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Biosensors for the detection of arthropod-borne veterinary viruses: A comprehensive review

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ABSTRACT

Veterinary arboviruses pose serious threats to animal health, especially in endemic areas. Traditional methods used for the diagnosis of these viruses are expensive, time-consuming, and require specialized personnel. This review discusses biosensor technologies for veterinary arboviruses, analyzing specific targets, mechanisms, sensitivity, specificity, and utility for use in the field. The remaining gaps were also mentioned.

A comprehensive literature search was carried out in the major databases from 2015 to 2025. We used the keywords "Biosensing Technologies"Arboviruses," "Veterinary Medicine," "Viral Diseases," and "Point-of-Care Systems," and names of veterinary arbovirus families and their viruses.

The findings reveal that biosensors have shown great sensitivity, specificity, and fast detection for various veterinary arbovirus families in the field. The technologies used were electrochemical, optical, CRISPR-based, and microfluidic formats, which are often improved by the use of nanomaterials and smartphone integration. The platforms directed against Japanese encephalitis, Rift Valley fever, and African swine fever had the lowest detection limits of femtomolar and also had the capability for multiplexing. Nevertheless, the technological development of biosensors remains restricted to a few viruses only, thus revealing substantial veterinary diagnostic gaps.

Overall, biosensors have great potential in veterinary virology, with the capability of early diagnosis and, consequently, better outbreak response. Many of these sensors are specific, sensitive, and portable, making them great options for point-of-care applications. Future attention should be given to less-studied viruses, large-scale field validation, and multitarget biosensing platforms to improve veterinary surveillance globally.

Introduction

Arthropod-borne veterinary viruses represent a major disease risk to animal health, food security, and public health. These pathogens can cause severe disease in livestock and wildlife [Blázquez & Jiménez de Oya, 2025, Vidic et al., 2017, Kim et al., 2018]. The increased prevalence of arboviruses, caused by climate change, global trade, and growing agricultural operations, has increased the importance of developing fast, sensitive, and field-adaptable diagnostic assays to facilitate early intervention and effective outbreak response [Blázquez & Jiménez de Oya, 2025, E Khristunova et al., 2020, Simão et al., 2020]. Traditional diagnostic approaches such as virus isolation, reverse transcription polymerase chain reaction (RT−PCR), and enzyme-linked immunosorbent assays (ELISAs) are considered the gold standards. Nevertheless, the associated diagnostic work is considered too intensive and complicated for laboratory infrastructures to implement, especially in settings with poor resources [Vidic et al., 2017, E Khristunova et al., 2020, A Roberts et al., 2023]. Such constraints severely impede prompt monitoring, especially in endemic locations where arboviruses present the highest risk for public health. Biosensors have offered novel solutions to these limitations and greatly transformed the technology of animal health diagnostics with rapid, sensitive, and convenient platforms. In a biosensor, a biorecognition element, such as antibodies, aptamers, or molecularly imprinted polymers (MIPs), is immobilized together with a transducer that converts biomolecular interactions into measurable signals [Naresh & Lee, 2021, Morales & Halpern, 2018]. Recent advancements have enabled the development of highly sensitive, fast, and portable platforms, making them well-suited for point-of-care (POC) diagnostic applications in the field [A Roberts et al., 2023, Valenga et al., 2025]. For example, nanomaterials increase the performance of sensors by acting as functional components that can increase signal intensity and sensitivity for fast and visual analysis [Abdoli et al.,

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2025, Cao et al., 2022, Khristunova et al., 2019, Wang et al., 2021].

Electrochemical immunosensors, fluorescence assays, and lateral flow devices are some examples of technologies that have shown high levels of performance for arbovirus detection, with their uses ranging from serum testing to environmental surveillance [A Roberts et al., 2022, Chin et al., 2017, Yin et al., 2022]. The objective of this review is to critically compare biosensors of various types that have been developed for the detection of veterinary arboviruses according to their particular targets, types of biosensors deployed, recognition capabilities, mechanisms and strategies employed, analytical performance characteristics, and aspects of deployability for virus families and to compare viruses of each family. In addition to charting the technology landscape, the review also performs a systematic comparative analysis within the families.

Materials and methods

Literature review and sources

We carried out a systematic search of major scientific databases, such as Google Scholar, PubMed, Scopus, and Web of Science, between 2015 and 2025. We used Medical Subject Headings (MeSH) keywords such as "Biosensing Technologies," "Arboviruses," "Veterinary Medicine," "Viral Diseases," and "Point-of-Care Systems," and the names of the veterinary arbovirus families and viruses contained therein. Boolean operators were used to combine the keywords in various search terms.

Inclusion and exclusion criteria

An inclusion and exclusion methodology was employed. Peer-reviewed publications in the English language were included. Papers that investigated arthropod-borne viruses and applied a biosensor were considered suitable for inclusion. Our comparative analysis took a broader and function-oriented approach. A limited number of studies included in our analysis do not belong to the classically defined group of biosensors. However, such studies have been retained since they also serve similar purposes, often having a biological recognition and a measurable signal. So, these few studies also give us valuable insights for the field and development of biosensors. In order to avoid confusion, we have indicated that they do not belong to the biosensors category. Non-peer-reviewed papers, conference papers, editorial commentaries, and letters to the editor were excluded.

Systematic study selection process (PRISMA flow diagram)

As mentioned, a comprehensive systematic search identified an initial pool of 1053 records. After excluding 243 duplicates, 810 studies underwent title and abstract screening. Exclusion during this stage occurred due to irrelevence of studies according to predefined inclusion and exclusion criteria (non-peer-reviewed content, conference abstracts or editorials, $n = 156$; studies not involving biosensor application for veterinary arboviruses, $n = 194$; studies focusing on non-arboviral pathogens, $n = 258$; or any other irrelevant topics, $n = 20$, hence, 182 records went into full-text evaluation. After careful screening, giving primary emphasis on peer-reviewed articles written in English related to the subject of biosensors of arthropod-borne viruses, a total of 122 articles were excluded from the initial search result. These articles were excluded due to insufficient focus on veterinary arboviruses ($n = 41$), absence of biosensor methodology ($n = 44$), non-peer-reviewed or gray literature ($n = 24$), and other mismatches ($n = 13$).

As there have been many recent review articles on the detection of Japanese encephalitis virus (JEV) in recent years, the analysis was conducted at a high-level overview and focused on general studies to emphasize important trends and avoid redundancy and overlap. For the togaviridae family, as there had not been many recent studies to adequately cover the sensors, the search parameters had to be expanded to include past studies and provide a better overview. Finally, 60 high-quality primary research papers were selected. This compilation provides the basis for this review. Additional references were also provided for background information. The selection process undertaken has been explained in the PRISMA Flow chart in Fig. 1.

Data collection and comparative framework

The relevant variables associated with each of 77 studies were extracted and compiled into a comparative matrix. Variables that were such included viruses of particular targets, types of biosensors deployed, recognition capabilities, mechanisms and strategies employed, analytical performance characteristics, biosamples and aspects of deployability. To facilitate cross-platform comparisons, the biosensors were categorized on the basis of the classification of virus families. Tables that compared each biosensor associated with each family were generated to permit readability and data export.

Limitations

We were limited in our review because it was based on peer-reviewed, English-language literature, and potentially published non-English research was excluded. Furthermore, the associated selection bias of the databases could have also impacted the coverage of the review. This was avoided by a good research strategy and clear criteria. Even with a systematic search strategy, the narrative and extensive nature of the review, with the aim of focusing on a broad spectrum of families of viruses as well as the technologies involved, may be different from a systematic review with a single research question.

Discussion

A biosensor is composed of a biorecognition component, a transducer, and an electronic system to detect analytes. The biorecognition component's function is to interact with the target analyte, and the transducer transforms this signal into a measurable signal [Naresh & Lee, 2021, Morales & Halpern, 2018]. Biorecognition elements are classified into natural biomolecules, pseudonatural assemblies, and pure synthetic molecules [Morales & Halpern, 2018]. Biosensors are also classified on the basis of their transduction mechanism. Biosensor transducers include electrochemical (amperometric, potentiometric, voltammetric, impedimetric, conductometric), optical (fluorescence, chemiluminescence, surface plasmon resonance, optical fiber), gravimetric (quartz crystal microbalance, magnetoelastic, piezoelectric), thermal, electronic (field-effect transistors), and acoustic wave types. Each of these has its own advantages and limitations [Naresh & Lee, 2021]. In this review, we provide a systematic family-by-family review of veterinary arboviruses. For each family of arboviruses, we assess biosensors in terms of their mechanism, sensitivity, specificity, and utility for field use. We also mention each family's remaining gaps.

