



TRANSFORMING FOOD ANALYSIS AND CONTROL:

NON-DESTRUCTIVE TECHNOLOGIES AND INNOVATIONS

K. Prasad, S. Shekhar, M. K. Paswan and R. Ahuja



Advancing Food Quality, Safety and Sustainability with
Smart, Innovative and Non-Destructive Technologies



SLIET
LONGOWAL



Sant Longowal Institute of Engineering
and Technology, Longowal

Transforming Food Analysis and Control: Non-Destructive Technologies and Innovations

Edited by

**Kamlesh Prasad, PhD
Shubhra Shekhar, M. Tech.
Mani Kant Paswan, PhD
Rajeev Ahuja, PhD**



**Sant Longowal Institute of Engineering and Technology,
Longowal – 148106, Sangrur, Punjab, INDIA**

Editors

Prof. Kamlesh Prasad, SLIET, Longowal
Mr. Shubhra Shekhar, UNSW, Sydney
Prof. Manikant Paswan, Director, SLIET, Longowal
Prof. Rajeev Ahuja, Director, IIT, Ropar

Copyright© SLIET Longowal

The data and views expressed in the book are those of the contributors and not of the editorial board. Though every care has been taken to reproduce the book accurately, the publisher is not responsible for any damage caused by misinterpretation of information expressed or implied within its pages.

Published By

Publication Division
Sant Longowal Institute of Engineering and Technology,
Longowal - 148106 (Punjab) INDIA

Transforming Food Analysis and Control: Non-Destructive Technologies
and Innovations

Sant Longowal Institute of Engineering and Technology, Longowal,
(Punjab) INDIA

SLIET Communication No. 4401/18112025

ISBN: 978-81-990304-0-4 (Hardback)

ISBN: 978-81-990304-1-1 (e-Book)

Hyperspectral Imaging as an Intelligent Nondestructive Food Quality Assessment Tool

Komalpreet Kaur , Shubhra Shekhar , Dhritiman Saha , and Kamlesh Prasad 

Abstract. Ensuring food safety and quality is a worldwide issue that demands swift, dependable, and non-invasive assessment techniques. Traditional analytical methods like chromatography and mass spectrometry, while precise, are destructive, labour-intensive, and not ideal for real-time industrial use. Hyperspectral Imaging (HSI), which combines imaging and spectroscopy, has emerged as a promising optical sensing method that captures both spatial and spectral data across numerous adjacent wavelength bands. This dual capability enables in-depth analysis of the chemical composition, physical structure, and contaminant identification in food matrices. This paper presents the core principles, components, and data-acquisition techniques of HSI, highlighting its benefits over conventional RGB, NIR, and multispectral imaging systems. Additionally, it delves into recent uses of HSI in assessing food quality, such as detecting adulteration, estimating moisture and protein levels, and analysing microbial contamination. HSI, combined with machine learning and deep learning, has amplified its potential for automated, real-time quality inspection and classification. Despite its benefits, industrial adoption is hindered by high system costs, data redundancy, and limited algorithmic generalisation. Future developments should aim at compact hardware design, effective spectral data reduction, and interpretable AI models for scalable implementation. In summary, HSI is a revolutionary, non-destructive approach to intelligent monitoring systems, promoting improved safety, authenticity, and sustainability in contemporary food production.

Keywords: Hyperspectral Imaging, Non-Destructive Testing, Food Quality, Machine Vision System, Deep Learning, Artificial Intelligence

K. Kaur (✉) and K. Prasad (✉)

Department of Food Engineering and Technology, SLIET, Longowal-148106, Punjab, India
email: komalpss410@gmail.com, profkprasad@gmail.com

Shubhra Shekhar (✉)

School of Chemical Engineering, UNSW, Sydney 2052, Australia
email: shekharshubhra@gmail.com

Dhritiman Saha (✉)

ICAR-Central Institute of Post-Harvest Engineering and Technology, Ludhiana-141004, Punjab, India
email: dhriti.iitkgp@gmail.com

© The Author(s), under exclusive license to SLIET, Longowal. 2026 K. Prasad et al. (eds.), Transforming Food Analysis and Control: Non-Destructive Technologies and Innovations, SLIET, Longowal, Punjab, INDIA.

