Bio-Convergence to Detect Plant Stress

Adi Avni - School of Plant Sciences and Food Security, Faculty of life sciences, Tel Aviv University

Yosi Shacham-Diamand - Department of Physical Electronics, school of electrical engineering, faculty of engineering, Tel Aviv University

Abstract

We propose a new paradigm for data-driven precision agriculture, using bio-convergence-based functional sensors to directly detect plant stress.

The ever-increasing global population, combined with reducing agricultural efficacy due to climate change poses a significant challenge to meeting the world's food requirements. Technological advances, in particular advances in agricultural sensor technology, have been noted to be one of the most promising directions in addressing this issue. Bio-convergence-based approaches can help improve the efficacy of agricultural sensing, whilst maintaining sustainability and cost-effectiveness. Using these approaches, we propose to develop a novel plant-based biosensor that can report the health and well-being of plants, using direct sensing of plants' genetic response to stress. This can allow for *in-vivo*, reliable, real-time reporting on the needs of plants, at a lower cost than existing sensor technologies. We propose to execute this using two major research and development directions: novel bio-synthetic logic gates for efficient detection of multiple stress parameters, and novel families of electrochemical sensing interfaces with intrinsic amplification. The development of the proposed sensors will include mathematical/circuit-based modeling, implementation in plants, and investigations into practicality for on-field use.

Description of the research program

We propose a new paradigm for precision agriculture (i.e. data-driven agriculture) where bio-convergence allows for direct sensing of plants' health status, using the plants as sensors themselves. This, in turn, allows for the optimization of resources (e.g. water, nutrients, etc.) required in the agricultural system. The proposed sensing methodology is expected to be significantly more accurate, faster, and low-cost compared to existing conventional technologies and methodologies. Global warming has had devastating effects on crop production, reducing the productivity of agricultural systems. In addition, the exponential population growth is consistently increasing the demand for agricultural products. This reduction in supply and increase in demand cause ever-increasing constraints on resources such as arable land, water, nutrients, etc., [7, 13] thus posing a major challenge to global food security. Moreover, emerging plant diseases caused by biological and environmental stresses endanger crop productivity worldwide [16]. A lack of food and water affects the daily life of a significant part of the global population leading to starvation, political instability, economic burdens, and even wars. Current agricultural practices are not ecologically sustainable and cannot cope with these challenges. In addition, the global agricultural system is facing many economic challenges in terms of productivity, cost-effectiveness, and increasing labor shortage.
Technological advances working towards precision agriculture have made it possible to address the issue of the growing demand for food. Among all technological developments in agriculture, sensor-based technology occupies a special niche as it can allow for significant improvements in yield and reduction in resource demand, purely by tailoring human intervention based on the exact needs of plants. Like in any other field of application, in agriculture, sensors are designed and developed according to the requirement of farmers according to their specific field conditions [8]. To date, traditional methods employed for monitoring plant health include remote and contactless sensing technologies such as proximal optical sensors, spectroscopy, machine vision systems, imaging techniques, and drones [10, 11]. The use of these technologies faces issues that still limit their application in personalized and long-term plant monitoring.

Innovative solutions are required to increase productivity and nutritional quality. Precision agriculture is one way of addressing this; however, the use of big-data techniques requires data from all along the food chain. The emerging bio-convergence field of synthetic biology implements engineering principles into biological systems and currently revolutionizes fundamental and applied research [14]. We propose to use bio-convergence concepts for crop performance monitoring. Using biosensors capable of early detection of plant health status will enable the use of precision agriculture to avoid stress-limiting effects and thereby increase crop yields. The ability to sense plant stress in real time will direct farmers on how to tailor the appropriate treatments and resources and minimize crop losses. Now, scientific advances are opening up countless new opportunities for plant biology. Bio-convergence-based approaches for improving agriculture productivity, food quality, and production, aim to attain a sustainable and cost-effective agricultural setup [14]. The ability to sense plant stress in real-time and know exactly what the plant is "feeling" under any given condition will improve the ability of farmers to tailor the appropriate treatment and allow for the minimization of crop losses due to excessive drought or ensuing pathogenic processes, i.e avoiding excess watering by optimizing the amount according to the sensing of physiological needs. Note that the successful use of our new paradigm requires integrating it into a complete system where the measured information is processed at device, edge, and cloud levels, using advanced AI algorithms. Although this research is focused on the sensing part only, we will take into account the integration with an AI cloud-based data processing setup, and make the sensor "AI-ready" and compatible with the agricultural needs for power, reliability, and cost.