Family Togaviridae

Biosensors have emerged as key tools for detecting viruses of the Togaviridae family [Lello Laura et al., 2022, Liu et al., 2018, Kulagina et al., 2007, Thach et al., 2003, Rider et al., 2003, Hu et al., 2004]. Given that enveloped, positive-sense RNA viruses necessitate biosafety procedures with strict guidelines, biosensor platforms to allow for safe, rapid diagnostics are essential [Lello Laura et al., 2022, Rider et al., 2003, Hu et al., 2004]. Because of the limited number of recent studies, we broadened our study scope to include previous studies. Earlier works are significant in providing a historical context. Lello et al. constructed a cell-based biosensor platform. The biosensor is highly specific to Eastern Equine Encephalitis Virus (EEEV) and Western Equine Encephalitis Virus (WEEV), with only minimal cross-reactivity to Semliki Forest complex alphaviruses [Lello Laura et al., 2022]. Liu et al. described a

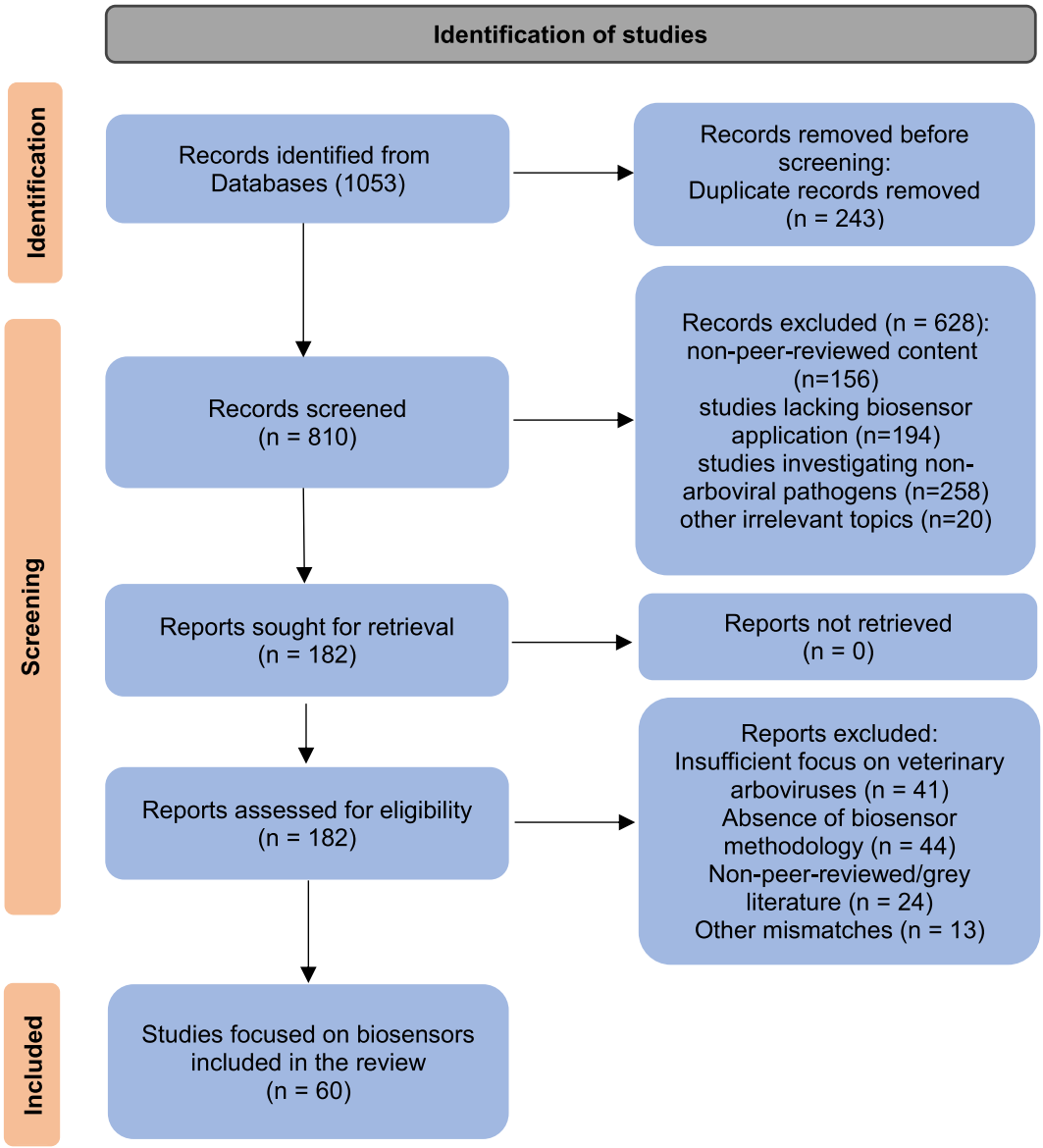

Fig. 1. Schematic presentation of the Identification, Screening, and Including processes of the previous published reports for the present study.

panel of single-domain antibodies (sdAbs) that targets the E2/E3E2 envelope proteins of WEEV. The sensor chip exhibited good specificity, thermal stability, and nanomolar binding affinities, with minimal cross-reactivity [Liu et al., 2018]. The data can be used in future sensor developments. Kulagina et al. also reported that Venezuelan Equine Encephalitis Virus (VEEV) can be identified in direct binding assays via peptide-based biosensors using immobilized antimicrobial peptides (AMPs) [Kulagina et al., 2007]. Moreover, immunosensors in the form of immunofiltration assays with light addressable potentiometric sensing (IFA/LAPS) can detect VEEV at a limit of detection (LOD) of 30 ng/ml [Hu et al., 2004]. An immunosensor is a type of biosensor that relies on the specific affinity between an antibody and its antigen to detect recognized target molecules by translating the biological recognition event into a measurable signal response (usually electric, optical, or piezoelectric) [Janik-Karpinska et al., 2022, Gupta et al., 2023].

Thach et al. investigated Sindbis virus (SV), a genetically similar alphavirus to VEEV, which results in measurable cellular responses in rat neural precursor cells (NPCs) and human peripheral blood mononuclear cells (PBMCs), indicating that SV may be useful in cell-based biosensor platforms. Although this was not a field study, it nonetheless provides initial markers for biosensor development in the future [Thach et al., 2003]. Biosensors for many members of the Togaviridae family, including Highlands J virus, Buggy Creek virus, Middelburg virus, Semliki Forest virus, and Getah virus, are understudied. Research in the future should aim at developing diagnostic tools for the understudied viruses. A comparison of each biosensor for this family is shown in Table 1.

Flaviviridae

Yellow fever virus

Flaviviridae biosensors have diverse and sensitive platforms. Yellow fever virus (YFV) remains a significant public health issue [Blázquez & Jiménez de Oya, 2025]. P. Simão et al. described a new electrochemical biosensor based on zinc oxide nanoparticles (ZnONp), cysteine (Cys), and concanavalin A (ConA) lectin to detect arboviruses such as YFV. The biosensor offers high sensitivity and reproducibility [Simão et al., 2020]. Electrochemical biosensors consist of a bioreceptor (enzyme, antibody, nucleic acid, or cell) with an electrochemical transducer (electrode system). When the bioreceptor binds with the analyte, it causes electron changes. This action can cause a change in measurable electrical

Table 1
Comparison of biosensor technologies for togaviridae viruses.

Paper Title	Biosensor Type	Virus Targeted	Sample type	Sensitivity/ LOD	Specificity	Advantages	Limitations	References
Activity, Template Preference, and Compatibility of Components of RNA Replicase of Eastern Equine Encephalitis Virus	Fluorescent and luminescent reporter-based cellular biosensor (using plasmid-derived RNA template with ZsGreen or luciferase reporters)	Alphaviruses	HEK293T cell cultures; tested with lab viruses, not clinical samples like blood/tissue.	Not quantified	Limited to alphaviruses; cross-compatibility with WEEV but not SFV complex	Species-level discrimination; mechanistically driven template recognition; potential for selective diagnostics	Requires transfection and cell culture; limited portability; not yet validated for field use	[Lello Laura et al., 2022]
Selection of Single-Domain Antibodies toward Western Equine Encephalitis Virus	Not a biosensor study. Focuses on the development of single-domain antibodies (sdAbs) against WEEV E2/ E3E2 protein for potential future use in sensors	WEEV	Llama serum, recombinant WEEV E3E2 protein	LOD not numerically defined but confirmed via concentration-dependent signal	High specificity for WEEV E2/ E3E2; minimal cross-reactivity with CHIKV, EEEV, VEEV	High stability; recombinant production; tailorable for assays	Not yet applied in a biosensor format; some sdAbs show low expression yield or moderate affinity	[Liu et al., 2018]
Antimicrobial peptides as new recognition molecules for screening challenging species	biosensor using immobilized antimicrobial peptides (AMPs) as capture molecules on a planar substrate; direct fluorescent binding assay	VEE (and vaccinia, *C. burnetii, B. melitensis*)	Fluorescently labeled, inactivated cells/viruses (laboratory-prepared samples)	Detection limit ~10^7 pfu/mL (varies by AMP)	Moderate (similar binding patterns for VEE/vaccinia	multiplex potential; complements immunoassays	Limited target discrimination; lower sensitivity than PCR; not suitable for precise identification	[Kulagina et al., 2007]
Assessing the feasibility of using neural precursor cells and peripheral blood mononuclear cells for the detection of bioactive Sindbis virus	Cell-based biosensor using rat neural precursor cells (NPC) and human PBMCs	Sindbis virus	Primary rat NPC cultures and human PBMC from blood; lab cell models, not clinical samples	Qualitative: apoptosis and proliferation markers observed within 24–48 h	Moderate; detects bioactivity but not virus-specific identity	Captures live virus effects; enables bioactivity profiling; supports gene expression analysis	Time-scale (days); not for rapid field use; Requires cell culture and staining	[Thach et al., 2003]
Development of an immunofiltration assay by light-addressable potentiometric sensor with genetically biotinylated recombinant antibody for rapid identification of Venezuelan equine encephalitis virus	Immunosensor (Immunofiltration Assay (IFA) coupled with a Light Addressable Potentiometric Sensor (LAPS). The system captures immunocomplexes on a biotinylated membrane and detects urease-generated pH change.)	VEE	Purified, inactivated VEE viral particles	~0.29 μg/ml (IFA/LAPS); comparable to ELISA (~0.25 μg/ml)	High (no cross-reactivity with WEE)	Rapid (<90 min), avoids chemical biotinylation, reproducible, portable sensor integration.	Requires purified virus and labeled antibodies; moderate sensitivity compared to PCR	[Hu et al., 2004]

