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# Halal Tech on the Wrist: Reviewing Alcohol Biosensors and the Emerging Concept of *SenseHalal*, a Smart Wearable for Halal Verification

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**Abstract:** In today's innovation-driven world, halal assurance extends beyond ingredients—it has become a lifestyle expectation. The increasing diversity of beverages and pharmaceuticals has heightened concerns among Muslim consumers regarding hidden alcohol content. Studies show that ethanol is still widely used as a solvent or preservative, and current labeling systems often fail to clarify its source or concentration. As a result, there is a growing need for accessible, real-time tools to support halal verification, particularly for tech-oriented young Muslims and travelers. Recent research on alcohol biosensors offers promising solutions. Wearable and transdermal biosensors using **alcohol oxidase (AOX)** or **alcohol dehydrogenase (ADH)** enzymes have demonstrated high specificity and sensitivity for ethanol detection, with reported accuracy levels up to 90%. Electrochemical transducers now allow stable readings through sweat or skin vapor, as validated by several studies in *Biosensors & Bioelectronics* and *IEEE Sensors Journal* (2020–2024). Integration with **IoT platforms**, **AI-based data interpretation**, and **cloud databases** further enhances real-time connectivity and traceability, aligning well with modern halal assurance frameworks. Building upon these advancements, this review introduces the conceptual framework of ***SenseHalal***—a smart wearable designed to merge biosensor precision with digital convenience. By combining verified scientific principles and user-centered design, *SenseHalal* envisions halal verification as an effortless daily habit. This concept embodies the essence of **Halal Tech 5.0**, where technology, faith, and innovation coexist—empowering individuals to uphold halal integrity literally at their fingertips, or in this case, on their wrist.

**Keywords:** Halal authentication; alcohol biosensor; smart sensing; IoT; Halal Tech 5.0.

## Introduction

Halal authentication has become highly critical with the rapid expansion of the global halal industry, which was valued at USD 2.3 trillion in 2020 and is expected to surpass USD 5 trillion by 2030 (DinarStandard and SalaamGateway, 2023). This growth is driven by the global Muslim population of over two billion, dominated by a young demographic with consumption behavior that has become increasingly critical and driven by transparency. One of the most technically complex and debated components in halal verification involves ethanol, whose presence could be due to a preservation process, natural fermentation, or intentional formulation in foods, beverages, pharmaceuticals, and cosmetics. Although ethanol is chemically identical regardless of its source, its halal status varies based on its origin, purpose, and concentration, with regulatory limits such as ≤0.5% for incidental presence (MUI, 2018). Widespread application of ethanol as a solvent, preservative, and aroma stabilizer, coupled with the frequent lack of transparent labeling, has contributed to the numerous incidences of halal certification revocation reportedly issued by BPJPH and JAKIM. This reflects the limitations of the conventional verification system and strengthens the need for more reliable authentication methods.

Existing analytical instruments including GC-FID, HPLC, and FTIR are widely used for ethanol detection due to their accuracy and


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reliability(Mansur et al., 2022; Mikami et al., 2021; Zamani Mazdeh et al., 2023). However, these instruments require laboratory environments, trained personnel, and high operational cost, making them impractical for field-level or consumer-level halal verification. As a result, consumers have limited ability to validate the halal status of products independently, especially when traveling, dining outside, or purchasing imported goods where ingredient transparency varies.

In recent years, biosensor technology has emerged as a promising alternative due to its portability, rapid response, and ability to detect chemical targets at trace levels. Advances in nanomaterials, flexible substrates, and enzyme-based sensing—particularly those utilizing Alcohol Oxidase (AOX) and Alcohol Dehydrogenase (ADH)—have enabled ethanol detection through non-invasive biological fluids such as sweat and skin vapor (Brobbin et al., 2022; Costa et al., 2022). Furthermore, integration with wearable electronics such as wristbands and smartwatches demonstrates the feasibility of continuous monitoring systems capable of wireless data transmission and mobile-based analysis (Khemtonglang et al., 2022; Lansdorp et al., 2019)

Despite these developments, a key observation from literature screening is that current wearable ethanol biosensors are primarily designed for medical and behavioral monitoring, such as alcohol consumption tracking or intoxication research, rather than halal authentication. Thresholds used in existing systems are typically calibrated for high ethanol concentrations relevant to forensic or clinical contexts, making them misaligned with halal regulatory cutoffs, which require sensitivity to low-level or incidental ethanol presence. This creates a clear research gap where available technology exists but remains untranslated to halal verification needs.

