

Supplementary Materials for

Postharvest Fruit Grading Technologies and Equipment: A Review

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Supplementary Methods S1. Evidence selection and maturity appraisal

Purpose and scope. The framework separates technical feasibility from evidence for transferability and commercial deployment. It was applied to primary empirical studies selected as representative examples in Table 1. Secondary reviews and contextual engineering or biological sources were mapped by role in Table S3 but were not assigned an empirical maturity score.

Representative-study selection for Table 1. A study had to address a distinct sensing modality, algorithm, equipment configuration or fruit-handling context, report at least one quantitative performance outcome, and meet at least one benchmark: at least 200 individual fruit or fruit clusters, at least 2000 labelled images or fruit instances, at least 4 fruit s-1, or at least 25 frames s-1. A study below these thresholds could still be selected if it included independent validation across batches, cultivars, seasons or sites, or an online, pilot-line or commercial-line trial. These thresholds are operational rules for this review and are not universal definitions of adequate study size or industrial performance.

Coding. Six domains were scored from 0 to 2. NR denoted information not reported in the reviewed source and received 0 points. Exact threshold values were assigned to the higher bin, while ambiguous or borderline cases were assigned to the lower bin. Any coding disagreement was resolved by rechecking the source against the prespecified definitions. If the higher category remained unsupported, the value was coded NR or retained in the lower category. Scores describe evidence maturity rather than intrinsic scientific merit.

Synthesis weighting. Totals of 0–3 were classified as limited, 4–6 as moderate, 7–9 as strong within the tested context, and 10–12 as deployment-level. Limited evidence was used only to support feasibility. Moderate evidence supported comparisons within the tested commodity and setting. Strong evidence could inform transferability or operational conclusions only within the validated scope. Deployment-level interpretation additionally required a validation score of 2 and an operational-setting score of 2, so sample scale or processing speed alone could not establish commercial maturity.

Table S1. Operational evidence-maturity criteria and thresholds.

Domain	0 points	1 point	2 points	Interpretive safeguard
Sample scale	NR, <100 fruit/clusters and <1000 labelled images/instances	100–199 fruit/clusters or 1000– 1999 images/instances	≥200 fruit/clusters or ≥2000 images/instances	Image and fruit counts are recorded separately; image- based credit requires a fruit- disjoint or otherwise independent unit of analysis.
Biological/environmental diversity	Single cultivar/batch/season/site or NR	Variation in one axis, such as cultivar, batch, season or site	Variation in at least two axes, or explicit multi-year plus external-cultivar/site coverage	Diversity earns credit only when linked to calibration or validation, not merely mentioned.

Validation independence	Training-only, resubstitution, internal random split or NR	Held-out prediction set, controlled independent test, or same-source machine/recorded-prospective commercial-line trial	Independent batch, cultivar, season or site test, or validation	Internal random splitting cannot receive 2 points.
Operational setting	Offline laboratory/static acquisition or NR	Online sensor, recorded line, bench line, pilot line or complete-machine trial	Prospective routine commercial-line operation	A portable instrument without line testing remains 0 unless operational use is documented.
Throughput	NR	Reported but <4 fruit s ⁻¹ or <25 frames s ⁻¹	≥4 fruit s ⁻¹ or ≥25 frames s ⁻¹	Frame rate is not treated as fruit throughput; both units remain explicit.
Reproducibility/reporting	Key protocol, validation partition or quantitative result not reported	Method, quantitative result and main limitation are reported	Repeated-run uncertainty plus accessible data/code or a sufficiently detailed public protocol	No credit is inferred from journal prestige or model complexity.

Table S2. Item-level appraisal of the representative studies reported in Table 1.

Scores were assigned conservatively from the information summarized in the revised manuscript and Table 1. S, sample scale; D, diversity; V, validation independence; O, operational setting; T, throughput; R, reproducibility/reporting; NR, not reported.

