjAb, ELISA, Fabrication of amperometric immunosensor"	NOT REPORTED	"The utilization of silica sol-gel technology in immunosensor configuration has been demonstrated effectively to give a helpful detecting gadget to straightforwardly observe the grouping of SjAb in serum samples."	2004	(Zhong et al. 2004)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Piezoelectric immunosensor	*Schistosoma japonicum*	Ethanolamine, 16-mercaptohexadecanoic acid (MHA), N-ethyl-N-3-dimethyl aminopropyl carbodiimide hydrochloride (EDC) and 2-N-morpholino-ethanesulfonic acid (MES), isometric completeFreund's adjuvant (CFA)	<150 Hz	S. japonicum egg antigen (SEA)	"1 mg/ counter immunoelectrophoresis (CIE test), Chip surface modification and antibodies immobilization, Measurements by piezoelectric immunosensor (QCM), Purification of polyclonal antibodies"	NOT REPORTED	"The novel immunosensor procedure has well potential to determine the Schistosoma japonicum coursing antigens (SjCAg) in serum tests for clinical determination of parasitosis in the beginning phase"	2008	Cheng et al. 2008)
Piezoelectric immunosensor	Schistosomajaponicum	Normal rabbit serum(NRS), infected rabbit serum samples (IRS), and S. japonicum Antigen, Bovine Serum Albumin (BSA)	9 MHz	Soluble egg antigen (SEA)	0.2 mg ml-1 / mixed self-assembled monolayer membrane (mixed SAM) technology, traditional single self-assembled monolayer immobilization method, ELISA techniques	NOT REPORTED	"Reusable piezoelectric immunosensor may address an option in contrast to the flow indicative techniques for S. japonicum disease in the clinical research facility or for investigation outside the lab".	2012	(Wang et al. 2012)
Nanoparticle biosensor	Brugia malayi	"Colloidal gold nanoparticles "(AuNPs), mouse anti-human IgG4 (MαHIgG4)	NOT REPORTED	Microfilaria	8-15 mg/ml-1" immunochromatographic strip test"	1.0 mg /ml−1	"The 30 nm AuNPs–MαHIgG4, with an optical density of 4 from the seeding-growth method, tested the high-quality performance for labelling ICG strips because it displayed the high-quality sensitivity and the perfect specificity when examined with serum samples from brugian filariasis patients and controls."	2012	(Makhsin et al. 2012)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Novel screen-printed immunosensor	*Schistosoma mansoni*	Soluble worm antigens (SWA), glutaraldehyde-chitosan,	50 mV/s	Adult worms	0.038 to 20 ng/m/ "Fabrication of nanocarbon-screen-printed electrode" (NCE)	NOT REPORTED	The quantitative reaction at the nano-level measures ofABs recommends that this technique can be utilized in the future to foster a disposable screen-printed anode for the conclusion of schistosome infections."	2016	(Shohayeb et al. 2016)
Optical biosensor	Echinococcus granulosus	"Porous silicon Bragg mirror sensor, protein Egp38, sulfo-N-hydroxysulfosuccinimde (NHS) sodium salt solution"	NOT REPORTED	Protoscolex and adult worm	0.5 and 15 pg/ml/ colloidal"quantum dots" (QDs), Preparation of Egp38 antigen, SDS-PAGE	300fg/mL	"The biosensor combining PSi Bragg mirror and QDs can doubtlessly be utilized for the medical detection of hydatid disease".	2017	(Li et al. 2017)
Immunosensor	Taenia Solium	Antigenprobe (rT24H) and an AC electrokinetics (ACEK)	NOT REPORTED	Larvae (Cysticercos)	ELISA and "enzyme immunoelectrotransfer blot" (EITB)	NOT REPORTED	"Capacitive biosensingby microelectrodes holds incredible promise as a direct, single-step measure methodology for point-of-care applications."	2018	(Lin et al. 2018)
Point-of-care biosensor	*Trichinella spiralis*	Cystatin-like protein, Excretory-secretory (ES) products, serum antibodies	NOT REPORTED	Larvae	200 to 1000 larvae/ rapid serological antibody test, Rapid Quantum Dot Nanobead-mAb Probe-BasedImmunochromatographic Assay, ELISA, quantum dot nanobead	NOT REPORTED	Techniques for unique and quantitative detection of parasite-related antibody are restricted to ELISA".	2021	(Xu et al. 2021