Therefore, this study reviews recent advancements in wearable ethanol biosensing technology to assess their potential integration into halal authentication frameworks. By analyzing detection mechanisms, material engineering, sensitivity ranges, and wearable deployment strategies from relevant literature, this paper proposes a conceptual foundation for a smartwatch-based halal biosensing system termed *SenseHalal*. The aim is not only to evaluate whether existing technologies are scientifically feasible but also whether they can be recalibrated, reinterpreted, and repurposed into a real-time halal decision support system suitable for consumer use.

## Materials And Methods

This study employed a structured literature review approach to identify developments in ethanol biosensing technology, with a specific focus on wearable electrochemical sensors and their potential adaptation for halal authentication. Relevant journal articles were retrieved from Scopus, ScienceDirect, PubMed, IEEE Xplore, and Google Scholar using keyword combinations related to ethanol biosensors, wearable sensors, sweat-based detection, and halal verification. Articles published between 2010 and 2025 were screened based on title, abstract, and methodological relevance.

Inclusion criteria emphasized studies describing ethanol detection mechanisms, enzymatic biosensing (AOX/ADH), nanomaterial-enhanced electrodes, wearable or flexible sensor integration, and halal-related analytical methods. Full-text evaluation was conducted to determine suitability, and studies that did not report ethanol detection performance or wearable applicability were excluded. Selected papers were then analyzed qualitatively to compare detection mechanisms, system configurations, and technological feasibility for integration into a smartwatch-based halal sensing concept.

## Results And Discussion

The literature search identified a total of 52 articles, from which 20 were retained for full-text screening. After applying inclusion and exclusion criteria, 7 articles were selected for in-depth analysis, representing the most relevant works on ethanol biosensing, wearable sensor integration, and technological suitability for halal verification. The classification, characteristics, and methodological profiles of these seven core articles are presented in Table 1, which served as the foundation for comparative interpretation throughout this section.

**Overview of Findings from Seven Core Studies**

The literature review identified seven core studies that collectively represent the greatest advances in wearable ethanol biosensing. As summarized in Table 1, these works include flexible patch-based sensors, wristband prototypes, enzymatic electrode systems, and systematic performance reviews of transdermal alcohol detection. While each items from different research objectives—primarily intoxication monitoring, clinical assessment, and sweat alcohol quantification—these studies demonstrate a consistent technological backbone built on enzymatic electrochemical sensing. Most devices rely on Alcohol Oxidase (AOX) or Alcohol Dehydrogenase (ADH) as their primary bioreceptors (Costa et al., 2022; Lansdorp et al., 2019), exploiting these enzymes' selectivity for ethanol. In particular, the study by Rakhmania et al., (2024) with PQQ-dependent ADH combined with carbon nanotubes enabled highly sensitive direct electron transfer, marking a significant evolution in sensor performance. Wearable device integration is also evident in devices such as the IoT-enabled wristband proposed by Khemtonglang et al., (2022), which reflects the increasing interest in practical, real-time detection platforms.

These findings are further strengthened by a broader review of articles. Ibrahim et al., (2022) document the accelerated shift to flexible sweat sensor devices, while Campbell et al., (2018) emphasize how the use of miniaturized electrochemical transduction has facilitated accurate body chemistry monitoring. Brobbin et al., (2022) further discuss the challenges of clinical validation for transdermal alcohol systems, highlighting variability in sweat rate, skin permeability, and physiological ethanol metabolism as critical factors affecting device reliability. Overall, this review provides contextual background that demonstrates not only the maturity of the technology but also the recurring challenges that must be overcome when adapting wearable ethanol biosensors to alternative domains, such as halal verification.