Ref.	Fruit	Method	S	D	V	O	T	R	Total	Category	Basis and limitation
[5]	Apple	Multiview RGB + YOLOv5	0	0	1	1	2	1	5	Moderate	Machine trial and 4 fruit s-1; sample scale and diversity were NR.
[11]	Apple	Portable Vis/NIR + PLS	0	0	2	0	0	1	3	Limited	Independent laboratory validation and field recalibration; sample scale and throughput were NR.
[12]	Apple	BiSeNet V2 + pruned YOLOv4	0	0	1	1	2	1	5	Moderate	Online grading and 9 ms image-1; independent production-line validation was not reported.
[13]	Apple	Three-channel helical conveyor	0	0	1	1	2	1	5	Moderate	Bench-line trial and more than 9 fruit s-1; sample scale and diversity were NR.
[14]	Orange	RGB detector + SORT tracking	2	0	1	1	2	1	7	Strong within tested context	300 fruit and 2400 images; recorded-line evaluation at 43 frames s-1; actuator remained conceptual.
[15]	Fresh jujube	Vision + electromagnetic actuation	0	0	1	1	2	1	5	Moderate	Complete-machine trial at 20 fruit s-1; sample scale and long-term drift were NR.

[16]	Apple	Dynamic Vis/NIR transmittance	2	0	1	1	0	1	5	Moderate	340 fruit and an online sensing configuration; single cultivar and throughput NR.
[17]	Peach	Multispectral structured illumination	2	0	1	0	0	1	4	Moderate	300 fruit with a controlled-impact dataset; static acquisition and no throughput report.
[18]	Apricot	Portable Vis/NIR + HSI	2	2	2	0	0	1	7	Strong within tested context	204 fruit, 17 cultivars, two years, and four external cultivars; offline acquisition.
[19]	Citrus	Four-path Vis/NIR transmittance	2	0	0	0	0	1	3	Limited	252 fruit; internal train/test evaluation, offline bench setting, and no throughput report.
[20]	Blueberry	YOLOv8 + Vision Transformer	2	0	0	0	0	1	3	Limited	4506 berries in 250 images; three random splits and no independent production validation.
[21]	Table grape	Noncontact FT- NIR + PLS	2	0	1	0	0	1	4	Moderate	338 clusters and a prediction set; offline testing and no throughput report.

Table S3. Evidence-role map for all references included in the review.

This table accounts for the complete reference list. Formal six-domain scores are reported in Table S2 for the representative empirical exemplars used in Table 1. Other primary studies contribute to modality- or commodity-specific narrative synthesis; secondary and contextual sources are not treated as empirical deployment evidence. The map contains 95 primary empirical studies, including 12 scored exemplars, 20 secondary or contextual synthesis sources, and 8 handling or mechanism studies.

Ref.	Year	Title	Evidence role	Appraisal disposition and use in synthesis
[1]	2017	Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[2]	2022	Mechanical damages and packaging methods along the fresh fruit supply chain: A review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[3]	2022	Fruit quality evaluation using machine learning techniques: review, motivation and future perspectives	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[4]	2025	Artificial Vision Systems for Fruit Inspection and Classification: Systematic Literature Review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[5]	2023	Apple Grading Method Design and Implementation for Automatic Grader Based on Improved YOLOv5	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.

[6]	2023	Apple Grading Based on Multi-Dimensional View Processing and Deep Learning	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[7]	2025	Non-Destructive Detection of Fruit Quality: Technologies, Applications and Prospects	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[8]	2020	Development of near-infrared online grading device for long jujube	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[9]	2022	Two-wavelength image detection of early decayed oranges by coupling spectral classification with image processing	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[10]	2023	Development of an optimally designed real-time automatic citrus fruit grading-sorting machine leveraging computer vision-based adaptive deep learning model	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[22]	2017	Towards a new definition of quality for fresh fruits and vegetables	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[23]	2020	Visible-NIR 'point' spectroscopy in postharvest fruit and vegetable assessment: The science behind three decades of commercial use	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.

[24]	2021	Nondestructive detection of decayed blueberry based on information fusion of hyperspectral imaging (HSI) and low-Field nuclear magnetic resonance (LF-NMR)	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[25]	2022	Mechanical damage of fresh produce in postharvest transportation: Current status and future prospects	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[26]	2021	Real-time visual inspection system for grading fruits using computer vision and deep learning techniques	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[27]	2025	Real-time banana freshness grading: A portable end-to-end detection system with high precision	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[32]	2024	Classification of Apple Color and Deformity Using Machine Vision Combined with CNN	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[33]	2025	Strawberry Fruit Deformity Detection and Symmetry Quantification Using Deep Learning and Geometric Feature Analysis	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[34]	2019	Grading bunch tightness for grape by multiperspective imaging approach coupled with multivariate classification methods	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[35]	2018	New approach of simultaneous, multi-perspective imaging for quantitative assessment of the compactness of grape bunches	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[36]	2025	Apple maturity quantification based on fine-grained coloration analysis using deep learning and computer vision	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[37]	2025	Identification of apple variety using machine vision and deep learning with Multi-Head Attention mechanism and GLCM	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[38]	2025	Detection of early decay in dekopon fruit based on structured-illumination reflectance imaging combined with a comparison between traditional machine learning and deep learning models	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[39]	2024	Developing universal classification models for the detection of early decayed citrus by structured-illumination reflectance imaging coupling with deep learning methods	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[40]	2025	Transforming Apple Grading: Standards Survey and Deep Learning Insights	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[44]	2020	Accurate non-destructive prediction of peach fruit internal quality and physiological maturity with a single scan using near infrared spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[11]	2020	Non-destructive evaluation of soluble solids content of apples using a developed portable Vis/NIR device	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.