By contrast to the majority of biosensors used in agricultural practice today, which are based on indirect sensing of environmental conditions [3, 6], we here suggest a direct sensing approach of endogenous plant parameters. This strategy provides better and more efficient estimation compared with the present measuring of temperature, precipitation, or soil water content.

In this proposal, we suggest applying a bio-convergence system to develop and test a **plant-based biochip system and the Internet of Things** for sensing various stresses in plants. The chief novelty and groundbreaking nature of the proposed project lie in combining biology and engineering technologies to advance the field of precision agriculture.

We propose a bio-convergence-based approach to develop a novel plant-based biosensor. The sensor will consist of an electrochemical biochip mounted directly on the plant, and connected to the cloud via a wired or wireless interface (Fig 1). *In-vivo* monitoring of plant physiological parameters will be the key to precision farming. This is especially relevant for valuable horticultural crops that require optimization of conditions throughout their growth cycle and thus would benefit from automated monitoring systems.

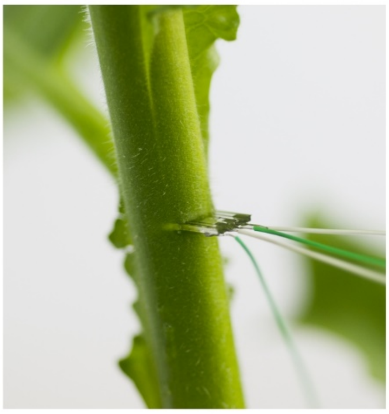

Fig 1. Biosensor mounted on tobacco stem.

Currently available platforms designed for studying physiological changes in plants are not generally compatible with *in-vivo* monitoring. **There are no biosensors for directly detecting endogenous stress (i.e. dehydration, toxic effects, pathogens, etc.) in plants by combining *in-vivo***

sensing with an electronic device. We propose a new class of sensors based on plant sensing integrated with a micro-electronic technology-based solid-state platform, which offers the possibility of transmission of the electrochemical sensing signal to the internet. We are currently developing plant cell sensors based on stress-responsive promoters that initiate transcription of the reporter gene encoding the enzyme β-glucuronidase (GUS). Thus, the activity of GUS will serve as the indicator of stress. This approach is based on our preliminary results of measuring the activity of constitutively expressed GUS by a three-electrode microchip in plant cell suspensions (Fig 2) [12].

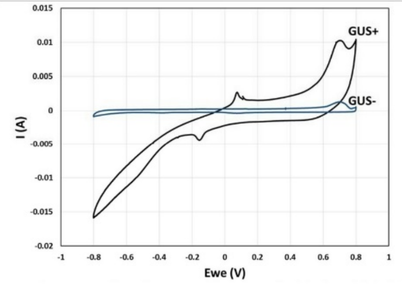

Fig 2 Cyclic voltametry of Msk8 cells with phenolphtalein β-glucoronide (phG) substrate; Wild type (GUS^-); GUS expressing cells (GUS^+)

Like in any other field of application, in agriculture, sensors are designed and developed according to the requirement of farmers in the field [4]. Thus, among all technological advancements in agriculture, the market of sensor-based technology is very promising providing specific solutions relying on a new agricultural technology upon request, i.e. sensing pathogen attacks, water shortage, heat, or lack of certain minerals.

In our proposal, we propose to test several different double-negative feedback (DNF) gene circuit models to achieve a highly sensitive sensor. To achieve the goals of this research we propose three major research directions:

1. Develop a sensitive sensor

Sensitivity dependence on the fold change activation (ON/OFF ratio). Namely, the ratio between apositive signal and the basal level. To enhance the ON/OFF ratio, we will apply our indirect coherent feed-forward loop design, which can experimentally reduce only the basal level (leakage) while keeping the maximum activity high. Such designs can increase the ON/OFF ratio by 10 times compared to unregulated promoters. . We will use the heat-shock promoter HSP70-1 [17] to demonstrate the enhancement of the ON/OFF ratio. We propose to apply a double-negative feedback (DNF) design [15] using the Crispr Cas6 gene family (Fig 3) [9]. The site-specific endoribonuclease (endoRNase) Cas6 recognizes the hairpin element in the RNA sequence and cleaves immediately downstream of it [1]. Inserting the recognition sequence of specific Cas6/Csy4 in the 5′UTR, right before the start codon reporter gene coding region, such that the 5′UTR, including the mRNA cap, would be removed after cleavage causing inhibition of translation. (Fig 3) [9]. We will constitutively express Csy4 at a low level. Therefore reducing

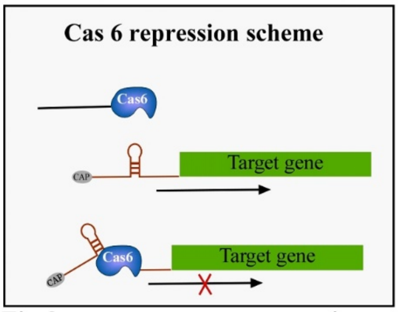

Fig 3 two-component expression-repression system to tightly control expression of transgene products.

the basal level of reporter expression. Upon heat-shock treatment, Cas6 will be induced causing inhibition of Csy4 gene. The inhibition of Csy4 will enable high expression of the reporter gene enhancing the ON/OFF ratio (Fig 4). . Such design can increase the ON/OFF ratio by an order of magnitude compared to unregulated promoters (Fig 4) [15].