The table shows different biosensors used to detect Togaviridae family viruses. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: EEEV, Eastern Equine Encephalitis Virus; WEEV, Western Equine Encephalitis Virus; VEE, Venezuelan Equine Encephalitis; sdAb, single-domain antibody; AMPs, antimicrobial peptides; PBMCs, peripheral blood mononuclear cells.

properties such as current, voltage, or impedance [Grieshaber et al., 2008, Wu et al., 2023]. Valenga et al. also presented a 3D-printed multiplex electrochemical system. In addition to specificity against other flavivirus proteins (including Dengue, Zika), selectivity could also be observed [Valenga et al., 2025]. A recent study presented a cysteine-modified gold electrode that is capable of PoC detection of YFV NS1 antibodies. This study was the first in which wave-based density functional theory (DFT) simulations were used [Liv & Özerdem, 2024]. Moreover, a paper-based electrochemical biosensor enabled sensitive detection of YFV DNA with a 0.01 μM LOD. The device was effective in synthetic serum [Mehto et al., 2022]. Furthermore, a 3D-printed genosensor with recycled poly (lactic acid) and carboxylated multiwalled carbon nanotubes was designed for YFV detection. The platform detected cDNA sensitivity via square wave voltammetry with stable performance for four weeks [Kalinke et al., 2023]. To further enrich the diagnostic landscape, a sandwich ELONA assay using aptamers was developed for the serological detection of YFV NS1. This aptamer pair demonstrated low cross-reactivity with other flavivirus NS1 proteins and achieved a 0.85 nM ± 0.05 LOD in buffer [Mok et al., 2023]. Finally, Kwon et al. described the use of a highly sensitive, MXene-based aptasensor for rapid and specific detection of YFV (Table 2) [Kwon et al., 2024]. An aptasensor is considered to be a type of biosensor, which makes use of aptamers as the biological recognition system. Aptamers refer to short, single-stranded DNA or RNA oligonucleotides that show high binding affinity and specificity towards specific molecules. The binding of aptamer and target can produce measurable signals [Economou et al., 2023, Hosseinzadeh & Mazloum-Ardakani, 2020].

Japanese encephalitis virus

Japanese encephalitis virus (JEV) has a single-stranded RNA genome encoding structural (envelope, capsid, protein M) and nonstructural (NS1–NS5) proteins, with NS1 serving as a key diagnostic biomarker. JEV biosensors utilize nanomaterials, graphene FETs, and CRISPR-based

Table 2
Comparison of biosensor technologies for yellow fever viruses.

Paper Title	Biosensor Type	Virus Targeted	Sample type	Sensitivity/ LOD	Specificity	Advantages	Limitations	References
Nanostructured impedimetric lectin-based biosensor for arboviruses detection	Electrochemical Impedimetric Biosensor. Platform: Gold electrode modified with cysteine, zinc oxide nanoparticles (ZnONp), and Concanavalin A (ConA) lectin.	YFV, DENV2, ZIKV, CHIKV	Serum from infected patients and purified, inactivated viral particles from cell culture.	0.0437 pfu/ mL	Lower (weakest response among ZIKV, DENV, CHIKV viruses)	Broad-spectrum detection	Weak specific responses for YFV	[Simão et al., 2020]
3D-printed multiplex system for electrochemical determination of yellow fever antigens and antibodies	Electrochemical multiplex immunosensor	YFV (antigen + antibody)	Diluted serum samples	Qualitative detection: 0.5–10 μg/mL (YFV); 1–10 μg/mL (Ab-YF)	High	Simultaneous detection, portable, serum-compatible	Requires clinical validation; long-term stability is untested	[Valenga et al., 2025]
First DFT-supported point of care and novel electrochemical biosensing: Determination of yellow fever NS1 antibody in human plasma	Electrochemical biosensor	YFV (NS1 antibody)	human plasma	96 ag/mL	Very high (minimal cross-reactivity with other flaviviruses)	First NS1 antibody sensor, DFT-supported, point-of-care compatible	Requires NS1 antigen production, early-stage validation	[Liv & Özerdem, 2024]
Toward papertronics-based electrode decorated with zinc oxide nanoparticles for the detection of the yellow fever virus consensus sequence	Electrochemical paper-based sensor (ZnO—NPs + PDNA)	YFV (consensus DNA)	artificial serum	0.01 μM	Moderate	Portable, quick to use, Simple	Synthetic targets only, limited clinical validation	[Mehto et al., 2022]
Recycled additive manufacturing feedstocks with carboxylated Multiwalled carbon nanotubes toward the detection of yellow fever virus cDNA	Electrochemical genosensor (3D-printed, COOH-MWCNT)	YFV (cDNA)	Synthetic DNA sequences; spiked human serum	0.138 μM	High (tested vs. Dengue)	Sustainable, portable, customizable	Moderate LOD, limited field validation	[Kalinke et al., 2023]
Development of an optical sandwich ELONA using a pair of DNA aptamers for the yellow fever virus NS1	Optical aptamer-based ELONA (not a biosensor, but these aptamers can help in the development of biosensors)	YFV (NS1 protein)	Buffer + serum-spiked samples	0.85 nM (buffer)	High	High specificity, ELISA alternative	Requires aptamer pair design, limited serum validation	[Mok et al., 2023]
Synthesis of Truncated DNA Aptamer and Its Application to an Electrochemical Biosensor Consisting of an Aptamer and an MXene Heterolayer for Yellow Fever Virus	Electrochemical aptasensor (MXene + truncated DNA aptamer)	YFV (NS1 protein)	Recombinant NS1 protein in PBS; 10 % human serum	2.757 pM (PBS), 2.366 pM (serum)	High (minimal cross-reactivity)	Rapid, high-sensitivity	Requires aptamer synthesis	[Kwon et al., 2024]

The table shows different biosensors used to detect YFV. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: YFV, Yellow Fever Virus; ZIKV, Zika Virus; DENV, Dengue Virus; CHIKV, Chikungunya Virus; Ab-YF, Anti-Yellow Fever Antibody; DFT, Density Functional Theory; ZnO—NPs, Zinc Oxide Nanoparticles; pDNA, Probe DNA; COOH-MWCNT, Carboxylated Multi-Walled Carbon Nanotubes; ELONA, Enzyme-Linked OligoNucleotide Assay; NS1, Non-Structural Protein 1; PBS, Phosphate Buffered Saline.

platforms for femtomolar and single-copy RNA detection [E Khristunova et al., 2020, A Roberts et al., 2023, Roberts & Gandhi, 2022, Wang et al., 2017, Santhanam, 2021, Roberts et al., 2020, Lai et al., 2017, Roberts & Gandhi, 2020]. Many studies have reviewed JEV sensors. We provide a brief overview of older methods to provide context, but we will continue focusing on recent methods. Electrochemical biosensors such as (3-aminopropyl) triethoxysilane (APTES)-glutaraldehyde-serum systems have LOD in the 10 ng/mL range. A CNP-Screen-Printed Carbon Electrode (SPCE) sensor has shown a 0.36 ng/mL LOD. Optical biosensors are also available, including fluorescence resonance energy transfer (FRET) and MIP-based, which are capable of picomolar sensitivity [Roberts & Gandhi, 2020]. The optical biosensor refers to a type of analytical device that combines a biological recognition component with an optical transducer to provide sensitive optical signals following specific biomolecular interactions [Chen & Wang, 2020]. Recent advances like graphene-based field-effect transistors (GraFET) and reduced graphene oxide-printed sensors detect femtomolar NS1 in seconds. Molecularly imprinted polymer (MIP) sensors, both optical and magnetic, provide picomolar sensitivity. Additionally, CRISPR integrated assays, like Reverse Transcription Loop-Mediated Isothermal