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Optical Biosensor	*Echinococcus granulosus*	Protein A-ConjugatedChitosan–Gold Nanoparticles, goldnanoprobe (chitosan–gold nanoparticle protein A), hydatid cyst antigen (Ag B)	35.6 mV	Protoscolices of fertile cysts	1.2 mg/mLE en" enhanced immuno-dot-blot assay, Preparation of Hydatid Cysts Fluid, Colorimetric Detection, Dot-Blot Assay, SDS–PAGE"	0.3 mg/mL	"This stronger immuno-dot-blot assay offers a simple diagnostic technique without the need for costly tools for analysis of echinococcosis."	2021	(Safarpour et al. 2021a)
gold nanoparticles	*Taenia solium*	surface plasmon resonance-based biosensor	NOT REPORTED	T. solium antigen	The biosensor is based on the localized surface plasmon resonance (LSPR) technique on gold nanoparticles (AuNPs) in colloidal suspension that were functionalized and activated with antibodies to perform an immuno-capture effect. The AuNPs were synthesized by Turkevich and seed-mediated growth methods.	0.1 µg/mL	AuNPs LSPR biosensor is potentially suitable for neurocysticercosis diagnosis	2021	(Arcas et al. 2021)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
nano-biosensor	*hydatid cyst*	gold nanoparticles (AuNPs)	NOT REPORTED	E. granulosus antibody	AuNPs were synthesized. Echinococcus granulosus antigen was coated on the ELISA microwells. Then, the E. granulosus IgG antibody was added to the microwells. After incubation and washing, the Ag-Ab complex was incubated with a human IgG HRP-conjugated antibody. Then, the synthesized AuNPs and tetramethylbenzidine (TMB), as a chromogenic substrate of HRP, were added to the reaction. Finally, the absorption rate was measured by spectrophotometry.	0.001 µg mL−1	Nanobiosensor is specific for E. granulosus antibody detection	2022	(Jafari et al. 2022)
Biomedical Sensor	*Schistosoma japonicum*	a soluble egg antigen (SEA)-based functionalized gridless and meander-type AlGaN/GaN high electron mobility transistors (HEMT) sensor	NOT REPORTED	Detection of antibodies to Schistosoma japonicum	Immobilization of the self-assembled membrane on the gate surface was verified using a semiconductor parameter analyzer, scanning electron microscope (SEM), and atomic force microscopy (AFM). The developed biosensor demonstrates remarkable performance in detecting anti-SEA	0.058 mA/log (ng/mL)	High electron mobility transistor sensors based on soluble egg antigen (SEA) were suitable for highly sensitive detection of anti-Schistosoma japonicum antibodies.	2023	(Hu et al. 2023)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
CRISPR-RPA biosensor	clonorchiasis	CRISPR-glucometer	NOT REPORTED	Digital detection of fish clonorchiasis	genes were quickly isothermal amplified by RPA from fish samples, and the nucleic acid signal was converted to glucose and digitally read by a glucometer via the CRISPR system and a glucose-producing reaction.	102-107 copies/μL	The CRISPR-RPA biosensor provides a portable and robust tool for detecting C. sinensis in fish, even with a metacercaria.	2025	(Ma et al. 2025)
Genosensors (the recognition element is DNA sequences)									
Genosensors	helminth parasite	Material used	Frequency range	**Target**	**Concentration/ Experimental method**	**Detection limit**	**Main results in article**	**Date**	**Ref**
Label-free from radioactive or fluorescent-tags biosensor	*Brugia malayi*	Quartz Crystal Microbalance DNA-Based Biosensor,	12MHz	Microfilaria	50 ng/ml PCR, DNA immobilization sensing,	0.05 μg/ml	"This biosensor system may additionally be developed for the diagnosis of lymphatic filariasis in clinical samples."	2012	(Abreu et al. 2002)
Label-free from radioactive or fluorescent-tags biosensor	*Brugia malayi*	Quartz Crystal Microbalance DNA-Based Biosensor,	12MHz	Microfilaria	50 ng/ml PCR, DNA immobilization sensing,	0.05 μg/ml	"This biosensor system may additionally be developed for the diagnosis of lymphatic filariasis in clinical samples."	2012	(Kaewphinit et al. 2012)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Electrochemical DNA biosensor,RPA-EC(recombinase polymerase amplification-electrochemical DNA sensor)	*Schistosoma japonicum*	Tetramethylbenzidine (TMB),	NOT REPORTED	Adult worms	10 -4-10 -8 ng"Combining recombinase polymerase reaction" (PRA)	10 -8 ng	"The establishingThe isothermal detection approach (RPA-EC) combinational detection technique set up reveals excessive sensitivity and precise specificity, and is effortless to operate, showing the viability for future application."	2016	