ISBN: 978-81-990304-0-4 (Hardback), 978-81-990304-1-1 (e-Book)

1. Introduction

Food safety and quality have become global concerns due to the growth of food supply chains, increased consumer awareness, and rising incidents of adulteration. The foodborne risks and adulterants pose significant public health threats; consumers are increasingly seeking food products that are not only safe but also nutritious, fresh, and authentic (Ahmed, Monjur, et al., 2025). Therefore, fulfilling these demands requires implementing a rapid, reliable, and precise quality-control strategy by both industry and regulatory bodies. Traditional food testing methods, such as chromatography, HPLC, GC, mass spectrometry, and classical wet chemistry, are well known for their accuracy and sensitivity (Saha et al., 2023). However, these techniques are destructive, labour-intensive, and not suitable for large-scale or real-time monitoring systems. These drawbacks have prompted the exploration of nondestructive, rapid, less labour-intensive, time-efficient technologies capable of continuous monitoring throughout the food supply chain. Various non-invasive techniques have been explored, including near-infrared spectroscopy (NIRS), X-ray imaging, E-nose, and machine vision. Among these, Hyperspectral Imaging (HSI) has garnered particular attention. HSI stands out as a nondestructive technique that combines imaging and spectroscopy to capture hundreds of spectral bands across the visible, near-infrared, and short-wave infrared regions (Cheng et al., 2025; Manea & Calin, 2015). This unique capability to deliver both spatial and spectral information enables a thorough assessment of food quality characteristics, including chemical composition, physical properties, and contaminant detection, all without damaging the samples. Over the past decade, the versatility of HSI has been demonstrated in a variety of food applications (Anderssen et al., 2020; Cao et al., 2021; Çetin et al., 2022; Chen et al., 2023; Choi et al., 2024). These applications include evaluating the ripeness and freshness of produce, estimating protein and moisture content, assessing meat quality, detecting adulteration in products such as milk, oils, cereals, and spices and identifying foreign objects like stones, plastics, and insects, thus improving food safety (Gul et al., 2024; Kabir et al., 2025). As chemometric tools, machine learning, and deep learning become more integrated, HSI is evolving from a laboratory-based method to a practical solution for continuous, real-time monitoring during food processing. Furthermore, HSIs with artificial intelligence have garnered increasing interest, expanding their capabilities beyond traditional spectral analysis to become more sophisticated sensing tools for spatial structures and molecular compositions. These advancements are paving the way for the development of intelligent, automated inspection systems within the food processing sector (Ang & Seng, 2021; Mavani et al.,

7. Conclusion

Hyperspectral imaging represents a major shift in spectroscopy and imaging. It captures valuable spatial and spectral information for evaluating food quality and safety. Its ability to assess various attributes, including identification and classification of constituents, nutritional profiling, and adulteration detection, makes it a quick, reagent-free, and non-destructive tool that fits present food production needs. However, significant challenges still hinder industrial use of HSI. Issues like measurement variability due to changing environmental conditions, high setup costs, operational complexity, and heavy computational load from large hyperspectral datasets. Therefore, advances in models and algorithms tailored to specific food types and imaging conditions are crucial for improving prediction accuracy and reducing processing time. The shift from large and costly lab instruments to smaller, compact, field-deployable systems is also urgent. Emerging advancements, including environmental compensation modules, are making meaningful progress. Hybrid approaches, such as targeted multispectral imaging and RGB-based hyperspectral systems, may offer a practical solution that reduces data requirements while maintaining the characteristic chemical sensitivity of the HSI. The lack of standardised protocols for data collection, preprocessing and model validation, along with a shortage of publicly available reference datasets, creates a major barrier to reproducibility and comprehensive transparency. Therefore, developing guidelines and making datasets available on public platforms will be essential to accelerating the regulatory acceptance and practical use of HSI-based quality assurance systems. In the future, improvements in deep learning models, combined with hyperspectral databases, are expected to improve model performance and prediction accuracy across various food categories. Hence, exploring the combined use of HSI with other sensor technologies, such as fluorescence imaging, Raman spectroscopy, or X-ray CT, shows great promise for next-generation non-destructive analysis throughout the food production chain.

References

- Ahmed, M. T., Monjur, O., Khaliduzzaman, A., & Kamruzzaman, M. (2025). A comprehensive review of deep learning-based hyperspectral image reconstruction for agri-food quality appraisal. *Artificial Intelligence Review*, 58(4). <https://doi.org/10.1007/s10462-024-11090-w>