[45]	2022	General model of multi-quality detection for apple from different origins by Vis/NIR transmittance spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[28]	2020	Nondestructive monitoring storage quality of apples at different temperatures by near-infrared transmittance spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[46]	2020	Quantitative detection of apple watercore and soluble solids content by near infrared transmittance spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[29]	2023	Detection of early bruises on apples using hyperspectral reflectance imaging coupled with optimal wavelengths selection and improved watershed segmentation algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[47]	2024	Deep learning algorithm development for early detection of Botrytis cinerea infected strawberry fruit using hyperspectral fluorescence imaging	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[48]	2022	Detection of soluble solid content in apples based on hyperspectral technology combined with deep learning algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[49]	2023	Non-destructive prediction of total soluble solids and titratable acidity in Kyoho grape using hyperspectral imaging and deep learning algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[50]	2025	Automatic early bruise detection in strawberry fruit by hyperspectral imaging and deep learning techniques	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[41]	2023	BraeNet: Internal disorder detection in 'Braeburn' apple using X-ray imaging data	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[42]	2020	Nondestructive measurement of kiwifruit firmness, soluble solid content (SSC), titratable acidity (TA), and sensory quality by vibration spectrum	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[51]	2024	Assessment of apple bruise resistance under transient collisions through X-ray computed tomography and image processing	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[30]	2021	Identification of the apple spoilage causative fungi and prediction of the spoilage degree using electronic nose	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[52]	2023	Spoilage Monitoring and Early Warning for Apples in Storage Using Gas Sensors and Chemometrics	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[43]	2024	Research on prediction of yellow flesh peach firmness using a novel acoustic real-time detection device and Vis/NIR technology	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[53]	2021	Classification of Apples Based on the Shelf Life Using ANN and Data Fusion	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[54]	2025	Multi-sensor fusion and deep learning for batch monitoring and real-time warning of apple spoilage	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[31]	2024	Internal quality evaluation of 'Fuji' apples during storage based on bulk optical properties or diffuse reflection and transmission spectra	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[55]	2026	Kolmogorov-Arnold Network-Enhanced Temporal Models on Cloud-Edge System for Real-Time Apple Spoilage Monitoring	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[58]	2019	Automatic grading of apples based on multi-features and weighted K-means clustering algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[62]	2021	Support vector machine and YOLO for a mobile food grading system	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[59]	2021	Identification of Lycium barbarum varieties based on hyperspectral imaging technique and competitive adaptive reweighted sampling-whale optimization algorithm-support vector machine	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[63]	2022	A comparative analysis of hybrid SVM and LS-SVM classification algorithms to identify dried wolfberry fruits quality based on hyperspectral imaging technology	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[64]	2023	Nondestructive detection of adulterated wolfberry (Lycium Chinense) fruits based on hyperspectral imaging technology	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[56]	2025	Detection of Early Damage in Kiwifruit Based on Near-Infrared Technology	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[60]	2025	Non-Destructive Detection of Pomegranate Blackheart Disease via Near-Infrared Spectroscopy and Soft X-ray Imaging Systems	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[61]	2026	Quality evaluation and variety discrimination of pear, apple, nectarine and potato using optical properties coupled with machine learning	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[57]	2021	Developing deep learning based regression approaches for prediction of firmness and pH in Kyoho grape using Vis/NIR hyperspectral imaging	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[65]	2025	Hyperspectral Imaging and Deep Learning for Quality and Safety Inspection of Fruits and Vegetables: A Review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[66]	2023	Detection model transfer of apple soluble solids content based on NIR spectroscopy and deep learning	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[67]	2021	Fused Deep Features-Based Grape Varieties Identification Using Support Vector Machine	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[68]	2024	Digital assessment of post-harvest Nendran banana for faster grading: CNN-based ripeness classification model	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[12]	2022	Real-Time Grading of Defect Apples Using Semantic Segmentation Combination with a Pruned YOLO V4 Network	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[69]	2024	A Lightweight and High-Precision Passion Fruit YOLO Detection Model for Deployment in Embedded Devices	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[70]	2021	Easy domain adaptation method for filling the species gap in deep learning-based fruit detection	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[71]	2023	Lightweight tomato real-time detection method based on improved YOLO and mobile deployment	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[72]	2024	YOLOv8-MDN-Tiny: A lightweight model for multi-scale disease detection of postharvest golden passion fruit	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[73]	2023	Improvement of the prediction of a visual apple ripeness index under seasonal variation by NIR spectral model correction	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[74]	2025	Nondestructive Quality Detection of Characteristic Fruits Based on Vis/NIR Spectroscopy: Principles, Systems, and Applications	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.

