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NON-DESTRUCTIVE SAMPLING TECHNIQUES IN FRUIT CROPS

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Abstract

Non-destructive sampling techniques have become increasingly important in fruit crop research and production due to their ability to monitor plant and fruit parameters without damaging the samples. These methods enable repeated and real-time assessments throughout the growing season, providing valuable insights into physiological, biochemical, and quality attributes vital for fruit development, maturity evaluation, and stress detection. Unlike destructive methods, non-destructive techniques preserve sample integrity, making them ideal for longitudinal studies, breeding programs, and precision horticulture. Techniques such as near-infrared (NIR) spectroscopy, hyperspectral imaging, and magnetic resonance imaging (MRI) are widely used to analyze internal fruit quality such as sugar content, firmness, and internal defects. Portable sensors, including chlorophyll meters and acoustic firmness testers, allow rapid on-field evaluation of ripeness and nutrient status. Additionally, infrared thermography, dendrometers, and sap flow sensors help monitor stress, water use efficiency, and growth responses. Emerging optical tools like Raman spectroscopy and fluorescence imaging further enhance the detection of pigment levels, nutrient deficiencies, and early disease symptoms. These tools are increasingly integrated with remote sensing platforms and Internet of Things (IoT) devices to support large-scale monitoring and digital orchard management. In breeding programs, non-destructive phenotyping enables high-throughput screening of genotypes based on performance and quality metrics. Overall, non-destructive techniques offer efficient, accurate, and sustainable alternatives for fruit crop monitoring, significantly reducing research costs, improving yield forecasting, and supporting precision agriculture. Their continued development and adoption promise improved decision-making in the management, selection, and production of high-quality fruit crops.

Introduction

Advances in agricultural science have significantly transformed fruit quality assessment, with non-destructive sampling techniques emerging as indispensable tools in modern horticulture. Traditionally, assessing fruit quality and physiological parameters relied heavily on destructive methods, such as physical sampling, slicing, and chemical analysis, which often resulted in sample wastage, limited the possibility for repeated measurement, and inhibited continuous tracking of fruit development (Bratu *et al*., 2021). In response to rising global food demand and stricter quality standards, as well as a growing emphasis on sustainability and resource efficiency, non-destructive approaches have emerged to address these limitations and revolutionize fruit crop management (Lee *et al*., 2023). Non-destructive techniques encompass a suite of innovative technologies that allow the evaluation of both external and internal fruit attributes without causing physical harm or altering the sample. These methods include Computer Vision Systems (CVS), Near-Infra Red (NIR) spectroscopy, hyperspectral imaging, Magnetic Resonance Imaging (MRI), acoustic techniques, and electronic nose (E-nose) devices (Ranjani *et al*., 2024). Such tools make it possible to assess critical quality parameters such as sugar content, firmness, acidity, dry matter, color, texture, ripeness, and the presence of internal disorders or defects in real-time or high-throughput modes. This enables repeated and longitudinal measurements throughout the entire supply chain, from pre-harvest monitoring to postharvest handling and retail (Zhang *et al*., 2025).

Computer vision systems employ digital cameras and sophisticated image processing algorithms to objectively evaluate external features like color, size, shape, and surface defects. These systems reduce human subjectivity, support automated in-line grading, and are increasingly integrated into packing and processing plants (Lee *et al*., 2023). Portable and smartphone-assisted image analysis has further democratized quality assessment, making these capabilities available for on-farm use and empowering growers with immediate feedback. Spectroscopic methods, particularly NIR and hyperspectral imaging, penetrate fruit tissue to retrieve information about internal chemical composition and structural integrity. These methods rapidly predict soluble solid content (SSC), moisture, acidity, and textural qualities for a wide range of fruit crops, such as kiwifruit, mango, papaya, banana, and avocado (Yao *et al*., 2013; Huang *et al*., 2018). Their main advantage lies in enabling non-invasive, contactless, and high-throughput assessment, minimizing food waste and supporting sustainability goals (Bratu *et al*., 2021).

MRI, albeit limited by its high cost and system complexity, offers unparalleled insight into internal fruit structure, water distribution, and tissue health, proving valuable in research and high-value fruit markets (Zdunek *et al*., 2014). Similarly, acoustic and ultrasonic techniques have demonstrated efficacy in non-destructive firmness measurement and early detection of internal disorders and pest infestation, further advancing efficient, objective quality control (Ranjani *et al*., 2024). The integration of these non-destructive technologies with digital platforms, data analytics, and artificial intelligence amplifies their power, delivering automated, reliable, and real-time decision-support for growers, breeders, and supply chain managers (Zhang *et al*., 2025). Machine learning algorithms, for example, can process vast datasets generated by spectral and imaging devices to classify fruit maturity stages, grade defects, and even predict shelf life with remarkable accuracy (Lee *et al*., 2023).