- Ahmed, M. T., Villordon, A., & Kamruzzaman, M. (2025). Hyperspectral imaging and explainable deep-learning for non-destructive quality prediction of sweetpotato. *Postharvest Biology and Technology*, 222. <https://doi.org/10.1016/j.postharvbio.2024.113379>
- Anderssen, K. E., Stormo, S. K., Skåra, T., Skjelvareid, M. H., & Heia, K. (2020). Predicting liquid loss of frozen and thawed cod from hyperspectral imaging. *LWT*, 133. <https://doi.org/10.1016/j.lwt.2020.110093>
- Ang, K. L. M., & Seng, J. K. P. (2021). Big data and machine learning with hyperspectral information in agriculture. *IEEE Access*, 9, 36699-36718. <https://doi.org/10.1109/ACCESS.2021.3051196>
- Aviara, N. A., Liberty, J. T., Olatunbosun, O. S., Shoyombo, H. A., & Oyeniyi, S. K. (2022). Potential application of hyperspectral imaging in food grain quality inspection, evaluation and control during bulk storage. *Journal of Agriculture and Food Research*, 8. <https://doi.org/10.1016/j.jafr.2022.100288>
- Bai, Z., Tian, J., Hu, X., Sun, T., Luo, H., & Huang, D. (2022). A back-propagation neural network model using hyperspectral imaging applied to variety nondestructive detection of cereal. *Journal of Food Process Engineering*, 45(3). <https://doi.org/10.1111/jfpe.13973>
- Bernard, A., Hamdy, S., Le Corre, L., Dirlewanger, E., & Lheureux, F. (2020). 3D characterization of walnut morphological traits using X-ray computed tomography. *Plant Methods*, 16(1). <https://doi.org/10.1186/s13007-020-00657-7>
- Bhargava, A., Sachdeva, A., Sharma, K., Alsharif, M. H., Uthansakul, P., & Uthansakul, M. (2024). Hyperspectral imaging and its applications: A review. In *Heliyon* (Vol. 10): Elsevier Ltd.
- Blasco, J., Aleixos, N., & Moltó, E. (2003). Machine vision system for automatic quality grading of fruit. *Biosystems Engineering*, 85(4), 415-423. [https://doi.org/10.1016/S1537-5110\(03\)00088-6](https://doi.org/10.1016/S1537-5110(03)00088-6)
- Cao, Y., Sun, J., Yao, K., Xu, M., Tang, N., & Zhou, X. (2021). Nondestructive detection of lead content in oilseed rape leaves based on MRF-HHO-SVR and hyperspectral technology. *Journal of Food Process Engineering*, 44(9). <https://doi.org/10.1111/jfpe.13793>
- Çetin, N., Karaman, K., Kavuncuoğlu, E., Yıldırım, B., & Jahanbakhshi, A. (2022). Using hyperspectral imaging technology and machine learning algorithms for assessing internal quality parameters of apple fruits.

- Chemometrics and Intelligent Laboratory Systems*, 230. <https://doi.org/10.1016/j.chemolab.2022.104650>
- Chandrasekaran, I., Panigrahi, S. S., Ravikanth, L., & Singh, C. B. (2019). Potential of Near-Infrared (NIR) Spectroscopy and Hyperspectral Imaging for Quality and Safety Assessment of Fruits: an Overview. In *Food Analytical Methods* (Vol. 12, pp. 2438-2458): Springer New York LLC.
- Chen, X., Jiao, Y., Liu, B., Chao, W., Duan, X., & Yue, T. (2022). Using hyperspectral imaging technology for assessing internal quality parameters of persimmon fruits during the drying process. *Food Chemistry*, 386. <https://doi.org/10.1016/j.foodchem.2022.132774>
- Chen, Y., Wang, Q., Fan, W., & Xu, B. (2023). Non-destructive determination and visualization of gel springiness of preserved eggs during pickling through hyperspectral imaging. *Food Bioscience*, 53. <https://doi.org/10.1016/j.fbio.2023.102605>
- Cheng, J., Sun, J., Xu, M., & Zhou, X. (2023). Nondestructive detection of lipid oxidation in frozen pork using hyperspectral imaging technology. *Journal of Food Composition and Analysis*, 123. <https://doi.org/10.1016/j.jfca.2023.105497>
- Cheng, J., Sun, J., Yao, K., Xu, M., & Zhou, X. (2022). Nondestructive detection and visualization of protein oxidation degree of frozen-thawed pork using fluorescence hyperspectral imaging. *Meat Science*, 194. <https://doi.org/10.1016/j.meatsci.2022.108975>
- Cheng, M. F., Mukundan, A., Karmakar, R., Valappil, M. A. E., Jouhar, J., & Wang, H. C. (2025). Modern Trends and Recent Applications of Hyperspectral Imaging: A Review. In *Technologies* (Vol. 13): Multidisciplinary Digital Publishing Institute (MDPI).
- Choi, J. Y., Lee, M., Lee, D. U., Choi, J. H., Lee, M. A., Min, S. G., & Park, S. H. (2024). Non-destructive monitoring of qualitative properties of salted cabbage using hyperspectral image analysis. *LWT*, 203. <https://doi.org/10.1016/j.lwt.2024.116329>
- Cong, S., Sun, J., Zhang, B., Shi, L., Zhou, X., & Wu, X. (2025). A new method to identify the adulteration levels of *Lonicerae Flos* in *Lonicerae Japonicae Flos* using fluorescence hyperspectral imaging combined with optimized convolutional neural network. *Microchemical Journal*, 210. <https://doi.org/10.1016/j.microc.2025.112974>