[13]	2023	Evaluation of a new apple in-field sorting system for fruit singulation, rotation and imaging	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[75]	2021	Application of multi-frequency power ultrasound in selected food processing using large-scale reactors: A review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[76]	2022	Use of Ultrasonic Cleaning Technology in the Whole Process of Fruit and Vegetable Processing	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[78]	2021	Experimental Research on Grape Cluster Vibration Signals during Transportation and Placing for Harvest and Post-Harvest Handling	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[79]	2021	Hanging force analysis for realizing low vibration of grape clusters during speedy robotic post-harvest handling	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[77]	2024	Recent Advances in Light Penetration Depth for Postharvest Quality Evaluation of Fruits and Vegetables	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[81]	2025	Online assessment of soluble solids content in strawberries using a developed Vis/NIR spectroscopy system with a hanging grasper	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[14]	2021	A Deep Learning-Based Vision System Combining Detection and Tracking for Fast On-Line Citrus Sorting	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.

[15]	2024	A grader for fresh jujube with electromagnetic synchronous actuator assembly	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[80]	2022	A Soft Gripper Design for Apple Harvesting with Force Feedback and Fruit Slip Detection	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[82]	2024	Influence of the peel on online detecting soluble solids content of pomelo using Vis-NIR spectroscopy coupled with chemometric analysis	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[83]	2024	State-of-the-Art Techniques for Fruit Maturity Detection	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[84]	2019	Maturity assessment of tomato fruit based on electrical impedance spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[85]	2025	Overview of Deep Learning and Nondestructive Detection Technology for Quality Assessment of Tomatoes	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[86]	2025	Advances in Computer Vision and Spectroscopy Techniques for Non-Destructive Quality Assessment of Citrus Fruits: A Comprehensive Review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[87]	2019	Monitoring strategies for quality control of agricultural products using visible and near-infrared spectroscopy: A review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.

[88]	2018	Near infrared spectroscopy: A mature analytical technique with new perspectives - A review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[89]	2025	A Computer Vision and AI-Based System for Real-Time Sizing and Grading of Thai Export Fruits	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[90]	2025	Improving SSC detection accuracy of hanging-transported strawberries through different correction methods and 1D-CNN	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[91]	2022	Fuzzy Comprehensive Evaluation for Grasping Prioritization of Stacked Fruit Clusters Based on Relative Hierarchy Factor Set	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[92]	2025	Automatic Fruit Grading System with High Adaptability Using Machine Learning Method	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[93]	2023	Designing, Optimizing, and Validating a Low-Cost, Multi-Purpose, Automatic System-Based RGB Color Sensor for Sorting Fruits	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[94]	2017	Grasping damage analysis of apple by end-effector in harvesting robot	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[95]	2021	An Octopus-Inspired Bionic Flexible Gripper for Apple Grasping	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.

