Design and Development of 3D Printed Stem-Mounted Microneedle-Based Platform for Multiplexed Monitoring of Phytohormones in Live Plants

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Abstract

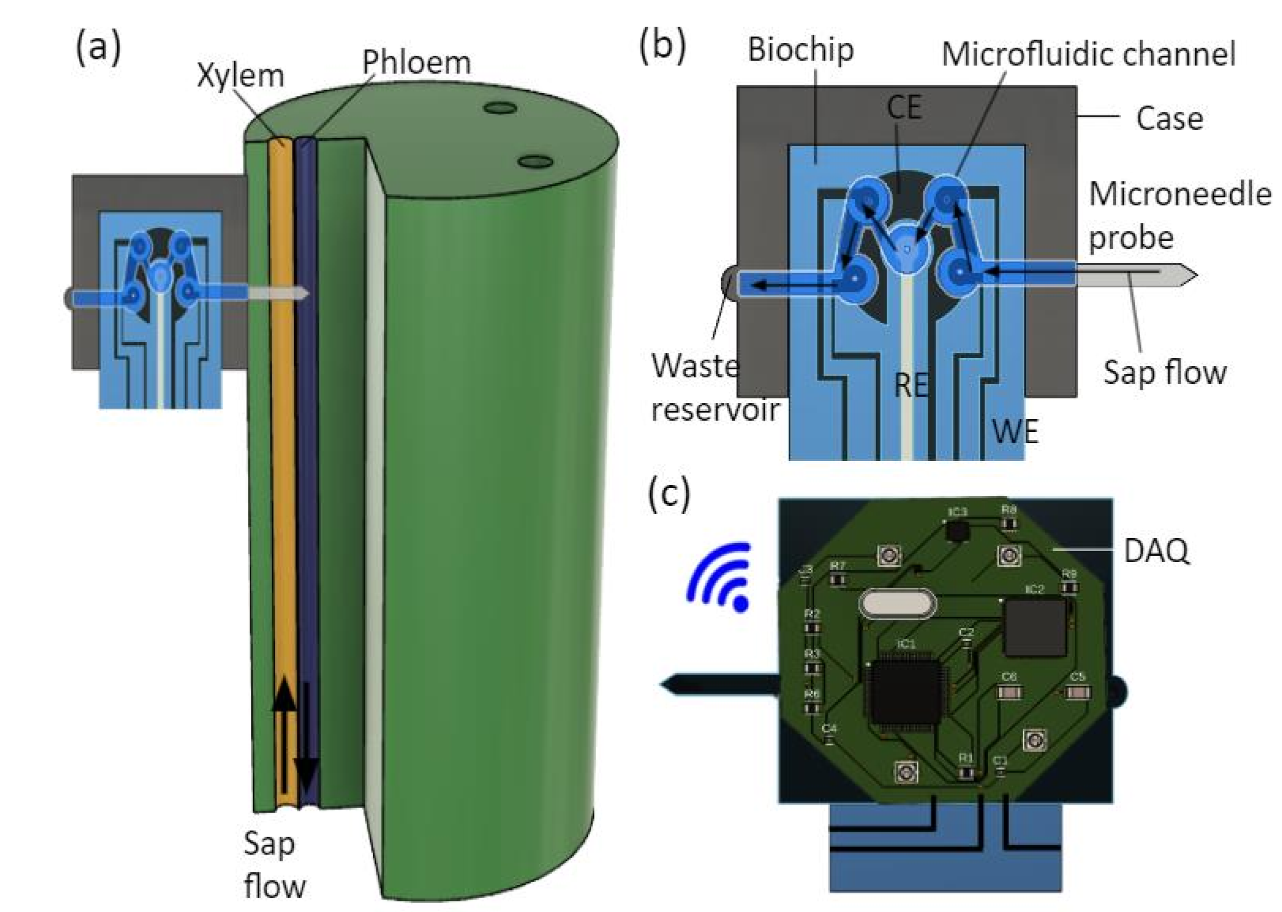
This work reports on the design and development of a 3D printed casing that will be used to house a multiplexed electrochemical sensor for monitoring stress-associated phytohormones in live plants. Two designs were drafted; the **first** was designed using a hollow microneedle to collect plant sap through a microfluidic channel and analyze it on an insertable biochip. The **second** design analyzes sap through electrodes that rest on the surface of the solid microneedle. The microfluidic design supports a more advanced system but risks fluid leakage. The surface-level design bypasses the leakage problem in exchange for a simpler design with less analytical capabilities.

Significance

- World population is expected to rise to nearly 10 billion within the next 30 years.
- With increased population comes increased demand for food supplies; thus, reducing crop productivity losses becomes essential to meet growing demands.
- Plants are subjected to various abiotic stressors, such as drought and salinity.
- Plants respond and adapt to these environmental stressors via phytohormone-mediated regulation of oxidative burst
- The conventional approaches to conducting molecular analyses of these phytohormone responses in plants are disruptive, in vitro, and time-intensive.
- Our designs aim to automate the collection and analysis of plant sap for real-time crop health monitoring.