Amplification with CRISPR (RAVI-CRISPR enable detection within an hour [Roberts & Gandhi, 2022]. The use of electrochemical biosensors has also been widely investigated in JEV detection [E Khristunova et al., 2020, A Roberts et al., 2023, Roberts & Gandhi, 2022, Santhanam, 2021, Roberts et al., 2020, Lai et al., 2017, Roberts & Gandhi, 2020]. Recent developments in label-free electrochemical biosensors provide a rapid detection alternative. Nanostructure electrode surfaces (such as gold nanoparticles, manganese oxide nanofibers) have been engineered. The utilization of the DNA/RNA probe, monoclonal antibody, and Peptide Nucleic Acid (PNA) incorporation produces detection limits near femtomolar to zeptomolar concentrations [E Khristunova et al., 2020]. Roberts et al. used a portable smartphone-enabled device known as "Sensit" to develop an immunosensor. The LOD was reported at a range of 1 fM to 1 μM [A Roberts et al., 2023]. Wang et al. created a novel electrochemical immunosensor using carbon nanoparticles (CNPs) and screen-printed electrodes that detects JEV NS1 protein at femtogram levels in 30 min [Wang & Yue, 2025]. Roberts et al. developed an immuno-chromatic LFA probe for JEV NS1 detection, which uses gold nanoparticle antibodies on nitrocellulose membranes, with an LOD of 10 pg/mL (range of 1 pg/mL–1 μg/mL) spiked in serum for under 10 min, and the probe was stable for up to one month at 4 °C. Additionally, this colorimetric immunosensor showed low crossactivity with other flaviviruses [A Roberts et al., 2022]. Recently, fluorescent biosensors have gained attention for JEV detection [Liu et al., 2020, He et al., 2016, Liang et al., 2016, Mohsin et al., 2022, Sasaki et al., 2025]. Sasaki et al. developed a luciferase-based biosensor for the detection of double-stranded RNAs, including JEV [Sasaki et al., 2025]. Collectively, biosensor technologies for JEV have progressed from simple antigen–antibody approaches to highly sensitive platforms that leverage nanomaterials. The portability, rapid detection, and specificity of biosensors make them ideal integrated devices for POC testing in endemic regions. Biosensors are expected to transform JEV surveillance and early diagnostic potential.

West Nile virus

West Nile virus (WNV), transmitted by arthropods, represents a significant threat to global public health [Staji & Angoshtan, 2025]. The emergence of biosensor platforms has allowed for the enhanced detection of West Nile virus. An electrochemical biosensor incorporating a truncated aptamer and an MXene layer detected WNV in ten percent human serum at an LOD of 1.06 pM within ten minutes by alternating current electrothermal flow [Park et al., 2023]. Another example of a biosensor is a surface-enhanced Raman scattering-lateral flow immunoassay (SERS-LFA) detector that utilizes nanoparticles to detect WNV nonstructural proteins with an LOD of 0.1 ng/mL. SERS-LFIA is the integration of the high sensitivity and specificity of the SERS detection with the simplicity and rapidity of LFIA [Jia et al., 2021]. This study was chosen to be included in the review because, even though it was presented as a portable detector, it contains the basic components of a biosensor, including the biorecognition component, the transducer, and the quantitative analysis component.

Furthermore, Cheremiskina et al. created a field-effect transistor-based biosensor tested for the West Nile virus envelope protein [Cheremiskina et al., 2025]. Each of these devices promotes quick and deployable testing diagnostics in field settings, but needs more validation in clinical settings (Table 3).

Tick-borne encephalitis

Tick-borne encephalitis virus (TBEV) is a matter of public health importance because of its ability to cause severe neurological damage, including encephalitis and meningoencephalitis [Kim et al., 2018, Kudryavtsev et al., 2025]. Sensitive and rapid detection methods are crucial for the effective management and control of TBEV infection. Khristunova et al. developed a silver nanoparticle-based electrochemical immunosensor for TBEV antibody detection via cathodic linear sweep

Table 3
Comparison of biosensor technologies for detecting West Nile virus.

Paper Title	Technology	Description	Sample type	Limit of Detection (LOD)	Specificity	advantages	limitations	Source
Automatic and sensitive detection of West Nile virus nonstructural protein 1 with a portable SERS–LFIA detector	SERS–LFIA Detector (mentioned as a portable detector)	Uses Au@Ag nanoparticles with double-layer Raman molecules for NS1 protein detection via portable strips.	Recombinant NS1 protein; inactivated virions in serum-like diluents	0.1 ng/mL	High, no cross-reactivity with DENV, YFV, ZIKV, EBOV, ADV	Ultrasensitive detection, High specificity, Portable and automated platform suitable for field use	Requires synthesis of dual-layer Au@Ag nanoparticles, Limited to NS1 detection; not multiplexed	[Jia et al., 2021]
Fast-response electrochemical biosensor based on a truncated aptamer and MXene heterolayer for West Nile virus detection in human serum	Electrochemical Biosensor	Employs a truncated aptamer and MXene layer with ACEF for protein detection in serum.	Recombinant NS1 protein in deionized water; 10 % human serum	2.57 pM for WNV diluted in deionized water and 1.06 pM for WNV diluted in 10 % human serum	High selectivity for WNV	Rapid response, high sensitivity, aptamer-based specificity	Requires MXene synthesis; aptamer stability may vary; single-target format	[Park et al., 2023]
Method for express-detection of recombinant West Nile Virus E protein	field-effect transistor fabricated by optical lithography using a silicon-on-insulator (SOI) biosensor	Detects E protein using SOI technology with hafnium oxide coating via current changes.	recombinant West Nile Virus E protein solutions	10 pg/μL	Specific for WNV E protein	Combines electrochemical and optical readouts, high sensitivity, and rapid detection	Requires dual instrumentation, limited field validation	[Cheremiskina et al., 2025]

The table shows different biosensors used to detect WNV. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: WNV, West Nile Virus; DENV, Dengue Virus; YFV, Yellow Fever Virus; ZIKV, Zika Virus; EBOV, Ebola Virus; ADV, Adenovirus; SERS, Surface-Enhanced Raman Spectroscopy; LFIA, Lateral Flow Immunoassay; NS1, Non-Structural Protein 1; CRISPR, Clustered Regularly Interspaced Short Palindromic Repeats; crRNAs, CRISPR RNAs; Cas12a, CRISPR-associated protein 12a; ACEF, alternating current electrothermal flow; SOI, Silicon-on-Insulator.

voltammetry on a gold–carbon electrode. The assay achieved an LOD of 50 IU/mL with high specificity, enabled by optimized antigen immobilization [Khristunova et al., 2019]. Ivanov et al. developed an electrochemical interface with a hydrogel and machine learning to analyze antibodies, antigens, and an antibody–antigen complex of TBEV with an accuracy of 93 % detection rate with complex samples. This platform enables rapid detection of the virus [Ivanov et al., 2020]. Furthermore, Khristunova et al. created an electrochemical immunoassay that detects the presence of TBEV antibodies through the utilization of silver nanoparticle bioconjugates and linear sweep anodic stripping voltammetry (LSASV) as a readout. The Abs@AgNP format, which was tested alongside two other formats, demonstrated the greatest sensitivity and reproducibility out of the three formats tested, with an LOD of 90 IU/mL. The method provides ease of preparation of the sensor via microtiter plates and represents a stable, low-cost alternative to ELISA for screening antibodies in serum [E Khristunova et al., 2020]. Baldina et al. utilized a biosensor based on polyelectrolyte matrices by using charged polyethyleneimine and negatively charged polystyrene sulfonate for immobilizing and detecting TBEV antibodies, which was highly sensitive for detecting viruses with an LOD of five viral particles [Baldina et al., 2022]. All of these biosensor technologies provide fast and sensitive alternatives to classical laboratory methods, meeting the urgent demand for time-consuming TBEV detection. These methods further improve the specificity and scalability of these assays, presenting new opportunities for improved diagnosis and prevention of TBEV [Kim et al., 2018, Khristunova et al., 2019, Ivanov et al., 2020, Baldina et al., 2022].

JEV biosensors utilize nanomaterials, graphene FETs, and CRISPR-based platforms for femtomolar and single-copy RNA detection [E Khristunova et al., 2020, Roberts & Gandhi, 2022, Santhanam, 2021, Wang & Yue, 2025, Mohsin et al., 2022]. Electrochemical sensors have been developed for TBEV detection [Khristunova et al., 2019, Ivanov et al., 2020, E Khristunova et al., 2020, Baldina et al., 2022]. Diagnostics based on biosensors for many flaviviridae viruses (including Omsk hemorrhagic fever virus, Usutu virus, Israel turkey meningoencephalitis virus, Wesselsbron virus, Tembusu virus, Louping ill virus, Kyasanur Forest disease virus, and Tyuleniy virus) are still underexplored, representing an important gap in molecular surveillance efforts (Table 4).

Bunya viridae

Bunyaviridae biosensors allow for rapid, sensitive diagnosis. Zaher et al. developed a colorimetric assay using gold nanoparticles to detect unamplified Rift Valley fever virus (RVFV) ribonucleic acid, achieving an LOD of 10 copies per reaction within 30 min by utilizing colorimetric shifts induced by surface plasmon resonance [Zaher et al., 2018]. Alharbi et al. described an electrochemical aptasensor that incorporates deoxyribonucleic acid aptamers and has an LOD of 0.015 ng/mL [Alharbi et al., 2024]. Furthermore, Shafagati et al. demonstrated that nanotrap particles significantly enhance the detection of nucleocapsid proteins in a range of matrices, such as serum, while also targeting and reducing interference, leading to improved sensitivity [Shafagati et al., 2015].

Together, these biosensor innovations will enable field-applicable and efficient detection.

