Sugar-based stabilizer keeps sweat sensors working under acidic conditions

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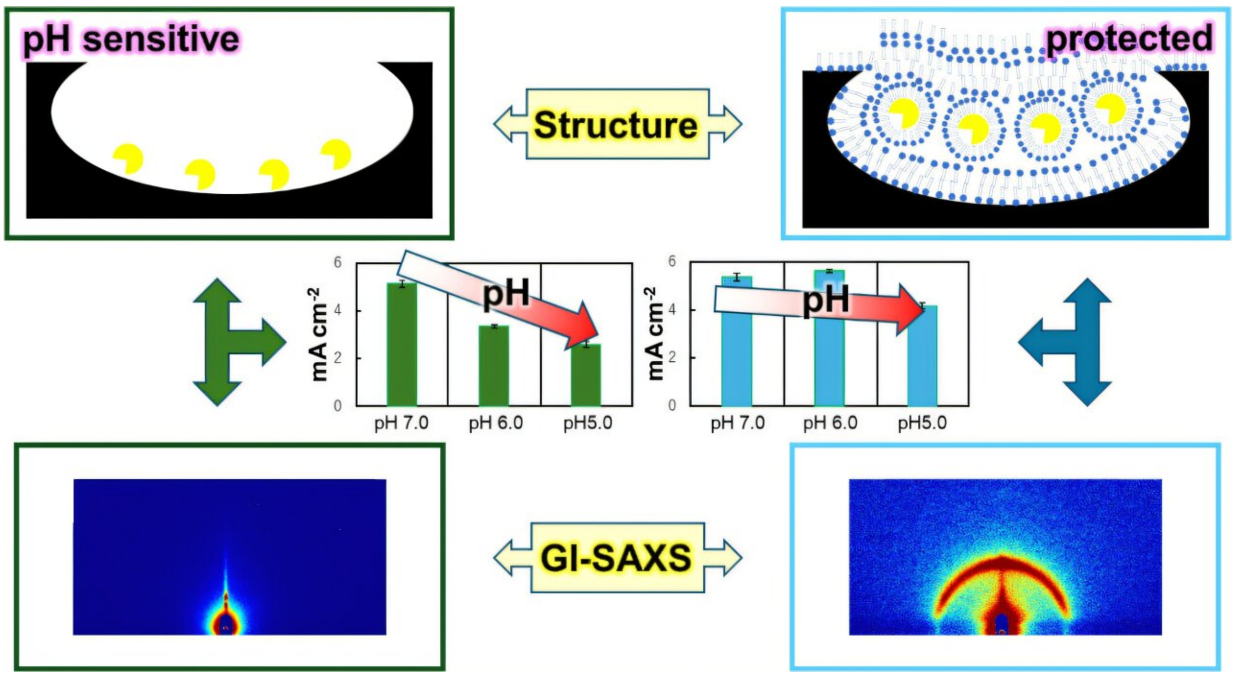

Sucrose monolaurate, when added as a stabilizer to the electrode, formed protective hexagonal and laminar nanostructures around lactate oxidase, shielding it from sweat and maintaining enzyme activity. This, in turn, enabled more accurate lactic acid detection. Credit: Dr. Isao Shitanda from Tokyo University of Science, Japan Image source link: https://pubs.acs.org/doi/10.1021/acs.langmuir.5c02857

The composition of sweat makes it a valuable diagnostic fluid. While it is mostly water, the small fraction containing electrolytes, metabolic byproducts, and chemical traces can reveal important information about a person's health. Today, commercial sweat-based sensors can already track dehydration, electrolyte loss, and more. One emerging application is the measurement of lactic acid in sweat.

Lactic acid, or more precisely L-lactate, is a byproduct of metabolism produced mainly in muscle cells when glucose is broken down for energy under low-oxygen conditions, such as during intense physical activity. Athletes and trainers use lactate measurements to assess endurance and plan workouts, but high levels can also be a warning sign for conditions like lactic acidosis.