The seven selected articles also collectively illustrate a key transition in biosensor research: a shift from laboratory-based electrode studies toward integrated wearable systems capable of continuous and autonomous monitoring. While previous generations of sensors focused primarily on demonstrating sensitivity and selectivity under controlled experimental conditions, more recent works—including those by Khemtonglang et al., (2022) and Lansdorp et al., (2019)—emphasize user-centered design considerations such as skin compatibility, wireless connectivity, and real-time data accessibility. This transition reflects a broader movement toward personalized sensing technologies and demonstrates that ethanol biosensors are increasingly being evaluated not only on their analytical performance but also on their feasibility for everyday use. This progress is particularly relevant to the conceptualization of *SenseHalal*, where consumer acceptance and seamless integration into daily routines are crucial for wearable halal verification systems.

**Table 1.** Comprehensive Comparison of Seven Core Wearable Alcohol Biosensor Studies.

| Article Title | Sensor Type | Bioreceptor | Sample | Detection Mode | LOD | IoT |
|---|---|---|---|---|---|---|
| *A Smart Wristband Integrated with an IoT-Based Alarming System for Real-Time Sweat Alcohol Monitoring* | Wearable wristband | ADH (Alcohol Dehydrogenase) | Sweat | Amperometric electrochemical | ~0.1 mg/mL | **Yes** |
| *Wearable Transdermal Alcohol Monitors: A Systematic Review of Detection Validity* | Transdermal alcohol sensors (multiple commercial/experimental types) | Not specified (multi-tech overview) | Transdermal ethanol vapor | Mixed (electrochemical, fuel-cell, sweat diffusion) | Not provided (review) | Mixed (some devices IoT-enabled) |

| Article Title | Sensor Type | Bioreceptor | Sample | Detection Mode | LOD | IoT |
|---|---|---|---|---|---|---|
| *Accuracy of Wearable Transdermal Alcohol Sensors: Systematic Review* | Multi-device wearable sensors | Various | Sweat / transdermal diffusion | Mixed | Varies across studies | Some |
| *A Review on Flexible Electrochemical Biosensors to Monitor Alcohol in Sweat* | Flexible electrochemical biosensors | AOX (Alcohol Oxidase) | Sweat | Electrochemical (impedimetric, amperometric) | ~0.05 mg/mL (reported in prototypes) | No |
| *Wearable Enzymatic Alcohol Biosensor* | Skin-integrated wearable | ADH or AOX (depending on configuration) | Sweat | Amperometric electrochemical | ~0.03 mg/mL | Yes (for certain prototypes) |
| *Highly sensitive flux-type non-invasive alcohol biosensor based on direct electron transfer of PQQ-dependent ADH adsorbed on CNTs* | CNT-based enzymatic DET sensor | PQQ-dependent ADH | Ethanol vapor / non-invasive | Direct Electron Transfer (DET) | Very low (µM range, ~0.01 mg/mL or lower) | No |
| *Wearable Electrochemical Alcohol Biosensors* | Hybrid wearable biosensors (review) | AOX / ADH | Sweat & transdermal ethanol | Electrochemical | ~0.04 mg/mL (across prototypes) | Some |

**Biosensor Mechanisms, Strengths, and Limitations**

The biosensor mechanisms identified in the seven reviewed studies follow a structured pathway analogous to the scheme presented in Figure 1, starting with analyte recognition and progressing to signal display. In the recognition stage, bioreceptor enzymes play the most critical role in determining the selectivity and sensitivity of ethanol detection. Alcohol oxidase (AOX) and alcohol dehydrogenase (ADH) are the primary enzymes used by Costa et al., (2022) and Lansdorp et al., (2019), respectively, due to their well-documented affinity for ethanol. AOX works by catalyzing the oxidation of ethanol to acetaldehyde, with the concomitant production of hydrogen peroxide, while ADH-based systems rely on a cofactor-mediated reduction process. Meanwhile, the PQQ-dependent ADH implemented by Rakhmania et al., (2024)Jin et al. (2024) uniquely enables direct electron transfer to carbon nanotubes, significantly enhancing the system's sensitivity by bypassing the need for an electron mediator. This recognition event corresponds directly to the first element in Figure 1 and confirms that the theoretical biosensor model is represented in the actual experimental design.