- Cortés, V., Blasco, J., Aleixos, N., Cubero, S., & Talens, P. (2019). Monitoring strategies for quality control of agricultural products using visible and near-infrared spectroscopy: A review. In *Trends in Food Science and Technology* (Vol. 85, pp. 138-148): Elsevier Ltd.
- Czarnecki, M. A., Morisawa, Y., Futami, Y., & Ozaki, Y. (2015). Advances in Molecular Structure and Interaction Studies Using Near-Infrared Spectroscopy. In *Chemical Reviews* (Vol. 115, pp. 9707-9744): American Chemical Society.
- Du, Z., Hu, Y., Ali Buttar, N., & Mahmood, A. (2019). X-ray computed tomography for quality inspection of agricultural products: A review. In *Food Science and Nutrition* (Vol. 7, pp. 3146-3160): Wiley-Blackwell.
- Du, Z., Zeng, X., Li, X., Ding, X., Cao, J., & Jiang, W. (2020). Recent advances in imaging techniques for bruise detection in fruits and vegetables. In *Trends in Food Science and Technology* (Vol. 99, pp. 133-141): Elsevier Ltd.
- Ekramirad, N., Doyle, L., Loeb, J., Santra, D., & Adediji, A. A. (2024). Hyperspectral Imaging and Machine Learning as a Nondestructive Method for Proso Millet Seed Detection and Classification. *Foods*, 13(9). <https://doi.org/10.3390/foods13091330>
- El-Mesery, H. S., Mao, H., & Abomohra, A. E. F. (2019). Applications of non-destructive technologies for agricultural and food products quality inspection. In *Sensors (Switzerland)* (Vol. 19): MDPI AG.
- ElMasry, G., Kamruzzaman, M., Sun, D. W., & Allen, P. (2012). Principles and Applications of Hyperspectral Imaging in Quality Evaluation of Agro-Food Products: A Review. In *Critical Reviews in Food Science and Nutrition* (Vol. 52, pp. 999-1023).
- ElMasry, G., & Sun, D. W. (2010). Principles of Hyperspectral Imaging Technology. In *Hyperspectral Imaging for Food Quality Analysis and Control* (pp. 3-43). Elsevier Inc. <https://doi.org/10.1016/B978-0-12-374753-2.10001-2>
- Faqeerzada, M. A., Perez, M., Lohumi, S., Lee, H., Kim, G., Wakholi, C., Joshi, R., & Cho, B. K. (2020). Online application of a hyperspectral imaging system for the sorting of adulterated almonds. *Applied Sciences (Switzerland)*, 10(18). <https://doi.org/10.3390/APP10186569>
- Feng, L., Zhu, S., Liu, F., He, Y., Bao, Y., & Zhang, C. (2019). Hyperspectral imaging for seed quality and safety inspection: A review. In *Plant Methods* (Vol. 15): BioMed Central Ltd.

- Florián-Huamán, J., Cruz-Tirado, J. P., Fernandes Barbin, D., & Siche, R. (2022). Detection of nutshells in cumin powder using NIR hyperspectral imaging and chemometrics tools. *Journal of Food Composition and Analysis*, 108. <https://doi.org/10.1016/j.jfca.2022.104407>
- Fu, L., Sun, J., Wang, S., Xu, M., Yao, K., Cao, Y., & Tang, N. (2022). Identification of maize seed varieties based on stacked sparse autoencoder and near-infrared hyperspectral imaging technology. *Journal of Food Process Engineering*, 45(9). <https://doi.org/10.1111/jfpe.14120>
- Gao, P., Li, W., Hashim, S. B. H., Liang, J., Xu, J., Huang, X., Zou, X., & Shi, J. (2025). Distributional uniformity quantification in heterogeneous prepared dishes combined the hyperspectral imaging technology with Moran's I: A case study of pizza. *Food Chemistry*, 466. <https://doi.org/10.1016/j.foodchem.2024.141511>
- Gao, P., Liang, J., Li, W., Shi, Y., Huang, X., Zhang, X., Zou, X., & Shi, J. (2024). Fusion of hyperspectral imaging and electronic nose for identification of green vegetable in egg pancakes. *Microchemical Journal*, 199. <https://doi.org/10.1016/j.microc.2024.110034>
- Gowen, A. A., O'Donnell, C. P., Cullen, P. J., Downey, G., & Frias, J. M. (2007). Hyperspectral imaging - an emerging process analytical tool for food quality and safety control. *Trends in Food Science and Technology*, 18(12), 590-598. <https://doi.org/10.1016/j.tifs.2007.06.001>
- Gruener Lima, M., & Inocente Jussiani, E. (2024). X-ray computed tomography for effective atomic number and density evaluation: A review. In *Radiation Physics and Chemistry* (Vol. 225): Elsevier Ltd.
- Gul, N., Muzaffar, K., Shah, S. Z. A., Assad, A., Makroo, H. A., & Dar, B. N. (2024). Deep learning hyperspectral imaging: a rapid and reliable alternative to conventional techniques in the testing of food quality and safety. In *Quality Assurance and Safety of Crops and Foods* (Vol. 16, pp. 78-97): Codon Publications.
- Guo, Z., & Jayan, H. (2023). Fast Nondestructive Detection Technology and Equipment for Food Quality and Safety. In *Foods* (Vol. 12): Multidisciplinary Digital Publishing Institute (MDPI).
- Handa, P., & Singh, B. (2016). Electronic nose and their application in food industries. *FOOD SCIENCE RESEARCH JOURNAL*, 7(2), 314-318. <https://doi.org/10.15740/has/fsrj/7.2/314-318>
- Hespeler, S. C., Nemati, H., & Dehghan-Niri, E. (2021). Non-destructive thermal imaging for object detection via advanced deep learning for