Lactic acid sensors typically use lactate oxidase (LOx), an enzyme attached to a biocompatible electrode, to measure lactate levels. LOx binds to L-lactate and catalyzes its oxidation into pyruvate, producing hydrogen peroxide as a byproduct. This hydrogen peroxide is then electrochemically oxidized or reduced at the electrode, generating a measurable current that corresponds to the lactate concentration in sweat.

However, LOx is pH sensitive. It works best at neutral pH and loses much of its activity in the acidic environment of sweat, which has a pH of around 4.0. One of the approaches to solving this problem is to add sugars that help stabilize the enzyme in acidic conditions.

In a recent study, researchers from Tokyo University of Science (TUS) in Japan, found that sucrose monolaurate provides significantly better protection for LOx than conventional sugars. In tests simulating the acidic pH of sweat, electrodes modified with sucrose monolaurate retained about 80% of LOx activity at pH 5.0, compared to only 50% without sucrose monolaurate.

Their work was published in the journal *Langmuir*. The study was led by

Associate Professor Isao Shitanda in collaboration with Anton Paar Japan K.K., and included contributions from Associate Professor Taku Ogura from the Research Institute for Science and Technology and Ms. Chiaki Sawahara, a master's graduate from the Department of Pure and Applied Chemistry at TUS, and Dr. Yuichi Takasaki from Anton Paar Japan K. K.

"Real-time monitoring of sweat lactate is becoming increasingly important for sports training and heatstroke management. To measure sweat lactate, the enzyme must remain stable on the sensor under acidic conditions. In this study, we show that the use of a stabilizing agent preserves enzyme activity in acidic solutions by forming a special structure," says Dr. Shitanda.

The team fabricated gold and carbon electrodes without stabilizers, with sucrose monolaurate, and with maltose (which is also a stabilizer). They then exposed the electrodes in neutral (pH 7.0), mildly acidic (pH 6.0), and more acidic (pH 5.0) solutions to test how they would perform when exposed to sweat.

Without a stabilizer, the measured current dropped significantly as the pH fell. Electrodes with maltose showed a small improvement at pH 6.0 but almost none at pH 5.0. In contrast, electrodes modified with sucrose monolaurate retained about 80% of their activity at pH 5.0.

To investigate why sucrose monolaurate offered such effective protection, the researchers examined the nanostructure of the electrode surfaces using grazing incidence small-angle X-ray scattering (GI-SAXS). This technique involves directing X-rays at a very shallow angle to directly observe how sucrose monolaurate and LOx arrange themselves on the electrode surfaces.

The researchers discovered that sucrose monolaurate formed neat hexagonal arrays with lamellar layers on smooth electrode surfaces. When LOx was added, it became embedded within these hexagonal and layered structures.

In dilute solutions, sucrose monolaurate has been observed to assemble into tiny core–shell micelles, which merge into rod-like shapes and pack into hexagonal arrays. The enzyme fits within these structures, creating a protective barrier that blocks hydrogen ions while still allowing water and metabolites like lactic acid to pass through, preserving the enzyme's ability to function while making it resistant to changes in pH.

By revealing this protection mechanism, the study paves the way for more durable and reliable lactic acid sweat sensors for continuous health monitoring. "Understanding this mechanism could facilitate the development of highly stable enzyme electrodes and high-performance biodevices," concludes Dr. Shitanda.

Additionally, sucrose monolaurate is a safe, affordable, and scalable stabilizer for commercial usage. Furthermore, the approach performed in this study could be utilized for other environmental conditions, rather than low pH and could be used for stabilizing other enzymes as well.

More information: Isao Shitanda et al, Sucrose Monolaurate as a Stabilizer for Lactate Oxidase Electrodes at Low pH: A Structural Analysis Based on Grazing Incidence Small-Angle X-ray Scattering, *Langmuir* (2025). DOI: 10.1021/acs.langmuir.5c02857

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