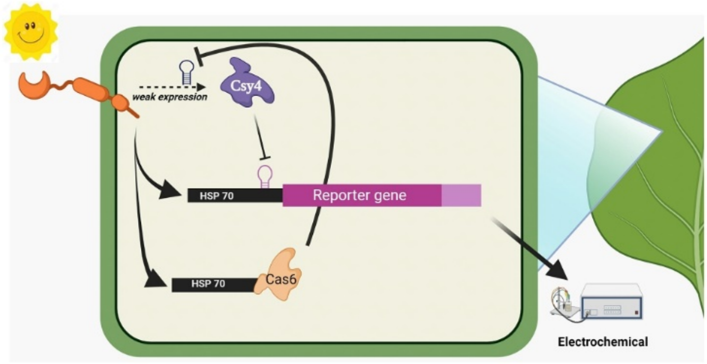

Fig 4 Designed enhance On/Off ration gene sensor model to implement in plants

2. Novel bio-synthetic logic gates to efficiently detect multiple stresses

We propose to develop novel bio-synthetic logic gates in plants, for example, a two-input AND logic gate to detect multiple stress. Logic gates are widely used in synthetic biology and especially for biosensing applications because such a logic gate can improve the specificity of the biosensors [2, 5]. In this proposal, we propose to implement AND logic gates in plants using a family of Cas6 proteins [18] using a double negative approach (Fig 5). Constitutive expression of EcCas6 or CdCas6 will inhibit the expression of the reporter gene. The induction of two inputs will inhibit the expression of EcCas6 and CdCas6 enabling the expression of the reporter gene. This is a novel approach that paves the way for a variety of other logic gates with the goal of improving the "signal-to-noise ratio (SNR)" in a multi-input environment.

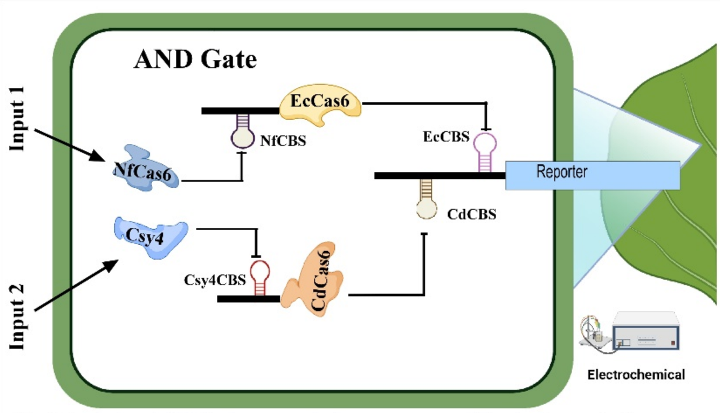

Fig 5 The designed AND logic gate synthetic gene sensor model to implement in plants

3. Research and develop novel families of electrodes, using bio-convergence concepts

One of the limiting factors of electrochemical sensors is the signal-to-noise ratio. In order to improve the utilization of synthetic biology-based sensors, we also need to create the right environment for them to be used in the field. It requires research and development of the electrode system, the sampling concept, the bio-chip environment, the electronics, and the supporting circuitry for signal storage, processing, and communication. We propose to use a strategy that links engineering concepts such as electrodes with internal signal amplification, and an integrated bio-chip. This will allow the mounting of and signal acquisition from the proposed sensors. We propose to research and develop a novel electrochemical sensor with over ten-fold internal amplification. To do so we will develop a multi-working--electrode biochip for functional sensing in plants (Fig 6). The biochip will sample the signal from the plant, e.g. roots, bark, stems or leaves, using redox cycling for signal amplification. This sensing methodology allows for a signal level that is an order of magnitude higher than previously reported by conventional single-electrode electrochemical sensors for functional sensing in plants. The bio-chip concept highlights are illustrated in the following scheme. The research questions are for example: How high of amplification is attainable? What are the physical and chemical principles that will limit the amplification? What are materials appropriate for such devices? What is the best way to filter the acquired signal and what are the preferred data storage methods for effectively optimizing "real life" parameters such as power consumption and reliability? Finally, we will investigate the integration of such devices onto IoT-based data-driven agriculture.