Another member of this family and a close relative of Crimean–Congo hemorrhagic fever virus (CCHFV) is the Nairobi sheep disease virus (NSDV). A biosensor assay was developed by Karaaslan et al. via split-NanoLuc technology to detect antibodies to the CCHFV nucleoprotein and GP38 glycoprotein. The cross-reactivity analyses indicated that antisera raised against NSDV had detectable responses [Karaaslan et al., 2025]. Orthobunyavirus spike characterization reveals that the Gc head domain is a crucial target for neutralizing antibodies and may also serve as a biomarker. It may be possible to engineer biosensors to detect trimeric spikes or head domains of viruses such as the Schmallenberg virus [Hellert et al., 2019]. Many veterinary bunyaviruses, including Soldado, La Crosse, Snowshoe hare, Cache Valley, Main Drain, Aino, and Bhanja, have not been evaluated for biosensor applications (Table 5).

Table 4
Comparison of biosensor technologies for Tick-borne encephalitis virus.

Paper Title	Biosensor Type	Sample type	Sensitivity/LOD	Specificity	Advantages	Limitations	References
Preparation and investigation of silver nanoparticle–antibody bioconjugates for electrochemical immunoassay of tick-borne encephalitis	Electrochemical immunosensor	immunoglobulin products	LOD: 50 IU·mL^{-1}	High (r^2 = 0.989)	Simple, effective for monitoring TBEV in immunological products	Limited range (50–1600 IU·mL^{-1}), requires stabilization	[Khristunova et al., 2019]
Tick-Borne Encephalitis Electrochemical Detection by Multilayer Perceptron on Liquid–Metal Interface	Electrochemical biosensor with machine learning	Hydrogel doped with TBE antigen (AG, 2 × 10^3 particles/mL), antibody (AB, 1:3000), or AB–AG; tested with BSA interference (0.07 wt %)	93 % classification accuracy; demonstrated detection at 2 × 10^3 particles/mL (AG) and AB at 1:3000 dilution; no formal LOD reported	High (93 % accuracy with interfering agents)	Rapid, convenient for express virus detection, no calibration needed	Requires machine learning model training	[Ivanov et al., 2020]
Electrochemical immunoassay for the detection of antibodies to tick-borne encephalitis virus by using various types of bioconjugates based on silver nanoparticles	Electrochemical immunosensor	Human serum (IgG antibodies to TBEV)	LOD: 90 IU·mL^{-1}; Range: 100–1600 IU·mL^{-1}	High (implied by antibody specificity and validated vs ELISA)	Simplified preparation, stable reagents, low-cost, compatible with serum	Requires an acid dissolution step, limited to antibody detection	[E Khristunova et al., 2020]
Immunochemical biosensor for single virus particle detection based on a molecular crowding polyelectrolyte system	Electrochemical immunosensor	Viral particle suspensions (Tick-borne encephalitis virus, Rabies virus; diluted in PBS or distilled water)	LOD: 5 viral particles in 5 μl (two orders lower than ELISA)	High (specific antibodies used)	low LOD, suitable for express diagnostics and Point-of-Care	Limited to TBEV, optimization of the 3D-matrix is required	[Baldina et al., 2022]

The table shows different biosensors used to detect Tick-borne Encephalitis Virus. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: TBEV, Tick-Borne Encephalitis Virus; LOD, Limit of Detection; r^2, Coefficient of Determination; ELISA, Enzyme-Linked Immunosorbent Assay; RT-qPCR, Reverse Transcription Quantitative Polymerase Chain Reaction; BSL-3, Biosafety Level 3.

Table 5
Comparison of biosensor technologies for bunyaviridae.

Paper Title	Biosensor Type	Virus Targeted	Sample type	Sensitivity/ LOD	Specificity	Advantages	Limitations	Reference
Colorimetric Detection of Unamplified Rift Valley Fever Virus Genetic Material Using Unmodified Gold Nanoparticles	Colorimetric assay (not mentioned as a sensor)	RVFV	serum	LOD: 10 RNA copies/ reaction	High accuracy and specificity	Rapid (30 min), no amplification, field-deployable	Qualitative results require optimization	[Zaher et al., 2018]
Development of a label-free electrochemical aptasensor for Rift Valley fever virus detection	Label-free electrochemical aptasensor	RVFV	serum	LOD: 0.015 ng/ mL	Negligible cross-reactivity with nonspecific proteins	Excellent sensitivity, rapid	Requires electrode preparation	[Alharbi et al., 2024]
Rapid, sensitive, and species-independent detection of Crimean Congo hemorrhagic fever virus nucleoprotein and GP38 antibodies	Luminescent biosensor using split-NanoLuc (NanoBiT)	CCHFV; cross-reactivity with NSDV	serum	~95.2 % sensitivity; detects antibodies within 30 min	>98 %; cross-reactivity observed with NSDV antisera	Rapid, species-independent, no need for secondary antibodies, suitable for field use	Cross-reactivity with NSDV may limit specificity in endemic regions	[Karaaslan et al., 2025]

The table shows different biosensors used to detect the Bunyaviridae family viruses. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: RVFV, Rift Valley Fever Virus; CCHFV, Crimean-Congo Hemorrhagic Fever Virus; LOD, Limit of Detection; NP, Nucleoprotein; SERS, Surface-Enhanced Raman Spectroscopy; NSDV, Nairobi Sheep Disease Virus.

Reoviridae

Blue tongue

Reoviridae virus biosensors achieve sensitive, multiplexed, and field-deployable diagnostics. Bluetongue, a disease of significant economic concern globally, is caused by the Bluetongue virus (BTV). Evanescent wave fiber-optic immunosensors (EWFIs) are a type of optical biosensor. Yin et al. reported an EWFI assay designed to detect the BTV VP7 protein that reached an LOD of 10 ng/mL with high specificity and real-time response in 15 min or less. This particular platform eliminates the need for washing and can be used up to ten times, which increases its applicability in the field [Yin et al., 2015]. Sahoo et al. created a lateral flow device (LFD) employing gold nanoprobes and reached an LOD of 1.875 μg/ml for BTV IgG in sheep. Importantly, they reported 96 % sensitivity and 99.23 % specificity [Sahoo et al., 2023]. In another study,

Table 6
Comparison of biosensor technologies for reoviridae.

Paper Title	Biosensor Type	Virus Targeted	Sample type	Sensitivity/ LOD	Specificity	Advantages	Limitations	References
Establishment of evanescent wave fiber-optic immunosensor method for the detection of bluetongue virus	Evanescent Wave Fiber-Optic Immunosensor	BTV	Purified monoclonal antibody 3E2 against VP7; viral antigens	10 ng/mL for monoclonal antibody 3E2.	Specific to BTV VP7, no cross-reactivity is mentioned.	Rapid (15 min); recyclable fiber (at least 10 times); sensitive and specific.	Potential need for optical equipment; limited to lab settings.	[Yin et al., 2015]
Development and evaluation of a gold nanoprobe-based lateral flow device for rapid and sensitive serodetection of Bluetongue in sheep	Lateral Flow Device (LFD) using gold nanoprobe-conjugated secondary antibodies/ better classified as a device rather than a biosensor	BTV	Sheep serum	Sensitivity: 96 %	Specificity: 99.23 %	Rapid, field-deployable, cost-effective, no need for skilled personnel or equipment	Detects IgG—may miss early infection; limited to serological surveillance	[Sahoo et al., 2023]
Development of Multiwalled Carbon Nanotube-Based Immunobiosensor for the Detection of Bluetongue Virus	Electrochemical immunosensor using functionalized MWCNTs on SPCE	Bluetongue virus (BTV), *Reoviridae*	Viral antigens	Not explicitly quantified; described as rapid and sensitive	Antigen-specific binding to BTV antibodies	-Rapid, pen-side applicability, Low-cost, farmer-friendly design	Prototype stage	[Sudan Guray et al., 2021]
Rapid homogenous detection of the Ibaraki virus NS3 cDNA at picomolar concentrations by magnetic modulation	Magnetic Modulation Biosensing (MMB)	Ibaraki Virus	NS3 cDNA	1.9 pM of NS3 cDNA.	Specific to target DNA; discriminates from controls.	Rapid (18 min); homogeneous (no washing); sensitive.	Requires a magnetic field setup, specific to DNA detection.	[Danielli et al., 2009]

The table shows different biosensors used to detect Reoviridae family viruses. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: BTV, Bluetongue virus; FLISA, Fluorescence-Linked Immunosorbent Assay; VP7, Viral Protein 7; CV, Coefficient of Variation; ELISA, Enzyme-Linked Immunosorbent Assay; LFD, Lateral Flow Device; IgG, Immunoglobulin G; MWCNTs, Multi-Walled Carbon Nanotubes; SPCE, Screen-Printed Carbon Electrode; FMIA, Fluorescent Microsphere Immunoassay; EHDV, Epizootic Hemorrhagic Disease Virus; cELISA, Competitive ELISA; AHSV, African Horse Sickness Virus; DIVA, Differentiating Infected from Vaccinated Animals; MMB, Magnetic Modulation Biosensing; NS3, Non-Structural Protein 3; pM, Picomolar.