- robotic inspection and harvesting of chili peppers. *Artificial Intelligence in Agriculture*, 5, 102-117. <https://doi.org/10.1016/j.aiia.2021.05.003>
- Hughes, N., Askew, K., Scotson, C. P., Williams, K., Sauze, C., Corke, F., Doonan, J. H., & Nibau, C. (2017). Non-Destructive, high-Content analysis of wheat grain traits using X-ray micro computed tomography. *Plant Methods*, 13(1). <https://doi.org/10.1186/s13007-017-0229-8>
- Hwang, J., Jeong, S., & Lee, S. (2025). Machine learning-combined hyperspectral imaging analysis for the non-destructive identification of wheat flours with varying gluten strengths. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, 338. <https://doi.org/10.1016/j.saa.2025.126118>
- Ismail, N., & Malik, O. A. (2022). Real-time visual inspection system for grading fruits using computer vision and deep learning techniques. *Information Processing in Agriculture*, 9(1), 24-37. <https://doi.org/10.1016/j.inpa.2021.01.005>
- Ji, Y., Sun, L., Li, Y., Li, J., Liu, S., Xie, X., & Xu, Y. (2019). Non-destructive classification of defective potatoes based on hyperspectral imaging and support vector machine. *Infrared Physics and Technology*, 99, 71-79. <https://doi.org/10.1016/j.infrared.2019.04.007>
- Jiang, X., Xue, H., Zhang, L., Gao, X., Zhou, Y., & Bai, J. (2018). Hyperspectral Data Feature Extraction Using Deep Learning Hybrid Model. *Wireless Personal Communications*, 102(4), 3529-3543. <https://doi.org/10.1007/s11277-018-5389-y>
- Jung, H. (2021). Basic Physical Principles and Clinical Applications of Computed Tomography. *Progress in Medical Physics*, 32(1), 1-17. <https://doi.org/10.14316/pmp.2021.32.1.1>
- Kabir, M. A., Lee, I., Singh, C. B., Mishra, G., Panda, B. K., & Lee, S. H. (2025). Detection of Mycotoxins in Cereal Grains and Nuts Using Machine Learning Integrated Hyperspectral Imaging: A Review. In *Toxins* (Vol. 17): Multidisciplinary Digital Publishing Institute (MDPI).
- Khan, A. I., & Al-Habsi, S. (2020). Machine Learning in Computer Vision. *Procedia Computer Science*,
- Li, M., Yin, H., Gu, F., Duan, Y., Zhuang, W., Han, K., & Jin, X. (2025). Recent Advances and Applications of Nondestructive Testing in Agricultural Products: A Review. *Processes*, 13(9), 2674-2674. <https://doi.org/10.3390/pr13092674>

- Li, Y., Huang, G., Lu, X., Gu, S., Zhang, Y., Li, D., Guo, M., Zhang, Y., & Guo, X. (2023). Research on the evolutionary history of the morphological structure of cotton seeds: a new perspective based on high-resolution micro-CT technology. *Frontiers in Plant Science*, 14. <https://doi.org/10.3389/fpls.2023.1219476>
- Liang, Y., Li, Z., Shi, J., Zhang, N., Qin, Z., Du, L., Zhai, X., Shen, T., Zhang, R., Zou, X., & Huang, X. (2025). Advances in Hyperspectral Imaging Technology for Grain Quality and Safety Detection: A Review. *Foods*, 14(17), 2977-2977. <https://doi.org/10.3390/foods14172977>
- Liu, W., Liu, P., Han, F., & Xiao, Y. (2023). Research on electronic nose for compound malodor recognition combined with artificial neural network and linear discriminant analysis. *Journal of Intelligent and Fuzzy Systems*, 44(4), 6991-7008. <https://doi.org/10.3233/JIFS-222539>
- Lopes, J. F., da Costa, V. G. T., Barbin, D. F., Cruz-Tirado, L. J. P., Baeten, V., & Barbon Junior, S. (2022). Deep computer vision system for cocoa classification. *Multimedia Tools and Applications*, 81(28), 41059-41077. <https://doi.org/10.1007/s11042-022-13097-3>
- Lu, L., Hu, Z., Hu, X., Li, D., & Tian, S. (2022). Electronic tongue and electronic nose for food quality and safety. In *Food Research International* (Vol. 162): Elsevier Ltd.
- Mahanti, N. K., Pandiselvam, R., Kothakota, A., Ishwarya S, P., Chakraborty, S. K., Kumar, M., & Cozzolino, D. (2022). Emerging non-destructive imaging techniques for fruit damage detection: Image processing and analysis. In *Trends in Food Science and Technology* (Vol. 120, pp. 418-438): Elsevier Ltd.
- Manea, D., & Calin, M. A. (2015). Hyperspectral imaging in different light conditions. *Imaging Science Journal*, 63(4), 214-219. <https://doi.org/10.1179/1743131X15Y.0000000001>
- Matenda, R. T., Rip, D., Marais, J., & Williams, P. J. (2024). Exploring the potential of hyperspectral imaging for microbial assessment of meat: A review. In *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy* (Vol. 315): Elsevier B.V.
- Mavani, N. R., Ali, J. M., Othman, S., Hussain, M. A., Hashim, H., & Rahman, N. A. (2022). Application of Artificial Intelligence in Food Industry—a Guideline. In *Food Engineering Reviews* (Vol. 14, pp. 134-175): Springer.

