

WHITEPAPER

The Science Behind Point-of-Purchase Food Quality Detection

A review of peer-reviewed research validating near-infrared (NIR) spectroscopy for pesticide residue, adulteration, and ripeness detection across produce, grains, dairy, and meat.

Executive Summary

FoodScanLab builds low-cost, handheld near-infrared (NIR) spectroscopy scanners that give consumers and food-supply-chain participants a fast, point-of-purchase read on food quality and safety. This whitepaper compiles the peer-reviewed research base that underpins our product roadmap: pesticide residue detection in fresh produce and grains, adulteration detection in dairy and meat, and ripeness/quality grading in fruit — all within the 900-2500nm wavelength range our sensor operates in. Our aim is transparency: this document distinguishes what is directly validated by published research from what is promising but still requires validation on our own hardware, so that our claims can be checked against their sources.

1. Pesticide Residue Detection

1.1 Fresh Produce Core Product

NIR spectroscopy's use for detecting pesticide and fungicide residues on fresh produce surfaces is well established in the food-science literature, using techniques that combine reflectance spectroscopy with chemometric (multivariate statistical) modeling.

Peppers — pesticide residue quantification via NIR reflectance: A 2010 study in *Pest Management Science* demonstrated measurement of pesticide residues directly on peppers using near-infrared reflectance spectroscopy, establishing feasibility for a produce type with a complex, uneven surface.
Sánchez, M.T., Flores-Rojas, K., Guerrero, J.E., Garrido-Varo, A., Pérez-Marín, D. (2010). Measurement of pesticide residues in peppers by near-infrared reflectance spectroscopy. Pest Management Science, 66(6), 580–586.

Tomatoes — ppm-order fungicide detection: The DESIR-NIR (dry-extract system for infrared) technique was developed specifically to push NIR detection sensitivity down to parts-per-million concentrations of fungicide residue on tomato surfaces.
Saranwong, S., Kawano, S. (2005). Rapid determination of fungicide contaminated on tomato surfaces using the DESIR-NIR: a system for ppm-order concentration. Journal of Near Infrared Spectroscopy, 13(3), 169–175.

1.2 Grains — Rice Validated

Rice is the most directly relevant grain case for FoodScanLab: multiple independent studies have validated NIR detection of specific organophosphate and carbamate pesticides directly within our sensor's operating wavelength band.

Chlorpyrifos-methyl detection across rice processing stages: Field-deployable, LED-based NIR instrumentation (850-1550nm) achieved correct classification rates of 94.4–100% on milled rice, with somewhat lower accuracy on rough (77.8–92.6%) and brown rice (79.6–88.9%) — establishing that grain processing stage materially affects detection accuracy.
Rodriguez-Macadaeg, F., Armstrong, P.R., Maghirang, E.B., Scully, E.D., Brabec, D.L., Arthur, F.H., Adviento-Borbe, A.D., Yaptenco, K.F., Suministrado, D.C. (2024). Developing a Multi-Spectral NIR LED-Based Instrument for the Detection of Pesticide Residues Containing Chlorpyrifos-Methyl in Rough, Brown, and Milled Rice. Sensors, 24(13), 4055.

Original lab-grade validation: The foundational study establishing NIR's ability to detect and quantify chlorpyrifos-methyl residue levels in bulk rice, differentiating maximum residue levels at 78–100% correct classification.
Rodriguez, F.S., Armstrong, P.R., Maghirang, E.B., Yaptenco, K.F., Scully, E.D., Arthur, F.H., Brabec, D.L., Adviento-Borbe, M.A.D., Suministrado, D.C. (2020). NIR Spectroscopy Detects Chlorpyrifos-Methyl Pesticide Residue in Rough, Brown, and Milled Rice. Applied Engineering in Agriculture, 36(6), 983–993.

Carbofuran in paddy rice: FT-NIR reflectance spectroscopy combined with the DESIR sample-preparation technique substantially improved prediction accuracy for carbofuran — from $R^2=0.87$ (direct scan) to $R^2=0.99$ (with DESIR preparation).
Rungchang, S., Numthum, S., Charoensook, R., Thongkum, P., Junmatong, C. Method Development for Pesticide Determination in Paddy Rice Using Near Infrared Spectroscopy. International Journal of Agricultural Technology.