Guray et al. created an immunosensor using multiwalled carbon nanotubes. This biosensor was functionalized with viral antibodies and modified onto screen-printed electrodes. This provides a cost-effective on-site diagnosis for the rapid detection of BTV [Sudan Guray et al., 2021]. There are immunoassays developed for Epizootic Hemorrhagic Disease Virus (EHDV) and African horse sickness (AHS) [Drolet & Reister-Hendricks, 2021, Sánchez-Matamoros et al., 2016]. However, there have not been any sensors developed for these viruses.

Ibaraki virus

Although recent studies on Ibaraki virus biosensors are limited, a review of the literature revealed a relevant study within a retrospective timeframe. Danielli et al. presented a method for detecting Ibaraki virus nonstructural protein 3 cDNA via a magnetic modulation biosensing (MMB) system. Compared with RT−PCR and laser scanning microscopy, the MMB system achieves clear signal differentiation after just one PCR cycle, detecting as little as 1.9 pM DNA within 18 min [Danielli et al., 2009]. Peruvian horse sickness virus, Equine encephalosis virus, Yunnan virus, and Kasba virus are the viruses from this family; their biosensors are not well studied (Table 6).

Rhabdoviridae

Vesicular stomatitis

Tunable resistive pulse sensing (TRPS) repeatedly and reliably measured particle concentrations at values as low as 10^7 particles/mL [Akpinar & Yin, 2015]. Furthermore, Monoclonal antibody 8G5F11 exhibits wide cross-reactivity against numerous vesiculovirus G proteins, and the specificity and strength of binding, established by both flow cytometry and surface plasmon resonance, demonstrate the viability of 8G5F11 as a molecular recognition element for detecting vesiculovirus [Munis Altar et al., 2018].

Bovine Ephemeral fever

Tobin et al. studied the potential utility of accelerometers as biosensors to detect Bovine Ephemeral Fever (BEF) by measuring movement intensity in cattle [Tobin et al., 2020]. A recent study revealed that accelerometer data based on movement variation detects BEFs in cattle, with changes observed one day before manager detection or on the same day, although further research is needed to reduce false positives arising from other similar conditions [Trieu et al., 2025]. Biosensors have not been developed for some Rhabdoviridae viruses, such as Kotonkan virus and Cocal virus (Table 7).

Asfarviridae

African swine fever virus

Asfaviridae biosensors are diverse, from CRISPR, electrochemical, Fluorescence-based, and microfluidic devices to behavioral [He et al., 2020, H Wang et al., 2024, Ki et al., 2022, Ye et al., 2019, Yuan et al., 2023]. Enhancements using CRISPR-Cas12a platforms allow for amplification-free detection either using fluorescence or surface-enhanced Raman scattering, achieving LODs of 100 fM and 10 fM, respectively [He et al., 2020, H Wang et al., 2024]. Furthermore, a colorimetric biosensor for African swine fever virus (ASFV) detection, which utilizes CRISPR/Cas with the assistance of CRISPR/Cas12a and urease, enables detection from clinical porcine tissue samples [Ki et al., 2022]. Moreover, a novel CRISPR/Cas14a and G-quadruplex DNAzyme was created as a biosensor coupled to a microfluidic paper-based analytical device with an LOD of 5 copies/μL [Zhao et al., 2024]. A universal CRISPR/Cas12a-based lateral flow biosensor for the direct detection of seven types of ASFV in whole blood demonstrated an LOD of 2.5×10^{-15} M in approximately 2 h, providing a visual readout without the need for specialized equipment [Wu et al., 2020]. An additional dual-mode recombinase polymerase amplification (RPA)-assisted CRISPR/Cas12a approach using magnetic separation with colorimetric and fluorescence detection yielded an LOD of 20 copies/mL, 100 % specificity, and sensitivity with clinical samples [Mao et al., 2023].

Microfluidic devices and plasmonic sensors have also been developed for ASFV. Wang et al. developed a magnetoelastic-chip integrated microfluidics biosensor that detects ASFV antigens with an LOD of only 0.83 pg/mL, delivering high sensitivity and portability by relying on

Table 7
Comparison of sensor technologies for rhabdoviridae.

Paper Title	Biosensor Type	Virus Targeted	Sample type	Sensitivity/ LOD	Specificity	Advantages	Limitations	References
Characterization of vesicular stomatitis virus populations by tunable resistive pulse sensing	Tunable Resistive Pulse Sensing (TRPS) – not a biosensor	Vesicular Stomatitis Virus (VSV)	Laboratory-prepared virus stocks from BHK-21 cell culture	Down to 10^7 particles/mL	High for sizing and counting; comparable to TEM but broader range	High-throughput; accurate sizing/ counting; 50-fold wider range than TEM; simpler than TEM	Reduced accuracy of TRPS at high particle concentrations due to potential nanopore clogging	[Akpinar & Yin, 2015]
Sensor-based disease detection: A case study using accelerometers to recognize symptoms of Bovine Ephemeral Fever	Accelerometer sensor	Bovine Ephemeral Fever Virus (BEFV)	Live cattle (heifers fitted with collars)	Detects changes 24 h before visual symptoms	Specific to BEF symptoms (lameness, fever); lower movement intensity (MI)	Remote/early detection; reduces observation time; potential for real-time monitoring	Case study (small sample, $n = 2$ ill); not validated for other diseases	[Tobin et al., 2020]
Potential of accelerometers to remotely early detect bovine ephemeral fever in cattle using pattern mining	Wearable sensor-based behavioral biosensor	Bovine Ephemeral Fever Virus (BEFV)	Live cattle (heifers fitted with collars; validated in a herd of 73 cows)	Behavioral changes detected 0–1 day before clinical signs	100 % sensitivity based on blood-tested BEF-positive animals (5/5 correctly predicted within 3 days of clinical signs)	Specificity not calculable	May misclassify behavior changes due to estrus, weather, or other diseases	[Trieu et al., 2025]

The table shows different biosensors used to detect the Rhabdoviridae family viruses. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table: VSV, Vesicular Stomatitis Virus; TRPS, Tunable Resistive Pulse Sensing; Movement intensity (MI); TEM, Transmission Electron Microscopy; BEFV, Bovine Ephemeral Fever Virus; N/A, Not Applicable.

resonance frequency changes [Z Wang et al., 2024]. A microfluidic device containing a label-free photonic integrated circuit biosensor reported 80.97 % sensitivity and 88.46 % specificity, with reference samples validated via PCR [Manessis et al., 2024]. Localized surface plasmon resonance (LSPR) sensors based on gold nanoparticles have been reported to have twice the sensitivity of ELISA and can detect ASFV antibodies at a dilution of 1:5120 [Lamtha et al., 2025]. Moreover, a one-step nanoplasmonic biosensor was developed to detect ASFV p30 antibodies in a setting of 20 min with a sensitivity of 1:100–1:16,000 dilution [Zhao et al., 2022].

Another detection method for this virus is the microfluidic-circular fluorescent probe-mediated isothermal nucleic acid amplification (CFPA) system, which allows for the detection of nucleic acids within 10.8 min (sensitivity 92.73 %, 100 % specificity), with an LOD of 10 copies/μL [Ye et al., 2019]. The photoreactive paper-based electrochromic sensing chips containing RPA achieved an LOD of 2.72 copies/μL, with field applicability enhanced via a smartphone RGB detection option [Yuan et al., 2025]. Combined with loop-mediated isothermal amplification (LAMP), a carbon nanodot-based fluorescence biosensor was employed to detect ASFV, where the LOD was determined to be 15.21 copies/μL, in "turn-off-on" mode on the basis of pH changes, which allowed quick and sensitive testing in the field [Cao et al., 2022]. Additionally, a strip lateral flow gene assay utilizing gold nanoparticles with RPA was used in blood with an LOD of 10^2 copies/μL, achieving rapid POC diagnostic in settings with limited capabilities [Wang et al., 2021].

A chimeric DNA/LNA-based biosensor detected the vp72 gene of ASFV with an LOD of 178 copies/μL at twenty minutes from pig blood [Biagetti et al., 2018]. Moreover, a quantum dot microsphere-based immunoassay detected ASFV antibodies in serum with an LOD of a 1:64,000 dilution. This method had a 98.7 % rate of agreement with ELISA, and it can be completed in 25 min with minimal steps, making it appropriate for resource-limited environments [Li et al., 2022]. Moreover, colloidal gold immunochromatography assays and electrochemical sensing chips targeting ASFV p54 have LODs of 1 ng/mL and 0.48 copies/μL, respectively [Yuan et al., 2023, Zhang et al., 2024]. Remote sensing can provide an epidemiological context for controlling this virus. Research in Germany has shown that satellite data can assist in carcass searches for wild boars, resulting in a better, rapid response plan [Bergmann et al., 2023]. In addition to detecting nucleic acids and antibodies, an accelerometer-based sensor has been validated to detect behavioral changes among wild boar during ASF, resulting in a 10–20 % reduction in activity during viremia [Morelle et al., 2005]. Oxford Nanopore MinION sequencing with ASF-FAST software also provides ASFV genome resolution in under 10 min [O'Donnell et al., 2019]. These newly developed sensor platforms show the promise of deploying ASFV diagnostics in the field. Despite the Thogoto virus belonging to the family Asfarviridae, no biosensor-based detection systems have been reported or investigated thus far (Table 8).