Methods

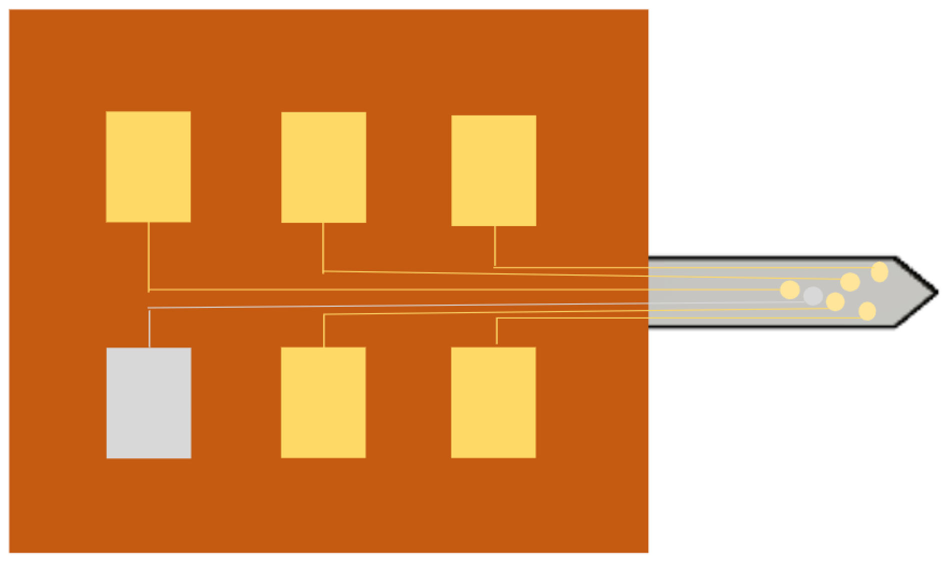
Design 1: Microfluidic Channel Sensor



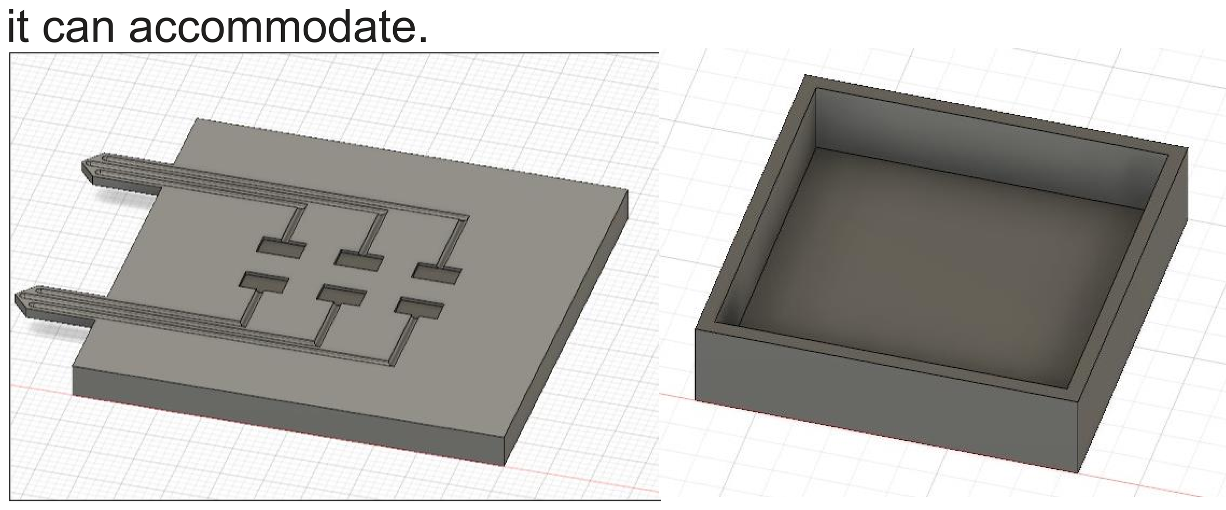
This design comprises 3 parts: a) a hollow microneedle to draw sap into a microfluidic channel, b) a top plate to cover the microfluidic channel, and c) a bottom plate to house the PCB. As sap flows through the channel, it will contact 5 sensor plates on an insertable biochip responsible for analyzing the sap for plant stress indicators. This design can accommodate more electrodes in order to detect a larger number of biomolecules. However, any design imbalance will cause the model to leak sap that has been extracted.

Fusion 360 Model of Microfluidic Casing
(Left) Microfluidic component
(Middle) Top Plate to enclose microfluidic channel and biochip
(Right) Bottom Plate to house the PCB

Design 2: Surface-Level Electrode Design



This design comprises 2 parts: a) a top plate that carries a microneedle and trenches for sensor plates and b) a bottom plate to house the PCB. The needle carries circular electrodes on its tip to detect phytohormones directly from the plant's sap. The rectangular regions represent contact pads. With this design, there is no risk of sap leakage as there is no collection of fluid, but it is incapable of the same level of analysis as the microfluidic sensor due to its limitation in how many electrodes it can accommodate.