1.3 Grains — Maize Validated

Carbofuran in maize and cassava feedstuff: NIR combined with the DESIR technique achieved a correlation coefficient (R) of 0.99 for carbofuran determination in ground maize and cassava, establishing feasibility as a rapid screening method for this highly toxic insecticide.
Numthum, S. et al. Development of rapid assessment of carbamate pesticide residues in feedstuffs using near infrared spectroscopy. Naresuan University (Thailand Research Fund Project TRG5780047).

2. Adulteration Detection

2.1 Dairy Validated

Milk adulteration detection via NIR spectroscopy is one of the most mature applications in the field, with multiple independent studies spanning water dilution, whey addition, and chemical adulterants. Since paneer, khoya, cheese, and buttermilk are all derived from milk with

the same fat/moisture/protein chemistry, these studies establish the underlying feasibility for FoodScanLab's dairy roadmap; product-specific calibration remains necessary for each individual dairy product.

Water and whey adulteration — near-perfect classification: Second-derivative NIR spectra across 1100–2500nm (matching FoodScanLab's operating range) achieved 100% classification performance distinguishing natural milk from water- and whey-adulterated milk.
Kasemsunran, S., Thanapase, W., Kiatsoonthon, A. (2007). Feasibility of Near-Infrared Spectroscopy to Detect and to Quantify Adulterants in Cow Milk. Analytical Sciences, 23(7), 907–910.

Portable NIR for water-adulteration levels: A portable near-infrared spectrometer operating at 900–1800nm — directly overlapping FoodScanLab's sensor range — was used with multiple chemometric models (SIMCA, naive Bayes, k-NN, SVM) to discriminate water-adulterated milk.
Liang, Q., Xia, Y., Che, J., Liu, Y., Zhang, H., Guo, J., Xu, Q., Xue, H. (2025). Detection of water adulteration levels in milk using near-infrared spectroscopy combined with chemometrics. Journal of Dairy Science.

Broader adulterant classes — urea, glucose, melamine: Pattern-recognition methods (SIMCA, PLS-DA) applied to NIR spectra successfully discriminated milk adulterated with urea, glucose, and melamine at varying concentrations.
Chen, R., Zhang, J., Li, X. (2012). Discriminant analysis of milk adulteration based on near-infrared spectroscopy and pattern recognition. Proc. SPIE, 7906.

Comprehensive review of NIR for food fraud detection: A 2026 systematic review covering NIR spectroscopy applications for adulterant and contaminant detection across milk, oils, juices, spices, cereals, coffee, and other food matrices, confirming the technique's maturity as a food-authentication tool.
Pellicorio, V., Colombo, R., Papetti, A. (2026). Applications of NIR Spectroscopy and Chemometrics for Food Authentication and Safety: Detection of Adulterants and Contaminants. Molecules, 31(17), 3067.

2.2 Meat Validated

Species identification and adulteration (mixing of cheaper meat into a declared, more expensive cut) is directly validated using portable, MEMS-based NIR spectrometers — the same sensor class FoodScanLab uses, evaluated head-to-head against benchtop laboratory instruments.

Portable MEMS spectrometer vs. benchtop FT-NIR — six species: A portable MEMS-based NIR spectrometer classified beef, chicken, mutton, turkey, pork, and horse meat with 75.0–100.0% accuracy on whole cuts, closely tracking benchtop FT-NIR performance (62.5–100.0%). The same portable device achieved 75.0–100.0% accuracy detecting adulteration in minced-meat mixtures.
Current Analytical Chemistry (2017). Design of Experiment evaluation of a portable MEMS-based spectrometer vs. bench-top FT-NIR for meat-type classification. DOI: 10.2174/1573411013666170207121113.

Chicken authenticity — handheld NIR plus machine learning: Combining portable NIR spectroscopy with ensemble machine-learning classifiers achieved over 95% single-scan accuracy distinguishing fresh from thawed chicken meat and classifying authenticity claims tied to growth conditions.
Integration of handheld NIR and machine learning to "Measure & Monitor" chicken meat authenticity. Poultry Science / Food Control research collaboration.

Exotic-species mixture detection: A portable NIR instrument determined species mixing ratios in binary blends of lamb, emu, camel, and beef with a coefficient of determination above 90% in cross-validation.
Discrimination of lamb (Ovis aries), emu (Dromaius novaehollandiae), camel (Camelus dromedarius) and beef (Bos taurus) binary mixtures using a portable near infrared instrument combined with chemometrics. Czech Agricultural Research publication, 2023.