Nucleic Acid-Based Biosensors (NABs)	*Filaria*	Nucleic Acid-Based Biosensors (NABs)	NOT REPORTED	microfilaria	2 µM/" lateral flow dipstick" (LFD), "goldNanoparticle" (AuNP) and turbidity in combination with PCR and LAMP amplification	NOT REPORTED	"NAB is highly sensitive and can be used as a selective diagnostic tool, especially as a rapid screening test for filarial nematodes, so it can be used as a recommended epidemiological investigation."	2016	(Jaratsing et al. 2016)
Impedimetric nanostructured genosensor	*Schistosomamansoni*	Self-assembled monolayer of mercaptobenzoic acid (MBA), gold nanoparticles (AuNPs), magnetite nanoparticles (Fe3O4 NPs)	100 mHz and 100 kHz	Schistosomamansoni DNA	2 µl"Electrochemical impedance spectroscopy" (EIS), "cyclic voltammetry" (CV), Synthesis of nanoparticles, Electrode modification	0.781 pg µl-1 in serum and 0.685 pg µl−1 in CSF	"The biorecognition brought about an expansion in the electron transfer opposition and a lessening of the current peaks at higher DNA fixations during electrochemical estimations, and the biosensor can be seen as a useful tool to explicitly recognize S. mansoni in low concentration in various natural fluids".	2017	(Santos et al. 2017)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Label-free nanostructured biosensor	*Schistosomamansoni*	3-mercaptopropyltrimethoxysilane (MPTS), electro-synthesized AuNPs	300 kHz	Schistosomamansoni DNA	2 µL/ Electrochemical EIS, (CV)	urine (27–50 pg µL−1),CSF (25–60 pg µL−1), and serum (27–42 pg µL−1)	"An increase in label-free genosensor was capable of identifying low concentrations of S. mansoni DNA in complex organic liquids"	2019	(Santos et al. 2019)
DNA electrochemical sensor	*Trichinella britovi*	ZnO nanostructure-based electrochemical biosensor,	NOT REPORTED	Larvae	100 ng/µl/ "Preparation of ZnO nanostructures and design of electrochemical sensors, Preparation of Trichinella brittovi and Trichinella spiralis PCR Products"	50 ng/µl	"The ZnO nanotubes sensor lets in unambiguously distinguishing complementary, non-complementary, and in part complementary DNA sequences for the Trichinella britovi primers in the analyte"	2019	(Gerbreders et al. 2019)
DNA biosensor	*Ascaridia galli*	We developed a loop-mediated isothermal amplification coupled with a lateral flow dipstick (LAMP-LFD) assay for the visual detection of A. galli eggs in faecal samples.	NOT REPORTED	A. galli eggs	The LAMP-LFD assay consists of six primers and one DNA probe that recognize the internal transcribed spacer 2 (ITS2) region; it can be performed within 70 min, and the results can be interpreted with the naked eye.	5 pg/µl	Using the LAMP-LFD method, A. galli DNA was specifically amplified without any cross-reaction with other parasites. The DNA biosensor is a suitable alternative for the detection of A. galli in chicken feces and can replace traditional screening methods for epidemiological, veterinary, and poultry surveys.	2023	(Panich et al. 2023)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Cytosensors (the target is the cell)									
Cytosensors	**helminth parasite**	**Material used**	**Frequency range**	**Target**	**Concentration/ Experimental method**	**Detection limit**	**Main results in article**	**Date**	**Ref**
Electrochemicalbio-sensor	*Schistosoma spp*	Magnetic porous pseudo-carbon paste electrode (MPPCPE), schistosoma egg antigen (SEA), polymethyl methacrylate microspheres (PMMA), magneticcarbon paste electrode (MCPE), N-acetylcysteine, ethanolamine, 1-ethyl-3-(3 3-dimethylaminopropyl) carbodiimide (EDC), N-hydroxysuccinimide (NHS), 3-aminopropyl-triethoxysilane (APTES)	0.27 V	Eggs	0.02 to 1 µg/mL/ Fast detection of schistosoma egg antigen (SEA), Fabrication of electrodes,	<0.01 µg/mL	"The SEA on the electrode was observed by anodic stripping voltam-metry (ASV) investigation utiliz-ing the strategy for gold nanoparticle-catalyzed silver enhancement. Compared with the past attrac-tive carbon glue cathode (MCPE), the identifica-tion affectability was significantly expanded".	2010	(Xu et al.2010a)
Electrochemical biosensors	*Schistosoma haematobium*	Biosensor-Based Rapi-dUrine Test, "horseradish peroxidase" (HRP), "tetra-methylbenzidine" (TMB),	200 kHz	Total RNA directly from S.haematobium eggs.	106 egg/ml "Probe design and analy-sis, Analytical sensitivity of the Electrochemical biosensor assay"	30 eggs/ml	"Biosensor-based method provides quantitative detec-tion of parasite-derived nucleic acids, which is doubtlessly much less subjective than the modern general method primar-ily based on egg counting".	2015	(Mach et al. 2015)