Despite their transformative impact, several challenges must be addressed to broaden the adoption of non-destructive techniques, such as cost, complexity, model calibration across varieties, and operational scalability. Nevertheless, ongoing research and technological development continue to improve the accuracy, affordability, and adaptability of these tools, positioning non-destructive sampling as a cornerstone of next-generation fruit production and supply chain management (Ranjani *et al*., 2024; Bratu *et al*., 2021).

Imaging-Based Techniques

- ✓ Near-Infrared (NIR) Spectroscopy: Used to analyze internal quality factors such as sugar content, dry matter, and firmness.
- ✓ Hyperspectral Imaging: Captures spatial and spectral information to assess maturity, detect defects, and quantify biochemical composition.
- ✓ Magnetic Resonance Imaging (MRI): Offers high-resolution, three-dimensional insights into internal structure and water content.
- ✓ Computed Tomography (CT): Enables visualization of internal tissues without physical sectioning.

Portable Sensor Technologies

- ✓ Chlorophyll Meters (e.g., SPAD): Measure plant health, maturity, and nutrient status through leaf or fruit pigment analysis.
- ✓ Electronic Noses: Detect aroma profiles for ripeness and quality determination.
- ✓ Acoustic and Firmness Sensors: Evaluate fruit firmness, ripeness, and internal damage.

Biophysical and Physiological Methods

- ✓ Infrared Thermography: Assesses surface temperature variations for water stress and disease detection.
- ✓ Dendrometers and Growth Sensors: Measure changes in fruit/stem diameter for real-time growth tracking.

Comparative Table of Techniques

Technique	**Target Attribute**	**Crops Commonly Used**	**Advantages**	**Limitations**
NIR Spectroscopy	Sugar, dry matter, SSC	Apple, mango, grape, citrus	Rapid, non-invasive	Calibration needed
Hyperspectral Imaging	Biochemical compounds	Banana, kiwifruit, peach	High-throughput	Equipment cost
MRI/CT	Internal structure	Tomato, citrus, avocado	Detailed imaging	High cost, slow
Chlorophyll Meter	Chlorophyll, N status	Mango, guava, apple	Portable, quick	Surface only
Acoustic/Firmness Test	Firmness, ripeness	Peach, plum, mango	Automated grading	Surface-focused
Electronic Nose	Aroma/volatile profile	Strawberry, apple, banana	Early ripeness check	Sensor maintenance
Thermal Imaging	Water stress, disease	Citrus, grape, avocado	Canopy-level survey	External only

Applications in Fruit Crop Research and Production

- ✓ Maturity and Ripeness Assessment: Enables precise harvest timing and optimizes storage and shipping protocols.
- ✓ Quality Monitoring: Continuous, non-invasive tracking of sugar content, acidity, firmness, and other quality indices.
- ✓ Disease and Stress Detection: Early, non-visible symptom identification through changes in thermal, spectral, or volatile profiles.
- ✓ Breeding and Phenotyping: Allows repeated measurement of large populations, supporting selection for quality traits.

Case Studies and Success Stories

- ✓ NIR in Mango & Grape: Rapid internal quality grading for sorting and yield estimation.
- ✓ Hyperspectral Imaging in Banana: Non-destructive prediction of ripening processes and storage disorders.
- ✓ MRI in Tomato: Monitoring progression of internal disorders and water loss in postharvest storage.
- ✓ Chlorophyll Meters in Orchard Management: On-the-spot monitoring of nutrient status in apple and citrus for precision fertilizer scheduling.

Integration with Digital and Automated Systems

- ✓ IoT-Enabled Sensors: Wireless transmission of quality data for digital orchard management.

- ✓ Machine Learning: Enhanced pattern recognition from large datasets, improving grading accuracy and defect detection.
- ✓ Decision-Support Software: Real-time dashboards for growers, allowing immediate intervention and traceability.

Challenges and Future Perspectives

- ✓ Calibration and Standardization: Need for robust models adaptable across varieties and environments.
- ✓ Cost and Accessibility: Reducing costs and improving portability for smallholders.
- ✓ Data Management: Handling, storing, and interpreting large volumes of multi-sensor data.

