TABLE I
LIST OF CAPACITIVE MEASUREMENT-BASED STUDIES

Reference	Application	Fruit	V_{P-P}	Temperature	Plate size / Volume dependence	Frequency
[14]	Ripening	Banana	5 V	Controlled	25 × 10 cm / Yes (estimated)	10 kHz–10 MHz
[15]	Ripening	Banana	2 V	N/A	20 × 9 cm / Yes (not estimated)	10 kHz–10 MHz
[16]	Firmness	Apple	5 V	N/A	8.5 × 98.5 cm / Yes (not estimated)	132, 640, 880 kHz
[17]	Conductivity spectra	Various	32 V	Yes	36 × 49 × 34 cm / Yes (estimated)	156 kHz–2.5 MHz
[50]	Maturity grading	Oil Palm Fresh Fruit	N/A	Controlled	40 × 40 cm / Yes (not estimated)	100 kHz
[51]	Prediction of banana volume	Banana	N/A	Controlled	25 × 10 cm / Yes (estimated)	1,10,100,450 kHz
[52]	Predicting the sweetness	Sapota Sapodilla	5 V	Controlled	5.53 × 11.35 cm / Yes (not estimated)	10, 15, 20, 25 MHz
This work	Aging / Damage detection	Banana / Nectarine	5 V	Yes	20 × 30 cm / No (not volume dependent)	5–200 kHz/10 Hz–10 MHz

N/A = Not Available.

sensitivity to certain sample properties. While single-frequency measurements are quick and straightforward, frequency sweeps, as in this study and in [14], [15], and [17], detect small variations across frequencies, although requiring more time. The choice between frequency range and single-frequency measurement depends on specific measurement goals. Overall, this method presents a novel approach to fruit quality investigation.

IV. Conclusion

In this work, EIS was employed as a noncontact method for assessing fruit quality. The investigation focused on two setups: first, a preliminary trial including four bananas and soap, and secondly, the examination of 51 nectarines. Both cases yielded promising results with the noncontact capacitive measurement method. During the initial setup, spanning seven days, the noncontact technique effectively observed the banana's aging process, showing a noticeable decline in series capacitance (C_s) with time. This sensitivity to biological changes allowed clear differentiation between the aging banana and the stable soap. Moreover, the correlation between capacitance and temperature underscored the necessity for temperature correction during data processing.

To explore temperature effects, simultaneous measurements of sample presence and absence were conducted, unveiling the impact of aging and environmental factors on system response. This innovative approach presents a means to mitigate temperature and other influences effectively. In addition, by analyzing C_s response to banana sample mass loss, the method acknowledges the role of biochemical changes over time in assessing fruit quality. In setup 2, the noncontact technique assessed mechanical damage in 51 nectarines, revealing an immediate increase in C_s postdamage, followed by a subsequent decrease after 24 h. This dynamic response reflects complex cellular alterations triggered by mechanical damage, including cell content leakage and membrane integrity changes. The method's ability to discern damaged fruit, even 24 h postdamage, suggests real-time quality evaluation feasibility in industrial settings.

Overall, these findings clear up the complex relationship between aging, mass loss, damage detection, capacitance reduction, and fruit properties, offering significant implications for industry and fruit quality assessment. The nondestructive, real-time nature of this technology presents an efficient means for fruit quality verification, enabling swift sorting, and minimizing financial losses. Future enhancements in measurement setup, calibration, and integration with automated sorting systems hold promise for increased productivity and customer satisfaction. Ultimately, this method stands to revolutionize fruit processing, reducing waste, and enhancing produce quality and safety.

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