Table 3 (continued)

Types of Sensors*	Helminth parasites	Material used	Frequency range	Target	Concentration/ Experimental method	Detection limit	Main results in the article	Ye	Ref
Schistosoma mansoni	protease-based biosensor	Elastase-specific biosensor, Tobacco Etch Virus (TEV) protease, cercarial elastase (ELA), control motif(CON), housed whole-cell biosensors,	NOT REPORTED	Schistosome cercariae	10 µl "Scanning – synthetic combinatorial library screening, Bacterial strains, plasmids and growth conditions, Strain and plasmid construction, Induction of Biosensor expression, Western blot, Biosensor assays, Flow cytometry, Lyophilisation of biosensor expression strains"	NOT REPORTED	Protease-based biosensors are the primary, entire cell-based biosensors that have been straightforwardly intended for the discovery of S. mansoni, and this offers the chance of growing further entire cell-based biosensors for different parasites."	2016	(Webb et al. 2016)
Quantum dot/porous silicon optical biosensor	*Echinococcus granulosus*	Porous silicon microcavity(PSM),P38 antigen	NOT R EPORTED	Matrix metalloproteinase of larvae	0.5×10−6 mg/ml to 2.0×10−5 mg/ml/ spectrophotometer	NOT REPORTED	"This method has additionally been utilized for the detection of protein kinase P38 for diagnosing hydatidosis hydatid disease."	2019	(Li et al. 2017)

The wide range of biosensors available for detecting parasites (Fig. 3), along with their notable advantages, may increase interest in exploring biological tools for detecting other parasites.

Reporting quality and risk of bias

The studies examined in this review show varying reporting quality, which was shown in Fig. 4. The reviewed studies provided full or partial descriptions of exposure frequency along with exposure duration and biosensor types.