Application of nanomaterials in sensors for veterinary viruses

Nanomaterials are utilized in a broad manner in different veterinary viral biosensors and work to improve the specificity, sensitivity, and rapidity of sensors. Many sensors have been developed for arboviruses of animal pathogens, in which different nanostructures are tailored to suit the specific viral requirements of the diagnosis. For example, MagPlex nanostructured magnetic microspheres in Western Equine Encephalitis Viruses, Zinc oxide nanoparticles in Dengue, Zika virus, Chikungunya, and Yellow fever virus, and carboxylated multi-walled carbon nanotubes in Yellow fever virus genosensing, all work to demonstrate the capability of nanostructured interfaces to refine electron transfer, bioreceptor immobilizations, and signal differences [Simão et al., 2020, Liu et al., 2018, Kalinke et al., 2023].

For Japanese Encephalitis Virus sensors, many nanostructures, including carbon nanoparticles, gold nanorods, graphene transistors, magnetic microspheres, and metallic nanoparticles, have been used in electrochemical, optical, and acoustofluidic platforms [E Khristunova et al., 2020, A Roberts et al., 2022, Roberts et al., 2020, Lai et al., 2017, Liu et al., 2020, He et al., 2016, Mohsin et al., 2022, A Roberts et al., 2022, Tung et al., 2019, Luo et al., 2019, A Roberts et al., 2023, Lim & Chin, 2017, Geng et al., 2016].

The use of gold nanoparticles has particularly illustrated the importance of nanomaterials in RVFV detection [Zaher et al., 2018]. Split-NanoLuc biosensors also help in the rapid detection of Crimean-Congo Hemorrhagic Fever Virus [Karaaslan et al., 2025]. Furthermore, Bluetongue Virus detection has been enhanced by multi-walled carbon nanotube-based electrochemical immunosensors and gold nanoprobe-derived lateral flow devices [Sahoo et al., 2023, Sudan Guray et al., 2021].

African Swine Fever Virus diagnosis was improved by lateral flow strips based on gold nanoparticles, carbon dots with loop-mediated isothermal amplification, nanoplasmonic biosensors, gold nanoparticle localized surface plasmon resonance chips, and nanopore sequencing platforms, which collectively enabled rapid and highly sensitive field testing for viral DNA and antibodies [Cao et al., 2022, Wang et al., 2021, Lamtha et al., 2025, Zhao et al., 2022, O'Donnell et al., 2019]. Similarly, gold-silver core-shell nanoparticles demonstrated the importance of Nanomaterials, wherein their use directly enhanced Raman signals, thus permitting highly sensitive field testing of viral antigens from West Nile virus [Jia et al., 2021]. Additionally, the use of silver nanoparticles in antibody bioconjugates and electrochemical platforms showed that Nanomaterials greatly improved signal stability and sensitivity, thus providing useful tools for trusted field testing of TBEV infection [Khristunova et al., 2019, E Khristunova et al., 2020]. Overall, Nanomaterials were shown to be versatile enhancers of viral biosensors.

Future perspectives

Recently, biosensors have progressed toward fast, specific, user-friendly, multitarget formats suitable for veterinary virus detection. Systems such as Luminex-based immunoassays, CRISPR-based, microfluidic devices such as magnetoelastic sensors, and lateral flow biosensors screen many veterinary arboviruses [Roberts & Gandhi, 2020, Mohsin et al., 2022, He et al., 2020, Ye et al., 2019, Mann & Pitts, 2022]. Furthermore, nanomaterials are also components of biosensors, increasing their sensitivity, miniaturization, and signal transduction efficiency [Naresh & Lee, 2021, Abdoli et al., 2025]. Various nanomaterials have been explored for use in arbovirus detection and diagnostic enhancement as mentioned above. Paying attention to the development of nanobiosensors would benefit future arbovirus detection and surveillance.

Moreover, commercialization is essential for making biosensors universally useful by comparing them with established methods such as qPCR and ELISA. Field tests can also confirm the performance under different conditions [Ulucan-Karnak et al., 2024]. Low-cost sensors, such as immunosensors for the detection of JEV [Wang & Yue, 2025], TBEV [E Khristunova et al., 2020], BTV, and CRISPR-based sensors [Mao et al., 2023] are essential in the context of low-resource settings. Easy application and minimal training are also essential for point-of-care biosensors [Zhou et al., 2021]. Behavioral sensors, such as accelerometers for BEFV and ASFV, offer new ways of identifying initial outbreaks [Tobin et al., 2020, Trieu et al., 2025]. Biosensors hold great promise for improving the diagnosis of veterinary arboviruses. Their development toward multitarget, hand-held, and networked forms will help establish more resilient disease surveillance systems, especially as climate change increases the threat of outbreaks [Morelle et al., 2005, O'Donnell et al., 2019].

Conclusion

The rapid development of biosensors has increased the monitoring of

Table 8
Comparison of biosensor technologies for African Swine Fever Virus.

Paper Title	Biosensor Type	Sample type	Sensitivity/LOD	Specificity	Advantages	Limitations	Reference
High-throughput and all-solution phase ASFV detection using CRISPR-Cas12a and fluorescence-based point-of-care system	CRISPR-Cas12a-based fluorescence detection system	Synthetic dsDNA (A-DNA, M-DNA) + spiked porcine plasma	Initial LOD: 1 pM (2 h); improved to 100 fM after 24 h incubation	High sequence specificity; discriminates closely matched targets	Amplification-free, highly sensitive, stable at physiological temperature, portable cartridge-based format	Requires a custom fluorometer; longer incubation for ultralow detection; not yet validated on field samples	[He et al., 2020]
A CRISPR/Cas12a-SERS platform for amplification-free detection of African swine fever virus genes	CRISPR/Cas12a-based SERS platform	Viral gene fragments; tested in the serum system and extracted nucleic acids from viral samples	Detection range: 100 nM to 10 fM; LOD: 10 fM	High selectivity; RSD < 8 %	Amplification-free, ultrasensitive, rapid (~2 h), suitable for serum and pseudovirus samples	Requires SERS setup and magnetic enrichment; not yet validated for field deployment	[H Wang et al., 2024]
CRISPR/Cas-Assisted Colorimetric Biosensor for Point-of-Use Testing for African Swine Fever Virus	Colorimetric biosensor	Synthetic dsDNA (ASFV target + mismatched controls) + porcine clinical tissue DNA (spleen, kidney)	50 Pm	The absorbance peak for ASFV was 5.95 and 3.61 times greater than that of the other mismatched ones.	Rapid, simple, robust, highly sensitive, no complex gene duplication	Requires magnetic separation, limited to specific samples	[Ki et al., 2022]
Microfluidic-CFPA Chip for the Point-of-Care Detection of African Swine Fever Virus with a Median Time to Threshold in approximately 10 min	Isothermal nucleic acid amplification biosensor	220 pig clinical samples (field validation)	Limit of detection: 10 copies/μL 92.73 % sensitivity (based on 220 clinical samples)	100 % specificity	Rapid (median threshold time ~10.8 min), portable, high-throughput, stable (C.V. < 5 %)	Requires fluorescence detection setup; may not distinguish gene-deleted strains	[Ye et al., 2019]
Sensitive detection of African swine fever virus p54 based on in situ amplification of a disposable electrochemical sensor chip	Electrochemical LAMP-based biosensor	ASFV p54 gene + good results in real samples	LOD: 3.0×10^{-13} g/L (≈0.48 copies/μL); range: 1.0×10^{-12} to 1.0×10^{-6} g/L	High specificity; validated on real samples	Ultrasensitive, portable, low-cost, disposable, suitable for on-site ASFV detection	Requires gold nanoparticle (AuNP) deposition and PDMS sealing; targets p54 protein only	[Yuan et al., 2023]
CRISPR/Cas14 and G-Quadruplex DNAzyme-Driven Biosensor for Paper-Based Colorimetric Detection of African Swine Fever Virus	CRISPR/Cas14a-based paper biosensor	porcine plasma, synthetic DNA	LOD: 5 copies/μL	High specificity; distinguishes wild-type vs mutant ASFV with a 2-nt difference	Amplification-free, low-cost, portable, suitable for low-resource settings and field use	Requires precise crRNA design; colorimetric signal may be affected by sample matrix or lighting	[Zhao et al., 2024]
A CRISPR/Cas12a-Based Universal Lateral Flow Biosensor for the Sensitive and Specific Detection of African Swine-Fever Viruses in Whole Blood	CRISPR/Cas12a-based lateral flow biosensor	recombinant plasmid DNA + whole blood (clinical swine samples)	LOD: 2.5×10^{-15} M; detection within 2 h	High specificity; detects 7 ASFV genotypes from whole blood	Visual, low-cost, rapid, multiplex-capable, field-adaptable	Requires PCR setup; lateral flow readout may be semiquantitative; not fully validated for food matrices	[Wu et al., 2020]
Fluorescence and Colorimetric Analysis of African Swine Fever Virus Based on the RPA-Assisted CRISPR/Cas12a Strategy	Dual-mode CRISPR/Cas12a biosensor (fluorescence + colorimetry)	Serum, tested in clinical samples	Limit of detection: 20 copies/mL; linear in serum	100 % specificity and sensitivity in clinical samples; no cross-reactivity	Combines high sensitivity of fluorescence with the visual simplicity of colorimetry; low-cost and field-adaptable	Requires magnetic separation and enzyme-linked substrate; the preamplification step adds complexity	[Mao et al., 2023]
Magnetoelastic-Chip Integrated Microfluidic Biosensor for the Detection of African Swine Fever Virus	Magnetoelastic microfluidic biosensor	ASFV antigen	Limit of detection: 0.83 pg/mL; linear range: 10 pg/mL–1 mg/mL	Specific in distinguishing ASFV	Portable, low-cost, rapid, suitable for field deployment	Requires precise microfabrication and calibration of magnetoelastic chips	[Z Wang et al., 2024]
Label-Free Detection of African Swine Fever and Classical Swine Fever in the Point-of-Care Setting Using Photonic Integrated Circuits Integrated in a Microfluidic Device	Photonic integrated circuits (PICs) sensor	oral fluid and serum samples	80.97 % sensitivity (ASF)	88.46 % (ASF)	Pen-side detection, novel technological advancements	Requires validation studies, moderate specificity	[Manessis et al., 2024]