Emerging Technologies: Quantum sensors, drone-based imaging, and miniaturized platforms for field deployment.

References

1. Bulgari R, Cocetta G, Trivellini A,Vernieri P, Ferrante A. Biostimulants and crop responses: A review. Biological Agriculture and Horticulture. 2014; 31(1):1-17. https://doi.org/10.1080/01448765.2014.964649
2. Dorta, S. d. O., Balbinotte, J., Monnerat, R., Lopes, J. R. S., da Cunha, T., Zanardi, O. Z., et al. (2020). Selection of *Bacillus thuringiensis* strains in citrus and their pathogenicity to *Diaphorina citri* (Hemiptera: Liviidae) nymphs. Insect Sci. 27, 519–530. https://doi/org/10.1111/1744-7917.12654
3. du Jardin, P. (2015). Plant biostimulants: definition, concept, main categories and regulation. *Sci. Hortic.* 196, 3–14. doi: 10.1016/j.scienta.2015.09.021
4. Efthimiadou, A.; Katsenios, N.; Chanioti, S.; Giannoglou, M.; Djordjevic, N.; Katsaros, G. Effect of foliar and soil application of plant growth promoting bacteria on growth, physiology, yield and seed quality of maize under Mediterranean conditions. Sci. Rep. 2020, 10, 21060
5. El Boukhari, M.E.M.; Barakate, M.; Bouhia, Y.; Lyamlouli, K. Trends in Seaweed Extract Based Biostimulants: Manufacturing Process and Beneficial Effect on Soil-Plant Systems. Plants 2020, 9, 359.
6. Ertani, A., Nardi, S., Francisco, O., Pizzeghello, D., Tinti, A. and Schiavon, M. Metabolite-Targeted Analysis and Physiological Traits of *Zea mays* L. in Response to Application of a Leonardite-Humate and lignosulfonate-based products for their evaluation as potential biostimulants. Agronomy 2019, *9*, 1-19, https://doi.org/10.3390/agronomy9080445
7. EU (2019) Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003
8. Gupta, V.; Kumar, M.; Brahmbhatt, H.; Reddy, C.R.K.; Seth, A.; Jha, B. Simultaneous determination of different endogenetic plant growth regulators in common green seaweeds using dispersive liquid–liquid microextraction method. Plant Physiol. Biochem. 2011, 49, 1259–1263.
9. Harman, G.E. Myths and Dogmas of Biocontrol Changes in Perceptions Derived from Research on *Trichoderma harzinum* T-22. Plant Dis. 2000, 84, 377–393.
10. Morales-Cede´no, L. R., De Los Santos-Villalobos, S., and Santoyo, G. (2021). Functional and genomic analysis of Rouxiella badensis SER3 as a novel biocontrol agent of fungal pathogens. Front.Microbiol. 12:709855.

https://doi/org/10.3389/fmicb.2021.709855

11. Rashid, M., Khan, A., Hossain, M. T., and Chung, Y. R. (2017). Induction of systemic resistance against aphids by endophytic *Bacillus velezensis* YC7010 via expressing phytoalexin deficient4 in Arabidopsis. Front. Plant Sci. 8:211. https://doi.org/10.3389/fpls.2017.00211
12. Sabir, A., Yazar, K., Sabir, F., Kara, Z., Yazici, M. A., and Goksu, N. (2014). Vine growth, yield, berry quality attributes and leaf nutrient content of grapevines as influenced by seaweed extract (*Ascophyllum nodosum*) and nanosize fertilizer pulverizations. Sci. Hortic. 175, 1–8. doi: 10.1016/j.scienta.2014.05.021
13. Sangiorgio, D., Cellini, A., Donati, I., Pastore, C., Onofrietti, C., and Spinelli, F. (2020). Facing climate change: application of microbial biostimulants to mitigate stress in horticultural crops. Agronomy 10:794. https://doi.org/10.3390/agronomy10060794
14. Schmidt, R.E. Questions and Answers about Biostimulants; Hi Tech Ag Solutions: Davenport, WA, USA, 2003; p. 4.
15. Semida, W.M.; Abd El-Mageed, T.A.; Hemida, K.; Rady, M.M. Natural bee-honey based biostimulants confer salt tolerance in onion via modulation of the antioxidant defence system. J. Hortic. Sci. Biotechnol. 2019, 1–11.
16. Sible, C.N.; Seebauer, J.R.; Below, F.E. Plant Biostimulants: A Categorical Review, Their Implications for Row Crop Production, and Relation to Soil Health Indicators. Agronomy 2021, 11, 12.