Discussion

An efficient diagnosis method is vital for preventing and treating parasitic diseases (Sin et al. 2014). Biological tools are analytical devices that translate the molecular recognition of target analytes into measurable signals, making them an easy-to-use, affordable, and sensitive technology for quickly identifying parasites and predicting effective treatments (Safarpour et al. 2021b). They require small fluid volumes, consume low energy, have short assay times, and offer high throughput and multiplexing capabilities. Various biosensors have been developed to identify helminth and protozoan parasites, which provide notable advantages over traditional methods (Ramos-Jesus et al. 2011), as outlined in the tables provided.

Immunosensors are biosensors used to detect parasites, made up of an antigen (Ag) or antibody (Ab) connected to a signal transducer. They are simple, portable, and offer high specificity along with rapid detection of Ag or Ab. Electrochemical immunosensors provide greater sensitivity than methods like ELISA, enabling earlier diagnoses and faster treatment while reducing the use of toxic drugs (Cabral-Miranda et al. 2014; Sharma et al. 2010; Esteves et al. 2017). They serve as reliable monitoring tools in endemic areas for disease screening and can also support in vitro drug sensitivity testing (de Souza Castilho et al. 2011).

Various types of immunosensors include electrochemical, amperometric, piezoelectric, SPR, label-free plasmonic, novel peptide-based, electrochemical sandwich enzyme-linked, enzyme-free dual electrochemical, novel screen-printed, and impedance immunosensors. Different materials such as nanoparticles, latex particles, quartz crystals, proteins, and magnetic particles have been used in their design. These immunosensors have proven effective in detecting parasites like *Leishmania spp.*, *Trypanosoma spp.*, *Plasmodium spp.*, *Toxoplasma gondii*, *Cryptosporidium parvum*, and *Schistosoma spp*.

Malaria is one of the severe parasitic diseases. Early detection can prevent serious outcomes. According to Table