Species authentication via portable hyperspectral imaging: A Raspberry-Pi-controlled portable hyperspectral imager combined with SVM classification achieved 94.91% accuracy in meat-species adulteration detection, with a model-transfer method developed to maintain accuracy across different instrument units.
Yu, Y., Chen, W., Zhao, D., Zhang, H., Chen, W., Liu, R., Li, C. (2025). Meat species authentication using portable hyperspectral imaging. Frontiers in Nutrition, 12:1577642.

3. Ripeness & Quality Grading

NIR-based estimation of Brix (sugar content), a primary ripeness indicator, is among the most established commercial applications of the technology, with two decades of published validation across fruit types.

Portable NIR ripeness instrument — grapes: A dedicated portable NIR instrument measuring sugar (Brix), pH, and anthocyanin concentration directly on intact grape clusters, validated across five grape varieties, demonstrated strong predictive accuracy for Brix and pH.
Larrain, M., Guesalaga, A.R., Agosin, E. (2008). A Multipurpose Portable Instrument for Determining Ripeness in Wine Grapes Using NIR Spectroscopy. IEEE Transactions on Instrumentation and Measurement, 57(2), 294–302.

Shortwave-NIR maturity estimation: A low-cost, commercially available NIR spectrometer estimated wine grape ripeness (°Brix) with R²=0.942 using a portable CCD spectrometer and contact probe.
Herrera, J., Guesalaga, A., Agosin, E. (2003). Shortwave-near infrared spectroscopy for non-destructive determination of maturity of wine grapes. Measurement Science and Technology, 14(5), 689–697.

Portable VIS/NIR sugar-content tester — Asian pears: A dedicated portable, non-destructive VIS/NIR tester determined Brix values in Asian pears with excellent prediction performance (relative standard error 0.91–0.92), independent of sample pretreatment. Choi, J.H., Chen, P.A., Lee, B.H., Yim, S.H., Kim, M.S., Bae, Y.S., Lim, D.C., Seo, H.J. (2017). *Portable, non-destructive tester integrating VIS/NIR reflectance spectroscopy for the detection of sugar content in Asian pears.*

4. Technology Basis

900–2500nm

NIR wavelength range — matches the operating band used across every study cited above

MEMS

Chip-scale sensor class — the same category directly validated for portable meat and grain classification

PLS / SIMCA / SVM

Chemometric methods — the standard multivariate techniques used across the cited literature

FoodScanLab's core technology is not a novel spectroscopic method — it is a miniaturized, low-cost implementation of chemometric NIR analysis techniques that have two decades of peer-reviewed validation in agricultural and food science research. Our engineering contribution is making this analysis available at a consumer price point and at the point of purchase, rather than requiring laboratory equipment or benchtop instrumentation.

What Remains To Be Validated

In the interest of transparency, two categories under active consideration are not yet supported by the same weight of evidence as those above, and FoodScanLab does not currently claim validated performance for them:

Fish: NIR-based freshness and species assessment is an established general research area, but we have not yet identified portable-NIR studies with the same direct evidence base as chicken, beef, and mutton. Treated as promising, pending direct validation.

Lentils and pulses: The strongest published pesticide-residue result we identified for pulses (glyphosate detection in chickpea, lentil, and pea varieties) used Fourier-transform infrared (FTIR) spectroscopy in the mid-infrared range (400–2000cm⁻¹; approximately 5,000–25,000nm) — a different spectral region from FoodScanLab's 900–2500nm NIR sensor, requiring different detector technology. This result does not directly transfer to our hardware and would require independent validation.