- Medina–García, M., Amigo, J. M., Martínez-Domingo, M. A., Valero, E. M., & Jiménez–Carvelo, A. M. (2025). Strategies for analysing hyperspectral imaging data for food quality and safety issues – A critical review of the last 5 years. In *Microchemical Journal* (Vol. 214): Elsevier Inc.
- Medus, L. D., Saban, M., Francés-Villora, J. V., Bataller-Mompeán, M., & Rosado-Muñoz, A. (2021). Hyperspectral image classification using CNN: Application to industrial food packaging. *Food Control*, 125. <https://doi.org/10.1016/j.foodcont.2021.107962>
- Meghar, K., Tran, T., Delgado, L. F., Ospina, M. A., Moreno, J. L., Luna, J., Londoño, L., Dufour, D., & Davrieux, F. (2024). Hyperspectral imaging for the determination of relevant cooking quality traits of boiled cassava. *Journal of the Science of Food and Agriculture*, 104(8), 4782-4792. <https://doi.org/10.1002/jsfa.12654>
- Michail, C., Liaparinos, P., Kalyvas, N., Kandarakis, I., Fountos, G., & Valais, I. (2024). Radiation Detectors and Sensors in Medical Imaging. In *Sensors* (Vol. 24): Multidisciplinary Digital Publishing Institute (MDPI).
- Mukhtar, S., Arbabi, A., & Viegas, J. (2025). Advances in Spectral Imaging: A Review of Techniques and Technologies. In *IEEE Access* (Vol. 13, pp. 35848-35902): Institute of Electrical and Electronics Engineers Inc.
- Nadimi, M., & Paliwal, J. (2024). Recent Applications of Near-Infrared Spectroscopy in Food Quality Analysis. In *Foods* (Vol. 13): Multidisciplinary Digital Publishing Institute (MDPI).
- Naik, S., & Patel, B. (2017). *Machine Vision based Fruit Classification and Grading-A Review* (International Journal of Computer Applications, Issue.
- Ni, P., Niu, H., Tang, Y., Zhang, Y., Zhang, W., Liu, Y., & Lan, H. (2023). Bibliometrics and Visual Analysis of Non-Destructive Testing Technology for Fruit Quality. In *Horticulturae* (Vol. 9): Multidisciplinary Digital Publishing Institute (MDPI).
- Nikzadfar, M., Rashvand, M., Zhang, H., Shenfield, A., Genovese, F., Altieri, G., Matera, A., Tornese, I., Laveglia, S., Paterna, G., Lovallo, C., Mammadov, O., Aykanat, B., & Di Renzo, G. C. (2024). Hyperspectral Imaging Aiding Artificial Intelligence: A Reliable Approach for Food Qualification and Safety. *Applied Sciences (Switzerland)*, 14(21). <https://doi.org/10.3390/app14219821>