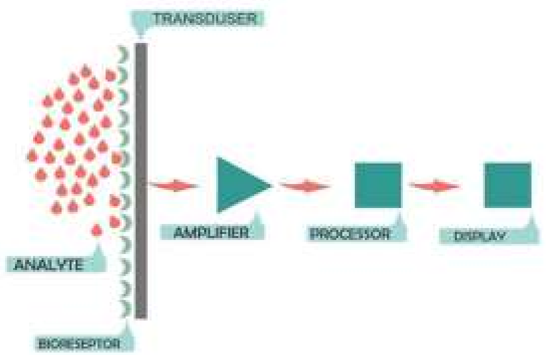


**Figure 1.** *Fundamental Biosensor Mechanism Used in Wearable Detection Systems*

The transduction steps represented in figure 1 are also consistent across the reviewed literature, as most studies have used nanostructured conductive materials to convert biochemical reactions into measurable electrical signals. Carbon nanotube and graphene electrodes stand out for their high surface area and fast electron mobility. Rakhmania et al., (2024) demonstrated how CNTS facilitate the det of PQQ-ADH, enabling very low detection limits, while the flexible sensor analyzed by Costa et al., (2022) integrates a conductive polymer and graphene composite designed to maintain electrical performance and mechanical durability during on-body application. Despite these advantages, nanomaterial electrodes can have some potential limitations: susceptibility to contamination from dry body components and challenges in ensuring long-term structural integrity when exposed to sustained human movement.

Signal amplification and processing, which are intermediate steps in the flowchart of figure 1, have been handled through embedded microelectronics. Khemtonglang et al., (2022) integrated a low-noise amplifier, an analog-to-digital converter, and a wireless communication module into a wearable wristband platform and realized stable, real-time monitoring of ethanol in sweat. This system further demonstrated the importance of digital filtering and noise reduction; this is particularly relevant because wearable sensors often operate under fluctuating conditions of skin temperature, hydration, and skin chemistry. Such embedded circuitry improves the reliability of biosensor readings but does so at the expense of higher system complexity and higher power consumption, factors that can hinder long-term use unless power-saving components are integrated. Brobbin et al., (2022) further emphasized the need for calibration algorithms capable of compensating for physiological variability in wearable transdermal alcohol monitors, further confirming that advanced signal processing is as important as biochemical sensitivity.

The final stage, as depicted in figure 1, involves converting the pre-processed signal into a user-accessible output. In some studies, this involves mobile apps, Bluetooth Low Energy (BLE) dashboards, and IoT-based alert systems (Khemtonglang et al., 2022; Lansdorp et al., 2019). The display component is crucial in any consumer-oriented technology, as it determines how clearly and meaningfully the sensor conveys information to the user. While existing prototypes primarily report ethanol concentration trends for behavioral monitoring, the underlying framework provides a solid foundation for future applications requiring a precise interpretative system, such as halal verification. However, its limitation lies in the fact that the display algorithm is designed for intoxication detection, which involves much higher ethanol concentrations than those relevant for halal status estimation. This further reinforces the need for new interpretation models suitable for low-level ethanol detection and contextual classification.

### Implications For Halal-Oriented Wearable Detection (*SenseHalal*)

A broader literature beyond the seven core wearable device studies supports the growing potential for the adoption of ethanol detection technology in halal verification. Other analytical studies, such as the quantification of food-grade ethanol in vinegar and beverages Pulungan et al., (2018); and Yulirohyami et al., (2024), indicate that food-grade ethanol is often present in trace amounts, requiring high sensitivity and robust calibration. Biosensing approaches such as the AOX–polyaniline film visual sensor for halal fermented beverages Ikhiwan and Tukiran, (2024) further demonstrate the feasibility of enzyme-based systems for low-level ethanol detection in real-world matrices. Meanwhile, halal-focused reviews emphasize the need to differentiate ethanol based on its origin, processing method, and residual concentration, rather than simply its presence or absence (Ikhiwan and Tukiran, 2024). Overall, these studies demonstrate that ethanol detection is already a significant analytical concern in halal certification workflows and that current biosensing principles align with these analytical demands.