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Table 8 (*continued*)

Paper Title	Biosensor Type	Sample type	Sensitivity/LOD	Specificity	Advantages	Limitations	Reference
Solid-state dewetting sputtered ultrathin Au films for LSPR sensing chip toward African swine fever virus detection.	LSPR-based antibody biosensor	swine blood serum	LOD: 1:5120 dilution in serum (2× more sensitive than ELISA)	High specificity for ASFV antibodies	Label-free, low-cost, reproducible, stable, regenerable, suitable for point-of-field (POF) use	Requires thermal annealing at 500 °C; detection limited to antibody presence (not viral genome)	[Lamtha et al., 2025]
One-Step Rapid and Sensitive ASFV p30 Antibody Detection via Nanoplasmonic Biosensors	Nanoplasmonic antibody biosensor (EOT-based)	Clinical pig serum samples	Linear detection range: 1:100–1:16,000 dilution; detection time: ≤20 min	96.6 % coincidence rate with clinical serum samples	Rapid, label-free, minimal sample prep, compatible with standard microplate readers, and avoids cross-contamination	Detects antibodies (not viral genome); may miss early infection before seroconversion; requires EOT-compatible setup	[Zhao et al., 2022]
Photoelectrochromic sensing chip with recombinase polymerase amplification for visual detection of African swine fever virus	Photoelectrochromic RPA-based sensor	Synthetic ASFV DNA	LOD: 2.72 copies/μL (1.7×10^{-12} g/L)	High specificity; no cross-reactivity reported	Visual, portable, intuitive, no complex instruments, smartphone-compatible, semiquantitative, and quantitative	Requires primer immobilization and photoactive material synthesis; performance may vary under ambient light.	[Yuan et al., 2025]
Carbon nanodots combined with loop-mediated isothermal amplification (LAMP) for the detection of ASFV.	Fluorescence-based LAMP biosensor	blood or tissue	LOD: 15.21 copies/μL	High accuracy in real samples; no cross-reactivity reported	Rapid, low-cost, simple, stable fluorescence, suitable for early ASFV detection	Requires precise pH control; fluorescence readout may be affected by sample matrix or ambient conditions	[Cao et al., 2022]
A strip of lateral flow gene assay using gold nanoparticles for point-of-care diagnosis of African swine fever virus in a limited environment	RPA-based lateral flow detection probe with AuNPs	Synthetic ASFV p72 gene DNA, blood	LOD: 10^2 copies/μL	Specific for ASFV; distinguishes from CSFV	Rapid (30 min), low-temperature (37–42 °C), visual, instrument-free, field-deployable	Semiquantitative; limited multiplexing; requires primer modification and AuNP probe synthesis.	[Wang et al., 2021]
Chimeric DNA/LNA-based biosensor for the rapid detection of African swine fever virus	DNA/LNA hybridization biosensor	blood	LOD: 178 copies/μL; LOQ: 245 copies/μL; field range: 373–1058 copies/μL	High specificity; excellent correlation with OIE-approved qPCR	Rapid (~5 min), reusable (up to 40 tests/surface), low-cost, no amplification required	Limited sensitivity compared to amplification-based methods; requires surface preparation	[Biagetti et al., 2018]
Rapid and ultrasensitive detection of African swine fever virus antibody on-site using QDM-based ASFV immunosensor (QAIS)	QDM-based antibody immunosensor	serum	Detection sensitivity: 1:64,000 serum dilution; $R^2 = 0.9947$	98.7 % coincidence with ELISA in 151 clinical samples	Ultrasensitive, rapid (25 min), simple operation, field-deployable, superior to ELISA and CGICS	Detects antibodies (not viral genome); may miss early infection before seroconversion	[Li et al., 2022]
An ultrasensitive strip sensor for rapid detection of African swine fever virus	Colloidal gold immunochromatographic assay (GICA)	p30 protein, clinical serum samples	LOD: 1 ng/mL of recombinant p30 protein	High specificity; no false positives in clinical negatives	Rapid (15 min), visual, stable (3 months), field-deployable, suitable for high-throughput screening	Targets p30 antigen only; may miss early infection before antigen expression; requires antibody pairing optimization	[Zhang et al., 2024]
Remote Sensing Provides a Rapid Epidemiological Context for the Control of African Swine Fever in Germany	Remote sensing-based epidemiological surveillance tool	Satellite imagery	Not applicable (surveillance tool, not diagnostic)	High spatial accuracy for habitat prediction; relevance confirmed by district-level authorities	Rapid, scalable, supports carcass search prioritization, fencing, and compliance monitoring; enhances outbreak zone delineation	Dependent on cloud-free imagery, limited uptake at higher jurisdictional levels; not a direct diagnostic tool	[Bergmann et al., 2023]
Accelerometer-based detection of African swine fever infection in wild boar	Accelerometer-based behavioral sensor	accelerometer recordings	Detects ASFV onset 3–4 days before death; daily activity reduction: 10–20 %	High specificity; validated against semi-free and free-ranging healthy controls	Noninvasive, real-time, sentinel-compatible, field-deployable, early warning potential	Requires tagging and tracking infrastructure; indirect detection via behavior; not pathogen-specific	[Morelle et al., 2005]
Rapid Sequence-Based Characterization of African Swine Fever Virus by Use of the Oxford Nanopore MinION Sequence	Nanopore sequencing-based genomic sensor	Cell culture ASFV isolates, whole blood from experimentally infected pigs	ASFV reads detected within 6 min; full genome resolution within 10 min	High specificity for ASFV genomic reads	Ultrarapid, portable, real-time sequencing; compatible with blood and cell culture samples;	Requires nucleic acid extraction and host DNA depletion; sequencing infrastructure needed	[O'Donnell et al., 2019]

(*continued on next page*)

Table 8 (*continued*)

Paper Title	Biosensor Type	Sample type	Sensitivity/LOD	Specificity	Advantages	Limitations	Reference
Sensing Device and a Companion Analysis Software Tool					supports outbreak tracing		

The table shows different biosensors used to detect African Swine Fever Virus. The table includes the sensitivity and specificity, as well as the advantages and limitations of each detection method. Abbreviations used in the table**:** ASFV, African Swine Fever Virus; CRISPR, Clustered Regularly Interspaced Short Palindromic Repeats; Cas12a/Cas14a, CRISPR-associated proteins; SERS, Surface-Enhanced Raman Spectroscopy; LAMP, Loop-Mediated Isothermal Amplification; RPA, Recombinase Polymerase Amplification; qPCR, Quantitative Polymerase Chain Reaction; LOD, Limit of Detection; LOQ, Limit of Quantification; RSD, Relative Standard Deviation; PPA, Positive Percent Agreement; NPA, Negative Percent Agreement; LSPR, Localized Surface Plasmon Resonance; Gold nanoparticle (AuNP); EOT, Extraordinary Optical Transmission; QDM, Quantum Dot Microparticle; GICA, Gold Immunochromatographic Assay; p30/p54, ASFV Proteins; VP7, Viral Protein 7; C.V., Coefficient of Variation; CSFV, Classical Swine Fever Virus; OIE, World Organization for Animal Health.

arboviruses. Many biosensors enable sensitive, specific, low-cost, fast, and POC diagnosis. Electrochemical biosensors and CRISPR-based biosensors have shown detection capabilities in the femtomolar to zeptomolar range, whereas behavioral sensors, such as accelerometers, create new opportunities for early outbreak detection. However, significant gaps remain, particularly for understudied viruses, for which more effort is needed. Furthermore, commercialization, high-volume comparisons with gold-standard methods, and the development of multiplexed, simple-to-use sensors are needed. Global warming will increase the likelihood of arbovirus epidemics. Hence, the combination of nanotechnology, AI, and networked biosensors holds great potential for establishing disease monitoring systems.

Declarations

Ethics approval and consent to participate

This review article does not involve any studies with human participants or animals performed by any of the authors. Therefore, ethics approval was not needed.

Consent for publication

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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