- Pasquini, C. (2018). Near infrared spectroscopy: A mature analytical technique with new perspectives – A review. In *Analytica Chimica Acta* (Vol. 1026, pp. 8-36): Elsevier B.V.
- Patel, D., Bhise, S., Kapdi, S. S., & Bhatt, T. (2024). Non-destructive hyperspectral imaging technology to assess the quality and safety of food: a review. In *Food Production, Processing and Nutrition* (Vol. 6): BioMed Central Ltd.
- Patel, K. K., & Pathare, P. B. (2024). Principle and applications of near-infrared imaging for fruit quality assessment—An overview. In *International Journal of Food Science and Technology* (Vol. 59, pp. 3436-3450): John Wiley and Sons Inc.
- Polak, A., Coutts, F. K., Murray, P., & Marshall, S. (2019). Use of hyperspectral imaging for cake moisture and hardness prediction. *IET Image Processing*, 13(7), 1152-1160. <https://doi.org/10.1049/iet-ipr.2018.5106>
- Qi, L., Zhao, M. c., Li, Z., Shen, D. h., & Lu, J. (2020). Non-destructive testing technology for raw eggs freshness: a review. In *SN Applied Sciences* (Vol. 2): Springer Nature.
- Qin, J., Chao, K., Kim, M. S., Lu, R., & Burks, T. F. (2013). Hyperspectral and multispectral imaging for evaluating food safety and quality. In *Journal of Food Engineering* (Vol. 118, pp. 157-171).
- Rabehi, A., Helal, H., Zappa, D., & Comini, E. (2024). Advancements and Prospects of Electronic Nose in Various Applications: A Comprehensive Review. In *Applied Sciences (Switzerland)* (Vol. 14): Multidisciplinary Digital Publishing Institute (MDPI).
- Raj, R., Cosgun, A., & Kulić, D. (2022). Strawberry Water Content Estimation and Ripeness Classification Using Hyperspectral Sensing. *Agronomy*, 12(2). <https://doi.org/10.3390/agronomy12020425>
- Rashvand, M., Ren, Y., Sun, D. W., Senge, J., Krupitzer, C., Fadiji, T., Miró, M. S., Shenfield, A., Watson, N. J., & Zhang, H. (2025). Artificial intelligence for prediction of shelf-life of various food products: Recent advances and ongoing challenges. In *Trends in Food Science and Technology* (Vol. 159): Elsevier Ltd.
- Rong, D., Xie, L., & Ying, Y. (2019). Computer vision detection of foreign objects in walnuts using deep learning. *Computers and Electronics in Agriculture*, 162, 1001-1010. <https://doi.org/10.1016/j.compag.2019.05.019>

- Saha, D., Senthilkumar, T., Singh, C. B., Pauls, P., & Manickavasagan, A. (2023). Rapid and non-destructive detection of hard to cook chickpeas using NIR hyperspectral imaging and machine learning. *Food and Bioproducts Processing*, 141, 91-106. <https://doi.org/10.1016/j.fbp.2023.07.006>
- Sharma, S., Sumesh, K. C., & Sirisomboon, P. (2022). Rapid ripening stage classification and dry matter prediction of durian pulp using a pushbroom near infrared hyperspectral imaging system. *Measurement: Journal of the International Measurement Confederation*, 189. <https://doi.org/10.1016/j.measurement.2021.110464>
- Shrestha, B. L., Kang, Y. M., Yu, D., & Baik, O. D. (2016). A two-camera machine vision approach to separating and identifying laboratory sprouted wheat kernels. *Biosystems Engineering*, 147, 265-273. <https://doi.org/10.1016/j.biosystemseng.2016.04.008>
- Signoroni, A., Savardi, M., Baronio, A., & Benini, S. (2019). Deep learning meets hyperspectral image analysis: A multidisciplinary review. In *Journal of Imaging* (Vol. 5): MDPI Multidisciplinary Digital Publishing Institute.
- Singh, S., & Gaur, S. (2023). Development of rapid and non-destructive electric nose (E-nose) system for shelf life evaluation of different edible seeds. *Food Chemistry*, 426. <https://doi.org/10.1016/j.foodchem.2023.136562>
- Siripatrawan, U., & Makino, Y. (2025). Rapid and chemical-free technique based on hyperspectral imaging combined with artificial intelligence for monitoring quality and shelf life of dried shrimp. *Food Research International*, 213. <https://doi.org/10.1016/j.foodres.2025.116422>
- Soltani Firouz, M., & Sardari, H. (2022). Defect Detection in Fruit and Vegetables by Using Machine Vision Systems and Image Processing. In *Food Engineering Reviews* (Vol. 14, pp. 353-379): Springer.
- Su, Z., Zhang, C., Yan, T., Zhu, J., Zeng, Y., Lu, X., Gao, P., Feng, L., He, L., & Fan, L. (2021). Application of Hyperspectral Imaging for Maturity and Soluble Solids Content Determination of Strawberry With Deep Learning Approaches. *Frontiers in Plant Science*, 12. <https://doi.org/10.3389/fpls.2021.736334>
- Sun, D.-W., Pu, H., & Yu, J. (2024). Applications of hyperspectral imaging technology in the food industry. *Nature Reviews Electrical Engineering*, 1(4), 251-263. <https://doi.org/10.1038/s44287-024-00033-w>