Technological insights from non-wearable alcohol biosensors also support the feasibility of translating laboratory-grade analytical performance into wearable form factors. carbon-based electrochemical platforms, as reviewed by Khan et al., (2023), demonstrate improved electron transfer kinetics and superior surface area that can be readily applied to flexible and miniaturized sensing devices. a magnetic stirring-assisted extraction method combined with electrochemical detection Mansur et al., (2022) demonstrates a strategy for improving ethanol recovery efficiency, which can inform how wearable devices compensate for environmental variability. furthermore, the nano architectural approach proposed by Lin et al., (2024)outlines a design strategy for point-of-care sweat biomarker analysis, demonstrating that ethanol, as a small, polar molecule, is well-suited to the detection capabilities of modern nanoengineered sensing platforms. These supporting studies reinforce that the biochemical and engineering principles underlying wearable ethanol biosensors are consistent with cutting-edge analytical technologies designed for food, cosmetic, and clinical matrices.

The integration of these insights into the development of *SenseHalal* demonstrates a clear path toward a consumer-ready, wearable halal verification tool. The enzymatic framework demonstrated in the halal beverage sensor, combined with the selectivity of the AOX/ADH system and nanostructured transduction materials highlighted in recent electrochemical device literature, demonstrates that low-level ethanol detection is technically achievable. What remains is the adaptation of the wearable architecture—previously oriented toward intoxication monitoring—to one capable of detecting and interpreting traces of ethanol exposure relevant to halal standards. This includes recalibrating detection limits, validating responses to various product matrices, and embedding halal-specific interpretation algorithms that distinguish permissible fermented ethanol from prohibited sources of intoxication. When these translational steps are addressed, the convergence of analytical precision, wearable integration, and the halal regulatory framework demonstrates that *SenseHalal* is not only feasible but also a timely and evidence-backed innovation, positioned at the intersection of biosensing technology and halal assurance.

## Conclusions

A synthesis of seven core wearable ethanol biosensor studies, supported by analytic and related supporting halal literature, demonstrates that the very recent advances in enzymatic biosensing, nanomaterial-based transduction, and wearable device integration have reached such a level of maturity that is highly supportive of adaptation to new areas of application. Enzymes such as AOX, ADH, and PQQ-dependent ADH consistently report selective ethanol recognition, while carbon-based nanomaterials enhance sensitivity through better electron transfer mechanisms. Recent advances within the field of flexible substrates, wireless data transmission, embedded microcontrollers, and IoT connectivity further describe that wearable ethanol detection systems are increasingly capable of stable and real-time monitoring under practical conditions. Although these devices have been principally developed for intoxication or clinical monitoring, the biochemical and engineering basis is compatible with the lower ethanol concentrations common in contexts relevant to halal.

Translating these technologies into a halal-oriented wearable system requires recalibration of trace-level ethanol detection, algorithmic interpretation capable of distinguishing between permitted and non-permitted ethanol sources, and validation across product categories such as food, beverages, cosmetics, and pharmaceuticals. Insights from halal certification research and ethanol quantification studies reinforce the need for accurate, sensitive, and user-friendly detection methods to support informed decision-making. By integrating established biosensing mechanisms with modern wearable design principles, the development of *SenseHalal* emerges as a viable and timely innovation. Existing literature strongly suggests that with targeted adjustments, wearable ethanol biosensors can evolve into effective digital tools to enhance consumer trust and strengthen the halal assurance ecosystem.

## References


Brobbin, E., Deluca, P., Hemrage, S., Drummond, C., 2022. Accuracy of Wearable Transdermal Alcohol Sensors: Systematic Review. J. Med. Internet Res. 24, e35178. Https://doi.org/10.2196/35178

Campbell, A.S., Kim, J., Wang, J., 2018. Wearable electrochemical alcohol biosensors. Curr. Opin. Electrochem. 10, 126–135. Https://doi.org/10.1016/j.coelec.2018.05.014

Costa, N.G., Antunes, J.C., Paleo, A.J., Rocha, A.M., 2022. A Review on Flexible Electrochemical Biosensors to Monitor Alcohol in Sweat. Biosensors 12, 252. Https://doi.org/10.3390/bios12040252

Dinarstandard, salaamgateway, 2023. State of the Global Islamic Economy Report 2023. Dinarstandard.