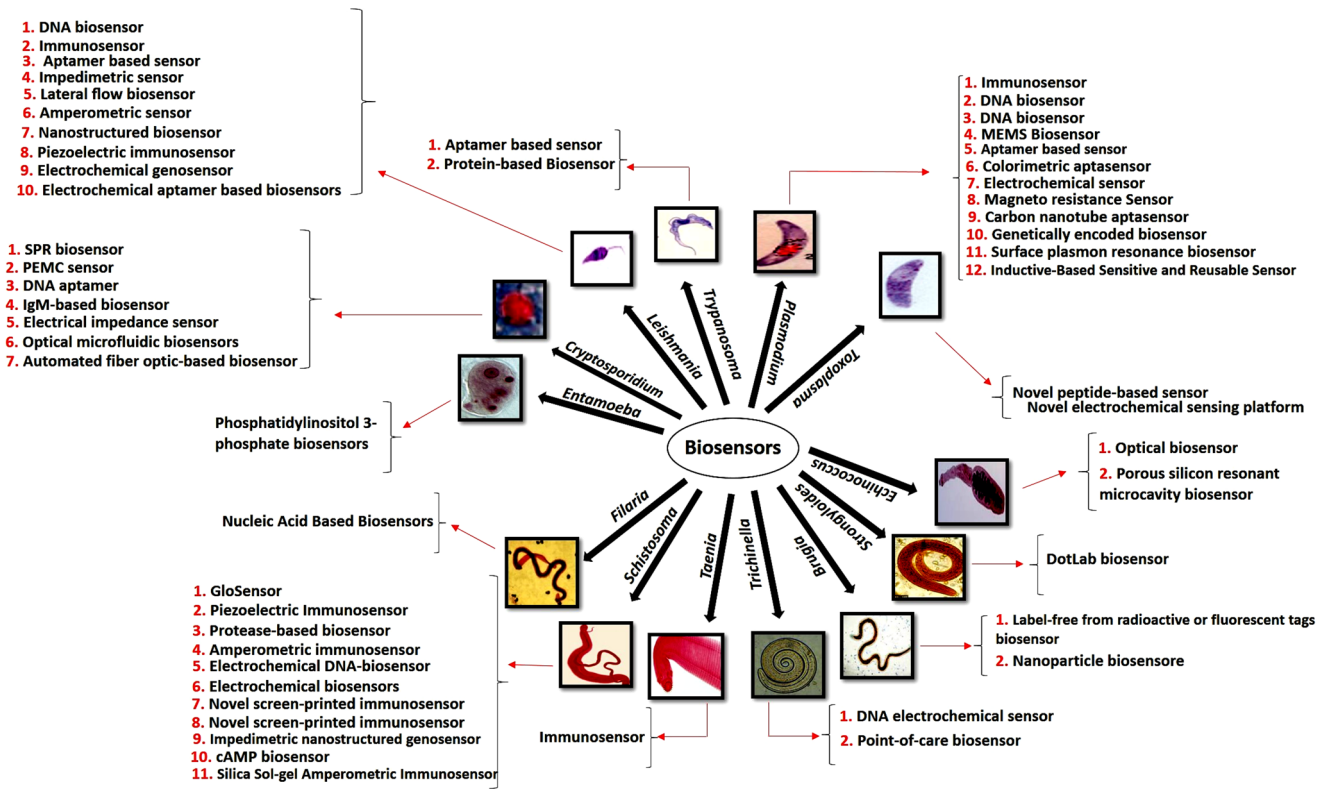

Fig. 3 Wide variety of biosensors for detecting parasites

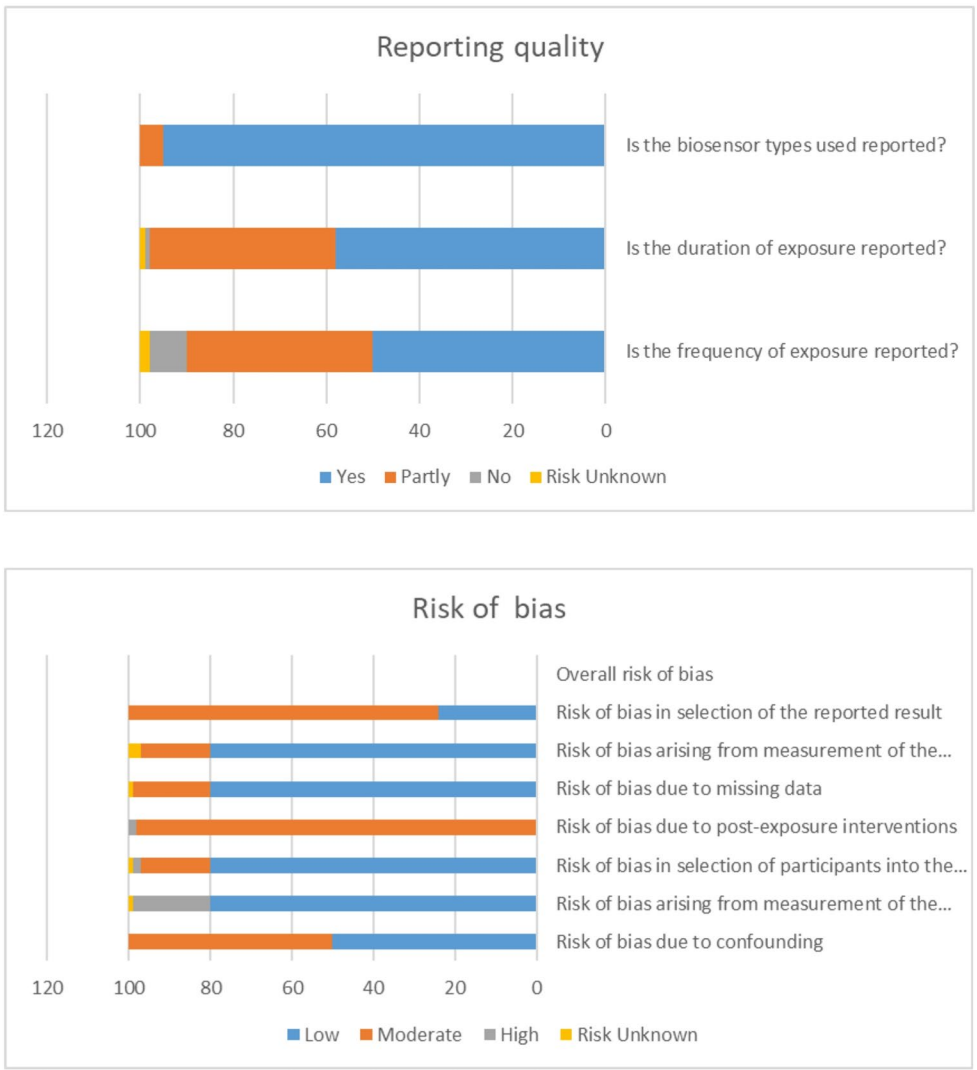

Fig. 4 The evaluation method involved rating 136 articles based on their reporting quality and potential for bias. Each article was reviewed for the presence of essential study details and marked as "Yes,""Partly," or "No." The researchers categorized the risk of bias in each article as "Low," "Moderate," or "High." If the risk of bias was not stated or addressed, the article was labeled as "Risk unknown" and assigned a corresponding score. The overall score represented the average percentage of all 136 articles

2, sensitive biosensors for detecting *Plasmodium falciparum* include various types, with immuno, geno, and aptasensors being the most effective. Their sensitivity depends on advanced nanocomposites and biosensor strategies, such as carbon nanofibers and magnetic nanoparticles (Gikunoo et al. 2014; Markwalter et al. 2016; Figueroa-Miranda et al. 2018; Potipitak et al. 2011). Schistosomiasis is a life-threatening helminth infection. The most sensitive diagnostic methods involve immuno/gemosensors, which use different nanoparticles and anisotropic-shaped gold nanoparticles, polyaniline-gold nanoparticles, nanocarbon, nanospheres, and magnetic nanoparticles (Delshadi-Jahromi et al. 2018; Garcia et al. 2015; Shohayeb et al. 2016; Xu et al. 2010a; Zhong et al. 2004).