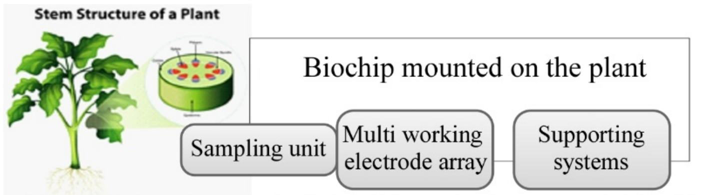

Fig. 6. Muti working electrode interfaing a plant on a mounted biochip

We propose to develop a full model for such a system:

1. Large signal model taking into consideration transport effects, surface reaction rate, and electrochemical reactions.
2. Small signal model – there is no small signal model published for a multi-working electrode sensor. It is a rather interesting problem due to the feedback between the electrodes. There is also a strong frequency dependence due to the delays of the electrochemical reactions, double-layer capacitance, transport effects, and the environment's passive components.
3. 3D modeling of a such system taking into consideration the real size and dimension of the biochip.

Collaboration

This proposal takes advantage of the collaboration of two complementary research groups. The first is the group of Prof. Adi Avni, an expert in plant biology who is involved inmaking plant-based sensors and genetic circuits in plants. The second is the group of Prof. Shacham who is workingfor the last 20 years in interfacing cell and tissue-based sensors with electronic systems, making biochip platforms, and developing new technologies for such hybrid systems. The collaboration between the groups is illustrated in Fig 7.

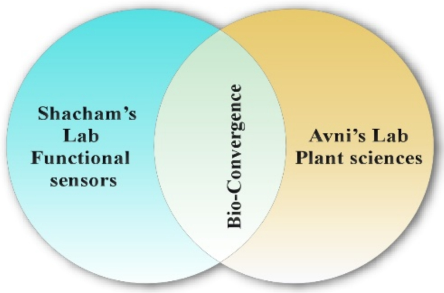

Fig 7 Collaboration between the groups

References

1. Haurwitz, R.E., M. Jinek, B. Wiedenheft, K. Zhou, and J.A. Doudna, *Sequence- and structure-specific RNA processing by a CRISPR endonuclease.* Science, 2010. **329**(5997): p. 1355-8.
2. Nissim, L. and R.H. Bar-Ziv, *A tunable dual-promoter integrator for targeting of cancer cells.* Mol Syst Biol, 2010. **6**: p. 444.
3. Gmur, S., D. Vogt, D. Zabowski, and L.M. Moskal, *Hyperspectral analysis of soil nitrogen, carbon, carbonate, and organic matter using regression trees.* Sensors (Basel), 2012. **12**(8): p. 10639-58.
4. Lopez, O., M.M. Rach, H. Migallon, M.P. Malumbres, A. Bonastre, and J.J. Serrano, *Monitoring pest insect traps by means of low-power image sensor technologies.* Sensors (Basel), 2012. **12**(11): p. 15801-19.
5. Moon, T.S., C. Lou, A. Tamsir, B.C. Stanton, and C.A. Voigt, *Genetic programs constructed from layered logic gates in single cells.* Nature, 2012. **491**(7423): p. 249-53.
6. Wilczek, A., A. Szypłowska, W. Skierucha, J. Cieśla, V. Pichler, and G. Janik, *Determination of Soil Pore Water Salinity Using an FDR Sensor Working at Various Frequencies up to 500 MHz.* Sensors, 2012. **12**(8): p. 10890-10905.
7. Ray, D.K., J.S. Gerber, G.K. MacDonald, and P.C. West, *Climate variation explains a third of global crop yield variability.* Nat Commun, 2015. **6**: p. 5989.
8. Bogue, R., *Sensors key to advances in precision agriculture.* Sensor Review, 2017. **37**(1): p. 1-6.
9. Liang, Y., S. Richardson, J. Yan, V.T. Benites, C. Cheng-Yue, T. Tran, J. Mortimer, et al., *Endoribonuclease-Based Two-Component Repressor Systems for Tight Gene Expression Control in Plants.* ACS Synth Biol, 2017. **6**(5): p. 806-816.
10. Kanning, M., I. Kühling, D. Trautz, and T. Jarmer, *High-Resolution UAV-Based Hyperspectral Imagery for LAI and Chlorophyll Estimations from Wheat for Yield Prediction.* Remote Sensing, 2018. **10**(12): p. 2000.
11. Mozgeris, G., D. Jonikavičius, D. Jovarauskas, R. Zinkevičius, S. Petkevičius, and D. Steponavičius, *Imaging from manned ultra-light and unmanned aerial vehicles for estimating properties of spring wheat.* Precision Agriculture, 2018. **19**(5): p. 876-894.
12. Pandey, R., O. Teig-Sussholz, S. Schuster, A. Avni, and Y. Shacham-Diamand, *Integrated electrochemical Chip-on-Plant functional sensor for monitoring gene expression under stress.* Biosens Bioelectron, 2018. **117**: p. 493-500.
13. Economic, U.N.D.o.I., U.N.D.f. Economic, S. Information, and P. Analysis, *World population prospects*. Vol. 2. 2019: United Nations, Department of International, Economic and Social Affairs.
14. Roell, M.S. and M.D. Zurbriggen, *The impact of synthetic biology for future agriculture and nutrition.* Curr Opin Biotechnol, 2020. **61**: p. 102-109.
15. Litovco, P., N. Barger, X. Li, and R. Daniel, *Topologies of synthetic gene circuit for optimal fold change activation.* Nucleic Acids Research, 2021. **49**(9): p. 5393-5406.
16. Ristaino, J.B., P.K. Anderson, D.P. Bebber, K.A. Brauman, N.J. Cunniffe, N.V. Fedoroff, C. Finegold, et al., *The persistent threat of emerging plant disease pandemics to global food security.* Proc Natl Acad Sci U S A, 2021. **118**(23).
17. Berka, M., R. Kopecká, V. Berková, B. Brzobohatý, and M. Černý, *Regulation of heat shock proteins 70 and their role in plant immunity.* Journal of Experimental Botany, 2022. **73**(7): p. 1894-1909.