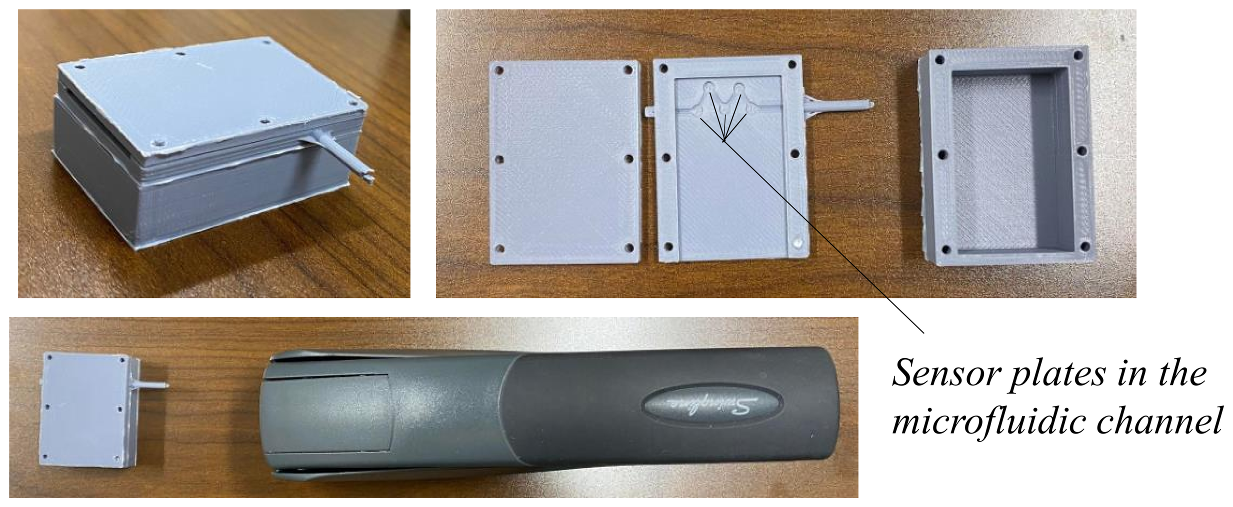


Fusion 360 Model of Surface-Level Electrode Sensor
(Left) Needle component to house electrodes, wiring, and sensor plates at the surface
(Right) Bottom Plate to house the PCB

Results

Design 1: Microfluidic Channel Sensor

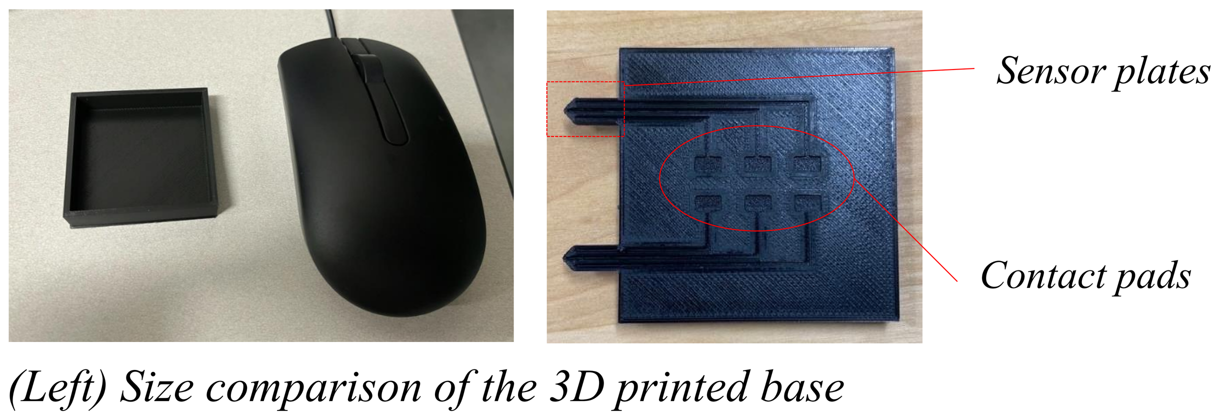
The 3D printed prototype had an overall dimension of 30x41 mm^2 with a thickness of 15mm. The compact design allows it to be lightweight and easy to produce. The microneedle had a diameter of 2mm with a wall thickness of 0.75mm and a length of 15mm. A rib was added to the needle to provide additional support when inserted into a plant stem.



(Top Left) The final 3D printed prototype
(Top Right) 3D printed components shown separately
(Bottom) Size comparison of the final prototype

Design 2: Surface-Level Electrode Design

The 3D printed bottom plate had a dimension of 5cm x 5cm x 12mm with an overall thickness of 2mm. The top plate was 5cm x 5cm x 5mm. The trenches for the rectangular contact pads and electrode lines are 0.5mm deep. The needles came out to a length of 10mm



(Left) Size comparison of the 3D printed base
(Right) 3D printed top plate that carries the needle and sensor plates

Conclusion

Through a series of trial-and-error, improvements were made in the 3D printed designs based on the original blueprints. With each design iteration, analysis of design flaws gave a greater understanding of what did and did not work with available equipment. This gave a final product that allowed greater use for each design. With more advanced equipment and printers, a more refined project can be completed in the future that would allow the analysis of more phytohormones within plants.

Acknowledgement

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