Among various types of biosensors used to detect parasites, Genosensors, a DNA-based biosensor, play a vital role in identifying pathogens like *Leishmania spp.*, *Plasmodium spp.*, *Cryptosporidium parvum*, *Schistosoma spp.*, and *Trichinella spp*. They can target different life stages, including larvae and adult worms. The most common types of DNA biosensors are optical, electrochemical, and piezoelectric biosensors. The DNA biosensors exclusively detected *P. falciparum* without cross-reacting with *P. vivax*. This innovative technology is more sensitive, faster, less costly, and easier to operate than standard real-time PCR. It offers good specificity and sensitivity for parasite identification and niclosamide damage to DNA in clinical samples (Ittarat et al. 2013). The ZnO nanostructure-based electrochemical biosensor effectively differentiates between complementary, non-complementary, and partially complementary DNA sequences for *Trichinella britovi* primers (Gerbreders et al. 2019). High sensitivity, excellent specificity, and simplicity suggest promising future applications for this method.

Genosensors are a type of biosensor used in parasitology for detecting *Leishmania spp.* and *Trichomonas vaginalis*. They come in various forms, including electrochemical,

optical, and label-free impedimetric genosensors. Their main goal is to identify DNA segments that enable the immobilization of biomolecules. Additionally, they are inexpensive and easy to operate, making them suitable for both human and veterinary medicine, especially in resource-limited settings (Delshadi-Jahromi et al. 2018; Nazari-Vanani et al. 2018; Frias et al. 2017; Andreadou et al. 2016). An electrochemical immunosensor can detect very low levels of *Cryptosporidium parvum*. Various types of electrochemical biosensors can be used to detect different parasites.