18. Gao, F., K. Zheng, Y.-B. Li, F. Jiang, and C.-Y. Han, *A Cas6-based RNA tracking platform functioning in a fluorescence-activation mode.* Nucleic Acids Research, 2022. **50**(8): p. e46-e46.

Budget Adi Avni and Yosi Shacham-Diamand

Budget Item	First Year ($)
Salaries	60000
Supplies Material & Services	10000
Operating Expenses	5000
University IN KIND	25000
Annual Totals	100000

- **Personnel.**

The project requires the involvement of two graduate students and a postdoc (or a research technician) who will devote full-time capacity. Moreover, funds are needed to support two undergraduate project students.

- **Supplies**.

Biology: The experiments in molecular biology described in this proposal require a running-budget disposable material. The commercial kits include kits for DNA and RNA isolation, polymerase chain reaction; kits for molecular biology. Media are needed to maintain plant tissue culture, bacterial cloning, and growing Agrobacterium. Operating expenses are needed for DNA sequencing services and to maintain plant material in greenhouses and in temperature-controlled growing chambers.

Engineering: Substrates for the biochips – silicon and/or glass, chemicals for the electrodes, clean room facilities: lithography, sputtering, and annealing, supplied for the electrode 2D printer – nanoparticle ink, filters, print heads, 3D printing materials, machine shop time for the bio-chip holders and the microfluidics.

Adi Avni

CURRICULUM VITAE (January 2023)

Personal: ID 054997770 h-index 30

E-mail: lpavni@tauex.tau.ac.il, Website: https://en-lifesci.tau.ac.il/profile/lpavni

Education:

The Hebrew University Jerusalem	B.Sc.	02/83	Biology
The Weizmann Institute of Science, Rehovot	M.Sc.	06/85	Neurobiology
The Weizmann Institute of Science, Rehovot	Ph.D.	06/90	Plant Biology

Personal Statement

My scientific interests are primarily in the area of plant innate immunity signaling and plant genetics. As part of my research, we isolated the receptor for a fugal effector and study the mechanisms underlying plant immunity. Recently my research focused on synthetic biology and genome editing via the CRISPR/Cas9 system and on using plants as biosensors, to detect plant stress. I have more than 30 years of experience in plant molecular biology, plant genetics, plant synthetic biology, and biochemistry.

Recently, we develop biosensors for agriculture where we use micro and nanoscale technologies. The goal is to develop low-cost sensors that will be integrated into the plant for early detection of various parameters that are the key factors in the food chain (i.e. farmers, wholesalers, transportation, government, and the food industry in general and the customers).