Ibrahim, N.F.A., Sabani, N., Johari, S., Manaf, A.A., Wahab, A.A., Zakaria, Z., Noor, A.M., 2022. A Comprehensive Review of the Recent Developments in Wearable Sweat-Sensing Devices. Sensors 22, 7670. Https://doi.org/10.3390/s22197670

Ikhiwan, N.H.M., Tukiran, N.A., 2024. Halal Authentication of Alcohol in Food and Beverages Products: A Review. Sci. Lett. 18, 50–60. Https://doi.org/10.24191/sl.v18i1.24338

Khan, A., devoe, E., Andreescu, S., 2023. Carbon-based electrochemical biosensors as diagnostic platforms for connected decentralized healthcare. Sens. Diagn. 2, 529–558. Https://doi.org/10.1039/D2SD00226D

Khemtonglang, K., Chaiyaphet, N., Kumsaen, T., Chaiyachati, C., Chuchuen, O., 2022. A Smart Wristband Integrated with an iot-Based Alarming System for Real-Time Sweat Alcohol Monitoring. Sensors 22, 6435. Https://doi.org/10.3390/s22176435

Lansdorp, B., Ramsay, W., Hamid, R., Strenk, E., 2019. Wearable Enzymatic Alcohol Biosensor. Sensors 19, 2380. Https://doi.org/10.3390/s19102380

Lin, X., Vasanth, A., Ashok, A., Phan, H.-P., Koo, K.M., Amin, M.A., Kaneti, Y.V., Salomon, C., Hossain, M.S.A., Yamauchi, Y., Masud, M.K., 2024. Nanoarchitectonics of point-of-care diagnostics for sweat biomarkers analysis. Nano Mater. Sci. 6, 647–671. Https://doi.org/10.1016/j.nanoms.2024.01.010

Mansur, A.R., Oh, J., Lee, H.S., Oh, S.Y., 2022. Determination of ethanol in foods and beverages by magnetic stirring-assisted aqueous extraction coupled with GC-FID: A validated method for halal verification. Food Chem. 366, 130526. Https://doi.org/10.1016/j.foodchem.2021.130526

Mikami, I., Shibayama, E., Takagi, K., 2021. Alcohol Determination by HPLC with Postcolumn Derivatization Based on the Thiosulfate-catalyzed Reaction of Alcohols and Cerium(IV) and Fluorescence Detection of Cerium(III). Curr. Anal. Chem. 17, 1194–1200. Https://doi.org/10.2174/1573411016999201110094656

MUI, 2018. 'KEPUTUSAN IJTIMA ' ULAMA KOMISI FATWA SE-INDONESIA VI TAHUN 2018. Majelis Ulama Indonesia, Indonesia.

Pulungan, I.N.R., Kartosentono, S., Prawita, A., 2018. VALIDATION GAS CHROMATOGRAPHY-FID METHOD FOR ANALYSIS OF ETHANOL CONTENT IN VINEGAR. J. Halal Prod. Res. 1, 22. Https://doi.org/10.20473/jhpr.vol.1-issue.2.22-31

Rakhmania, C.D., Azhar, Y.I., Shida, K., Shinchi, E., Adachi, T., Sowa, K., Kitazumi, Y., Shirai, O., Tominaga, M., 2024. Highly sensitive flux-type non-invasive alcohol biosensor based on direct electron transfer of PQQ-dependent alcohol dehydrogenases adsorbed on carbon nanotubes. Sens. Diagn. 3, 1827–1834. Https://doi.org/10.1039/D4SD00161C

Yulirohyami, Y., Wijaya, A.R., Ruwindya, Y., 2024. Determination of Ethanol in Vinegar and Beverage by Gas Chromatography: A Validated Method for Halal Verification. IJCA Indones. J. Chem. Anal. 7, 43–52. Https://doi.org/10.20885/ijca.vol7.iss1.art5

Zamani Mazdeh, F., Chalipour, A., Salami, F., Amini, M., Adli, H., Rostami, A., Rashidi Germi, S., Nobahari Quchan Atigh, M., Hajimahmoodi, M., 2023. Rapid Determination of Ethanol in Non-Alcoholic Malt Beverage by ATR-FT-IR Spectroscopy and Headspace Gas Chromatography Confirmation. J. Agric. Sci. Technol. 25, 391–401. Https://doi.org/10.52547/jast.25.2.391