Aptamers are short nucleotide sequences that act as vital biosensors in parasitology (Nagarkatti et al. 2012). They are used in various types of biosensors, including Carbon nanotube aptasensors, Aptamer-based concentration methods, Colorimetric aptasensors (GNPs-based DIRK aptasensor), Aptamer-based detection, DNA aptamers, Aptamer-tethered enzyme capture biosensors, Electrochemical aptasensors, and BioFET sensors. These modern diagnostic tools have been employed to detect protozoa such as *Leishmania infantum*, *Plasmodium spp.*, *Cryptosporidium parvum*, and *Trypanosoma cruzi*, as listed in the provided tables. With low detection limits, these biological tools can specifically bind to their targets, which may be a whole cell, a protein, or a small molecule (Ramos et al. 2010).

Cytosensors are popular cell-based biosensors known for their ease of use, portability, and small size, which enable non-invasive cell detection. They offer quick and cost-effective way to detect Helminths and Protozoan parasites using simple equipment. The main biosensors in this category are potentiometric and amperometric types, which use cell surface or membrane markers. Aptamers and antibodies act as capture agents for analyzing target cells.

Critical evaluation and challenges A wide range of biosensors has underlined the excellent sensitivity and specificity properties to recognize parasitic infections (Rather et al. 2024). Nevertheless, several critical challenges hamper the transition of these instruments into daily clinical and field applications (Hemdan et al. 2024). Firstly, the reproducibility aspect still holds the main position among challenges in performance because of assay conditions, types of samples, and methods of fabrication (Lavín et al. 2018). In fact, direct comparisons between different works are restricted (Wu et al. 2018). Secondly, there is a need to address the limited application of these techniques in real-world scenarios involving human samples. Most biological tools are tested under stable laboratory conditions, but they often struggle to maintain their effectiveness in complex biological or environmental samples. Matrix effects and the number of false positives have a significant impact on diagnostic accuracy (Goumas et al. 2025). Third, setting as well as cost barriers seem to be the issues that are the least considered (Migliozzi et al. 2018). The process of taking these devices to the market is associated with the strict observance of regulatory standards for diagnostic tools, something most prototypes are not yet able to achieve (Green Jr et al. 2022). Furthermore, manufacturing has been a costly and challenging process, particularly in low-resource settings where parasitic diseases are prevalent (Ogwu et al. 2025; Thwala et al. 2023). The deployment of on-premise care platforms and healthcare infrastructure is still under discussion. Although advancements in size, multiplexing, and phone-based readouts are promising, testing in real-life situations in affected regions is necessary to ensure accessibility, affordability, and user-friendliness (Beduk et al. 2022; Parihar et al. 2025; Sasidhar et al. 2025).

To effectively address these challenges, we need a multidisciplinary approach that includes the standardization of protocols, reliable clinical validation, and collaboration among engineers, clinicians, and policymakers. This approach will ensure that biosensor technologies progress beyond the proof-of-concept stage and can be utilized practically on a large scale (Marx et al. 2025).

Conclusions

This scoping review highlights significant advancements in biosensor-based diagnostic tools for parasitic infections. Key biosensor types—immunosensors, genosensors, and aptasensors—show great promise in diagnosing parasitic protozoa and detecting helminthic diseases. The integration of nanomaterials with advanced electrochemical biosensors has pushed detection limits to femtogram levels. However, critical challenges remain. Many tools are still in the concept phase and have only been validated in controlled laboratory settings, with a few tested in real-world conditions. To enable routine use, issues such as reproducibility, false positives, and regulatory approvals must be addressed. Additionally, ensuring cost-effectiveness and scalability is crucial for deployment in low-resource areas where these diagnostics are urgently needed. Overcoming these challenges will be essential to fully realize the potential of biosensor technology.

Future research should focus on standardizing and validating diagnostic platforms for various sample types and environmental conditions. Emphasis should be placed on point-of-care integration, including miniaturization and smartphone-based readouts for use in remote areas. Multiplexing technology allows for the simultaneous detection of multiple pathogens, while pathways for approval and safety measures can help reduce production costs. Biological tools that achieve these objectives could revolutionize

global health by providing quick, affordable, and accurate diagnostics for parasitic diseases, aiding in their prevention and eradication.

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