1990 – 1992	USDA/ARS, MD, USA	Plant Molecular Biology	Research Associate
1992 - 1993	USDA/ARS, MD, USA	Weed Science	Research Associate
1993- 1999	Tel-Aviv University	Department of Plant Sciences	Lecturer
1999 - 2005	Tel-Aviv University	Department of Plant Sciences	Senior Lecturer
2001 - 2002	USDA/ARS, MD, USA	Soybean Genomic	Sabbatical fellow
2005 - 2010	Tel-Aviv University	Department of Plant Sciences	Associate Professor
Summer 2005	Wageningen University	Plant Pathology	Sabbatical fellow
2010 - to date	Tel-Aviv University	School of Plant Sciences and Food Security	Full Professor
Summer 2010	Instituto Leloir	Nuclear Receptors Laboratory	Sabbatical fellow
Summer 2016	IPS2 Paris	Flower and Carpel Development Group	Sabbatical fellow
Summer 2022	IPS2 Paris	Flower and Carpel Development Group	Sabbatical fellow

Peer-reviewed Publications (prtial list)

Akao, P. K., A. Kaplan, D. Avisar, A. Dhir, A. Avni and H. Mamane (2022). "Removal of carbamazepine, venlafaxine and iohexol from wastewater effluent using coupled microalgal–bacterial biofilm." Chemosphere 308: 136399.

Desagani, D., A. Jog, O. Teig-Sussholz, A. Avni and Y. Shacham-Diamand (2022). "Drought monitoring in tobacco plants by in-vivo electrochemical biosensor." Sensors and Actuators B: Chemical 356: 131357.

Leibman-Markus, M., S. Schuster, B. Vasquez-Soto, M. Bar, A. Avni and L. Pizarro (2022). "Dynamin-related proteins enhance tomato immunity by mediating pattern recognition receptor trafficking." Membranes 12(8): 760.

Marash, I., M. Leibman-Markus, R. Gupta, A. Avni and M. Bar (2022). "TOR inhibition primes immunity and pathogen resistance in tomato in a salicylic acid-dependent manner." Molecular Plant Pathology.

Akao, P. K., B. Singh, P. Kaur, A. Sor, A. Avni, A. Dhir, S. Verma, S. Kapoor, U. G. Phutela and S. Satpute (2021). "Coupled microalgal–bacterial biofilm for enhanced wastewater treatment without energy investment." Journal of Water Process Engineering 41: 102029.

Bar-On, L., U. Garlando, M. Sophocleous, A. Jog, P. Motto Ros, N. Sade, A. Avni, Y. Shacham-Diamand and D. Demarchi (2021). "Electrical Modelling of In-Vivo Impedance Spectroscopy of Nicotiana tabacum Plants." Frontiers in Electronics 2: 753145.

Bar-On, L., U. Garlando, M. Sophocleous, A. Jog, P. M. Ros, N. Sade, A. Avni, Y. Shacham-Diamand and D. Demarchi (2021). "Electrical Modelling of In-Vivo Impedance Spectroscopy of Nicotiana."

Kadan-Jamal, K., A. Jog, M. Sophocleous, J. Georgiou, A. Avni and Y. Shacham-Diamand (2021). "Towards optimization of plant cell detection in suspensions using impedance-based analyses and the unified equivalent circuit model." Scientific reports 11(1): 1-7.

Kadan-Jamal, K., M. Sophocleous, A. Jog, D. Desagani, O. Teig-Sussholz, J. Georgiou, A. Avni and Y. Shacham-Diamand (2021). "Electrical impedance spectroscopy of plant cells in aqueous buffer media over a wide frequency range of 4 Hz to 20 GHz." Methods X 8: 101185.

Jog, A., L. Bar-on, A. Avni and Y. Shacham-Diamand (2020). Feasibility of Signal Transmission for Plant Body Channel Communication in Tobacco. 2020 IEEE SENSORS, IEEE.

Kadan-Jamal, K., M. Sophocleous, A. Jog, D. Desagani, O. Teig-Sussholz, J. Georgiou, A. Avni and Y. Shacham-Diamand (2020). "Electrical Impedance Spectroscopy of plant cells in aqueous biological buffer solutions and their modelling using a unified electrical equivalent circuit over a wide frequency range: 4Hz to 20 GHz." Biosensors and Bioelectronics 168: 112485.

YOSI Y. SHACHAM-DIAMAND

CURRICULUM VITAE (January 2023)

PERSONAL:

Date and Place of Birth:	June 26, 1953, Petach-Tikva, Israel
Nationality:	Israel
Marital Status:	Married + 4
Address (Home):	13 Hanotrim St, P.O. Box 1522, Zichron-Yakov 30900, Israel
Telephone No.:	+972-(0)3-6408064 (office); +972-(0)4-639-2195/2186 (home); +972-(0)50-6672978 (Mobile)
E-mail address:	yosish@eng.tau.ac.il
FAX:	+972-3-6423508 (office)
Current position	Full professor, the Bernard Schwartz chair for nano scale integrated technologies at the department of physical electronics, the school of electrical engineering and the department of material science and engineering, faculty of engineering, Tel Aviv University, Israel
Address (Office)	Room 226, Engineering Labs Building Department of Physical Electronics, Faculty of engineering, Tel Aviv University, Ramat Aviv 69978, Israel