[96]	2023	Research on Flexible End-Effectors with Humanoid Grasp Function for Small Spherical Fruit Picking	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[97]	2021	Soft Grippers for Automatic Crop Harvesting: A Review	Secondary review or contextual synthesis	Mapped for context, terminology or prior synthesis; not assigned an empirical maturity score and not used as direct deployment evidence.
[98]	2024	Design and Preliminary Evaluation of Automated Sweetpotato Sorting Mechanisms	Contextual engineering or handling study	Used for mechanism or equipment-design context; not treated as direct evidence of grading-model transferability or commercial readiness.
[99]	2024	Nondestructive determination of edible quality and watercore degree of apples by portable Vis/NIR transmittance system combined with CARS-CNN	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[16]	2024	Non-destructive online detection of early moldy core apples based on Vis/NIR transmission spectroscopy	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[100]	2023	Multi-Index Grading Method for Pear Appearance Quality Based on Machine Vision	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[101]	2022	Complementary deep learning and chemometrics: A case of pear fruit centroid detection and spectral model application for fruit spectral image processing	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[102]	2024	Detection of Pear Quality Using Hyperspectral Imaging Technology and Machine Learning Analysis	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[103]	2018	Postharvest Dry Matter and Soluble Solids Content Prediction in d'Anjou and Bartlett Pear Using Near-infrared Spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[104]	2023	Application of deep learning diagnosis for multiple traits sorting in peach fruit	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[17]	2024	Early Detection of Slight Bruises in Yellow Peaches (<i>Amygdalus persica</i>) Using Multispectral Structured-Illumination Reflectance Imaging and an Improved Otsu Method	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[105]	2018	Evaluation of plum fruit maturity by image processing techniques	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[106]	2025	Non-Destructive Detection and Grading of Plum Quality Based on Multimodal Data	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[107]	2024	Prediction of prunoideae fruit quality characteristics based on machine learning and spectral characteristic acquisition optimization	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[18]	2025	Vis/NIR Spectroscopy and Vis/NIR Hyperspectral Imaging for Non-Destructive Monitoring of Apricot Fruit Internal Quality with Machine Learning	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.

[108]	2022	Hyperspectral dimension reduction and navel orange surface disease defect classification using independent component analysis-genetic algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[109]	2024	Fast detection of the early decay in oranges using visible-LED structured-illumination imaging combined with spiral phase transform and feature-based classification model	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[110]	2024	Qualitative and quantitative analysis of Nanfeng mandarin quality based on hyperspectral imaging and deep learning	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[111]	2025	External defect detection of Orah mandarin based on a non-brightness correction algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[19]	2023	Detection and Classification of Citrus Fruit Infestation by <i>Bactrocera dorsalis</i> (Hendel) Using a Multi-Path Vis/NIR Spectroscopy System	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[112]	2023	Characterisation and optical detection of puffy Satsuma mandarin	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[113]	2024	Prediction of Soluble-Solid Content in Citrus Fruit Using Visible-Near-Infrared Hyperspectral Imaging Based on Effective-Wavelength Selection Algorithm	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[114]	2025	Evaluating ripeness in post-harvest stored kiwifruit using VIS-NIR hyperspectral imaging	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[115]	2020	Kinetic models applied to quality change and shelf life prediction of kiwifruits	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[116]	2024	Non-destructive prediction of ready-to-eat kiwifruit firmness based on Fourier transform near-infrared spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[117]	2021	Mango maturity classification instead of maturity index estimation: A new approach towards handheld NIR spectroscopy	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[118]	2024	Non-destructive methods for mango ripening prediction: Visible and near-infrared spectroscopy (visNIRS) and laser Doppler vibrometry (LDV)	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[119]	2018	Integration of computer vision and colorimetric sensor array for nondestructive detection of mango quality	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[120]	2023	Nondestructive Detecting Maturity of Pineapples Based on Visible and Near-Infrared Transmittance Spectroscopy Coupled with Machine Learning Methodologies	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.

[121]	2025	Surface Defect and Malformation Characteristics Detection for Fresh Sweet Cherries Based on YOLOv8-DCPF Method	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[20]	2025	Maturity Classification of Blueberry Fruit Using YOLO and Vision Transformer for Agricultural Assistance	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[122]	2025	Non-destructive early bruise detection of blueberries based on hyperspectral image feature fusion PKOA- SVM model	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.
[21]	2019	Measuring Internal Maturity Parameters Contactless on Intact Table Grape Bunches Using NIR Spectroscopy	Representative primary empirical study	Formally scored in Table S2; used with the synthesis weight permitted by its maturity category and validation scope.
[123]	2026	Study on Quality Detection Methods for Table Grapes Based on Spectral and Imaging Information	Primary empirical study in narrative synthesis	Used for modality- or commodity-specific findings; no broad transfer or deployment claim was assigned unless independent or online evidence was explicitly reported.