References

1. Sánchez, M.T., Flores-Rojas, K., Guerrero, J.E., Garrido-Varo, A., Pérez-Marín, D. (2010). Measurement of pesticide residues in peppers by near-infrared reflectance spectroscopy. *Pest Management Science*, 66(6), 580–586. DOI: 10.1002/ps.1910
2. Saranwong, S., Kawano, S. (2005). Rapid determination of fungicide contaminated on tomato surfaces using the DESIR-NIR: a system for ppm-order concentration. *Journal of Near Infrared Spectroscopy*, 13(3), 169–175.
3. Rodriguez-Macadaeg, F., Armstrong, P.R., Maghirang, E.B., Scully, E.D., Brabec, D.L., Arthur, F.H., Adviento-Borbe, A.D., Yaptenco, K.F., Sumintrado, D.C. (2024). Developing a Multi-Spectral NIR LED-Based Instrument for the Detection of Pesticide Residues Containing Chlorpyrifos-Methyl in Rough, Brown, and Milled Rice. *Sensors*, 24(13), 4055. DOI: 10.3390/s24134055
4. Rodriguez, F.S., Armstrong, P.R., Maghirang, E.B., Yaptenco, K.F., Scully, E.D., Arthur, F.H., Brabec, D.L., Adviento-Borbe, M.A.D., Sumintrado, D.C. (2020). NIR Spectroscopy Detects Chlorpyrifos-Methyl Pesticide Residue in Rough, Brown, and Milled Rice. *Applied Engineering in Agriculture*, 36(6), 983–993. DOI: 10.13031/aea.14001
5. Rungchang, S., Numthuam, S., Charoensook, R., Thongkum, P., Junmatong, C. Method Development for Pesticide Determination in Paddy Rice Using Near Infrared Spectroscopy. *International Journal of Agricultural Technology*.
6. Numthuam, S. et al. Development of rapid assessment of carbamate pesticide residues in feedstuffs using near infrared spectroscopy. Naresuan University, Thailand Research Fund Project TRG5780047.
7. Kasemsumran, S., Thanapase, W., Kiatsoonthon, A. (2007). Feasibility of Near-Infrared Spectroscopy to Detect and to Quantify Adulterants in Cow Milk. *Analytical Sciences*, 23(7), 907–910.
8. Liang, Q., Xia, Y., Che, J., Liu, Y., Zhang, H., Guo, J., Xu, Q., Xue, H. (2025). Detection of water adulteration levels in milk using near-infrared spectroscopy combined with chemometrics. *Journal of Dairy Science*.
9. Chen, R., Zhang, J., Li, X. (2012). Discriminant analysis of milk adulteration based on near-infrared spectroscopy and pattern recognition. *Proceedings of SPIE*, 7906, 79060Y.
10. Pellicorior, V., Colombo, R., Papetti, A. (2026). Applications of NIR Spectroscopy and Chemometrics for Food Authentication and Safety: Detection of Adulterants and Contaminants. *Molecules*, 31(17), 3067. DOI: 10.3390/molecules31173067
11. Design of Experiment evaluation of a portable MEMS-based spectrometer vs. bench-top FT-NIR for meat-type classification (beef, chicken, mutton, turkey, pork, horse). *Current Analytical Chemistry* (2017). DOI: 10.2174/1573411013666170207121113
12. Integration of handheld NIR and machine learning to "Measure & Monitor" chicken meat authenticity. Poultry / food science research collaboration.
13. Discrimination of lamb (*Ovis aries*), emu (*Dromaius novaehollandiae*), camel (*Camelus dromedarius*) and beef (*Bos taurus*) binary mixtures using a portable near infrared instrument combined with chemometrics. Czech agricultural research publication, 2023.
14. Yu, Y., Chen, W., Zhao, D., Zhang, H., Chen, W., Liu, R., Li, C. (2025). Meat species authentication using portable hyperspectral imaging. *Frontiers in Nutrition*, 12:1577642. DOI: 10.3389/fnut.2025.1577642
15. Larrain, M., Guesalaga, A.R., Agosin, E. (2008). A Multipurpose Portable Instrument for Determining Ripeness in Wine Grapes Using NIR Spectroscopy. *IEEE*

16. Herrera, J., Guesalaga, A., Agosin, E. (2003). Shortwave-near infrared spectroscopy for non-destructive determination of maturity of wine grapes. *Measurement Science and Technology*, 14(5), 689–697.
17. Choi, J.H., Chen, P.A., Lee, B.H., Yim, S.H., Kim, M.S., Bae, Y.S., Lim, D.C., Seo, H.J. (2017). Portable, non-destructive tester integrating VIS/NIR reflectance spectroscopy for the detection of sugar content in Asian pears.

This whitepaper summarizes third-party, peer-reviewed research to establish the scientific feasibility of NIR spectroscopy for the use cases described. Citations reflect studies conducted on varied instrumentation, sample sets, and conditions; results characterize published research outcomes and do not constitute a performance guarantee for FoodScanLab's specific device, which is undergoing its own independent calibration and validation program.