EDUCATION

B,Sc, (Summa com Laude)	Electrical Engineering, the Technion	1978
M,Sc,	Electrical Engineering, the Technion	1980
Doctor of Science	Electrical Engineering, the Technion	1983

PROFESSIONAL EXPERIENCE:

1977-1979	Teaching Assistant, Dept. of EE, the Technion - IIT
1979-1983	Instructor, Department of Electrical Engineering at Technion
1983-1985	Postdoctoral, Visiting Research Associate at the Electronics Research Laboratories, Department of EECS, University of California, Berkeley.
1985-1986	Lecturer, Dept. of EECS and a Visiting Research Associate at the Electronics Research Laboratory, University of California, at Berkeley
Oct. 1986-Jan. 1987	Lecturer, Department of Electrical Engineering at the Technion - IIT
Feb. 1987-Sept. 1989	Senior Lecturer, Department of Electrical Engineering at the Technion - Israel Institute of Technology.
June-September 1988	Visiting Research Associate for the Electronics Research Laboratories, Dept. of EECS, University of California at Berkeley.
Aug. 1989-June 1990	Visiting Assistant Professor, School of Electrical Engineering, Cornell University, Ithaca, New York.
July 1990-1997	Assistant Professor, School of Electrical Engineering, Cornell University, Ithaca, New York.
Aug. 1995 - Aug. 96	Visiting Scientist, Faculty of EE, The Technion IIT, Haifa, Israel.
1996 - 1997	Academic and Business Manager of the Israeli Consortium for 0.25μm/300mm technologies.
October 1997 – Sept 2002	Associate Prof. At the Department of Physical Electronics, faculty of Engineering, Tel-Aviv university.
October 2002 – Now	Full Professor at the Department of Physical Electronics, faculty of Engineering, Tel-Aviv university.
Jan. 2000 – Aug.- 2001	Academic Director, Micro Technologies Laboratory, Faculty of Engineering, Tel-Aviv university.
September 2001 – August 2004	Director, Tel-Aviv University research institute for Nano-Science and nano-Technology.
August 2004 – August 2005	Sabbatical leave in Tokyo as a Visiting Professor, Dept. of Applied Chemistry, Waseda University, Tokyo, Japan.
August 2005 – Now	Visiting Professor, Dept. of Applied Chemistry, Waseda University, Tokyo, Japan.
April 2007	The Bernard L. Schwartz Chair for nano scale information technologies.

November 2007-May 2011	Head of the department of Physical Electronics, faculty of Engineering.
November 2007-October 2012	Engineering faculty Vice-dean for Industrial relations and with the friends of the faculty in Israel and abroad.
Nov 2009-Aug 2010	Member of the nomination committee for the chairman of the Tel Aviv University board of governors
February 2009 – January 2014	Member of the board of directors of "RAMOT" by Tel Aviv University.
June 2010 – November 2013	Member of the MAGNET committee promoting basic and generic technologies in Israel, Office of the chief scientist, Ministry of trade and Industry.
October 2011-October 2012	Head of the Engineering Industrial Relation Committee and the Industrial relation office, Tel Aviv University
February 2012-Now	Member of the Editorial board of the Journal of Microelectronic Engineering, Elsevier B.V.
November 2012 – October 2013	Sabbatical leave in Rome as a Visiting professor at the Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e Microsistemi (CNR-IMM) , Rome, Italy.
October 2013 – now	Distinguished international chair professor, Feng Chia University, Taiwan
October 2013-2014	Visiting Professor, Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e Microsistemi (CNR-IMM) , Rome Italy
April 2014 – now	Member of the MAGNET committee promoting basic and generic technologies in Israel, Office of the chief scientist, Ministry of trade and Industry.
October 2015-now	Member of the department of Materials science and engineering, Tel Aviv University.
April 2018-September 2018	Visiting professor, (position granted under the Visiting Professor Initiative, Politecnico di Torino), Department of electronics and telecommunication, Politecnico di Torino, Torino, Italy
May 2018-Now	TAU Ventures, investment committee.
October 2018-Now	Director, CAMTEK Inc.
August 2019-Now	Endowed Chair Professor, Thapar Institute for Engineering and Technology (TIET), Patiala, India.
August 2019-Now	International director, Tel Aviv University/Thapar Institute for Engineering and Technology Food Security Center of Excellence
October 2020-Sept 2021	International school of electrical engineering, Tel Aviv University, head
December 2020 – March 2022	Israel Infrastructure Committee (TELEM) – Bioconvergence subcommittee.
November 2021-Now	Head of the Technical committee, the Israeli consortium for generic Biochip technologies.
August-October 2022	Visiting Professor, Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e Microsistemi (CNR-IMM) , Rome Italy
June-Sept 2022	Visiting Professor, Central Research Labs (Bio), Hamamatsu, Japan
Oct 1 2022 - Now	Professor Emeritus, Tel Aviv university