- Sun, J., Yao, K., Cheng, J., Xu, M., & Zhou, X. (2024). Nondestructive detection of saponin content in *Panax notoginseng* powder based on hyperspectral imaging. *Journal of Pharmaceutical and Biomedical Analysis*, 242. <https://doi.org/10.1016/j.jpba.2024.116015>
- Tan, B., You, W., Huang, C., Xiao, T., Tian, S., Luo, L., & Xiong, N. (2022). An Intelligent Near-Infrared Diffuse Reflectance Spectroscopy Scheme for the Non-Destructive Testing of the Sugar Content in Cherry Tomato Fruit. *Electronics* (Switzerland), 11(21). <https://doi.org/10.3390/electronics11213504>
- Temiz, H. T., & Ulaş, B. (2021). A Review of Recent Studies Employing Hyperspectral Imaging for the Determination of Food Adulteration. In *Photochem* (Vol. 1, pp. 125-146): Multidisciplinary Digital Publishing Institute (MDPI).
- Torres-Rodríguez, I., Sánchez, M. T., Entrenas, J. A., Vega-Castellote, M., Garrido-Varo, A., & Pérez-Marín, D. (2022). Hyperspectral Imaging for the Detection of Bitter Almonds in Sweet Almond Batches. *Applied Sciences* (Switzerland), 12(10). <https://doi.org/10.3390/app12104842>
- Wang, J., Zhou, X., Liu, Y., Sun, J., Guo, P., & Lv, W. (2025). An efficient nondestructive detection method of rapeseed varieties based on hyperspectral imaging technology. *Microchemical Journal*, 210. <https://doi.org/10.1016/j.microc.2025.112913>
- Wang, M., & Chen, Y. (2024). Electronic nose and its application in the food industry: a review. In *European Food Research and Technology* (Vol. 250, pp. 21-67): Springer Science and Business Media Deutschland GmbH.
- Wen, J., Xu, G., Zhang, A., Ma, W., & Jin, G. (2024). Emerging technologies for rapid non-destructive testing of grape quality: A review. In *Journal of Food Composition and Analysis* (Vol. 133): Academic Press Inc.
- Wesoły, M., Przewodowski, W., & Ciosek-Skibińska, P. (2023). Electronic noses and electronic tongues for the agricultural purposes. In *TrAC - Trends in Analytical Chemistry* (Vol. 164): Elsevier B.V.
- Wu, K., Zhang, Z., He, X., Li, G., Zheng, D., & Li, Z. (2025). Using visible and NIR hyperspectral imaging and machine learning for nondestructive detection of nutrient contents in sorghum. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-90892-6>
- Xie, A., Sun, J., Wang, T., & Liu, Y. (2022). Visualized detection of quality change of cooked beef with condiments by hyperspectral imaging

- technique. *Food Science and Biotechnology*, 31(10), 1257-1266.
<https://doi.org/10.1007/s10068-022-01115-x>
- Xin, X., Sun, J., Shi, L., Yao, K., & Zhang, B. (2025). Application of hyperspectral imaging technology combined with ECA-MobileNetV3 in identifying different processing methods of Yunnan coffee beans. *Journal of Food Composition and Analysis*, 143.
<https://doi.org/10.1016/j.jfca.2025.107625>
- Xing, L., Wang, Y., Luo, R., & Zou, L. (2021, 2021/5//). Application of computer vision technology in agricultural products and food inspection. *Journal of Physics: Conference Series*,
- Xu, F., Huang, X., Tian, X., Yu, S., Zhang, X., & Zareef, M. (2024). Application of hyperspectral imaging and colorimetric sensor array coupled with multivariate analysis for quality detection during salted duck eggs processing. *Journal of Food Process Engineering*, 47(3).
<https://doi.org/10.1111/jfpe.14589>
- Ye, W., Yan, T., Zhang, C., Duan, L., Chen, W., Song, H., Zhang, Y., Xu, W., & Gao, P. (2022). Detection of Pesticide Residue Level in Grape Using Hyperspectral Imaging with Machine Learning. *Foods*, 11(11).
<https://doi.org/10.3390/foods1111609>
- Zhang, X., Alhendi, O., Hamid, S. H. A., Japar, N., & Nor, A. M. (2024). A Computer Vision Model for Seaweed Foreign Object Detection Using Deep Learning. *Sustainability (Switzerland)*, 16(20).
<https://doi.org/10.3390/su16209061>
- Zhang, X., Huang, X., Tian, X., Wang, L., Dai, C., Chang, X., Ren, Y., Yu, S., Wang, C., & Han, F. (2025). Non-destructive quality monitoring of Shanxi vinegar production during the fumigation stage using computer vision, electronic nose and near-infrared spectroscopy assisted by machine learning. *Journal of Food Composition and Analysis*, 146.
<https://doi.org/10.1016/j.jfca.2025.107908>
- Zhao, F., Zhang, J., Meng, Z., Liu, H., Chang, Z., & Fan, J. (2023). Multiple vision architectures-based hybrid network for hyperspectral image classification. *Expert Systems with Applications*, 234.
<https://doi.org/10.1016/j.eswa.2023.121032>