Publication report

Google scholar: 441 recorded publications

	All	Since 2017
Citations	9946	2842
h-index	50	22
i10-index	179	77

Web of science: 259 Recorded publications, 3919 citations, h-index 32

George S. Wise Faculty of Life Sciences
Prof. Abdussalam Azem
Dean

TEL AVIV UNIVERSITY אוניברסיטת תל אביב
פרופ׳ עבדאלסלאם עאזם

January 24 2023

To: the Zimin Institute for Engineering Solutions Advancing Better Lives grant committee

Re: The research proposal of Prof. Adi Avni and Prof. Yosi Shacham

I strongly and unequivocally endorse to the proposal titled "Bio-Convergence to Detect Plant Stress" that was conceived by prof. Adi Avni from the faculty of life sciences and Prof. Yosi Shacham-Diamand from the engineering faculty.
Using a bio-synthetic approach in plants is a very novel topic that will open the door to basic science discoveries and potentially to advances in agriculture and food production. It is an excellent example of the bio-convergence concept as both researchers integrate micro-system technology, an engineering concept, with biological concepts converging into a new entity. This can be achieved only by a meaningful collaboration between our faculty and the faculty of engineering using bio-convergence concepts and themes.

Such research is important to our faculty bringing life sciences closer to engineering students and faculty and hopefully creating new paradigms. It is important to the bio-converge thrust in Israel. Both researchers are well-known and recognized as leaders in. their field. They also educated a significant number of graduate students, many of them senior faculties in other research universities in Israel and abroad.

Prof. Avni's facilities are well equipped for this research and he got the admin and infrastructure support of our faculty in everything he deeds,

With best regards

AZEM

Abdussalam Azem

Prof. Abdussalam Azem, Ph.D.
Dean of George S. Wise faculty of Life Sciences
School of Neurobiology, Biochemistry and Biophysics
Sagol School of Neuroscience
Tel Aviv University

קרית האוניברסיטה, רמת אביב תל אביב 69978. דואל: azema@tauex.tau.ac.il

TEL AVIV 69978, ISRAEL. + 972-3-6408008; e-mail: deanls@tauex.tau.ac.il

●●● Office of the Dean

לשכת הדֵּקָן ורֹאשַׁת המִנְהָל ●●●

The Iby and Aladar Fleischman
Faculty of Engineering
Tel Aviv University

הפקולטה להנדסה
ע"ש איבי ואלדר פליישמן
אוניברסיטת תל אביב

January 25, 2023

To: **The Zimin Institute for Engineering Solutions Advancing Better Lives**

Re: **The research proposal of Prof. Yosi Shacham and Prof. Adi Avni**

Dear grant committee members,

I certify our endorsement of the proposal titled "Bio-Convergence to Detect Plant Stress" written by Prof. Yosi Shacham-Diamand from our engineering faculty in collaboration with prof. Adi Avni from the faculty of life sciences. We most gladly welcome their participation in that joint research as principal investigators. It is an excellent example of a strong collaboration between our faculty and the faculty of life sciences at Tel Aviv University.

Prof. Shacham-Diamand and Prof. Avni have an excellent record in novel research integrating micro technologies, sensors for bio-synthetic constructs implemented in plants. They already advised a significant number of joint students and run a joint research program in this field for almost 5 years following more than 20 years in this field in general. Both researchers are good examples of the bio-convergence concept combining engineering concepts, like micro-system technologies, microelectrodes, and microfluidics, with biological concepts.

Both researchers are well-recognized in their fields and contribute significantly to science and engineering research in Israel and abroad.

Prof. Shacham-Diamand has the facilities to do this research and he got the administrative support of faculty and university administration.

Sincerely,

Professor Noam Eliaz

Dean

Dean's Office, The Iby and Aladar Fleischman Faculty of Engineering, Tel Aviv University,
30 Haim Levanon St., P.O.Box 39040, Ramat Aviv, Tel Aviv 6997801, Israel.
Room 200, Wolfson Bldg., Tel: +972 (3) 640-8736/8, Cellular: +972 (54) 998-0029,
Fax: +972 (3) 640-7221, email: deaneng@tauex.tau.ac.il, Web: https://engineering.tau.ac.il