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QUALITY ASSURANCE INSTRUMENTS IN THE READY-TO-EAT FOOD INDUSTRY: A LITERATURE ANALYSIS

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Ewa Szataniak[1] – *orcid id: 0000-0002-6010-5758, e-mail: ewa.szataniak@pcz.pl*

[1]Department Faculty of Management, Czestochowa University of Technology, Armii Krajowej 19B, 42-201 Czestochowa, **Poland**

Abstract: Ready-to-eat (RTE) foods require robust, auditable quality assurance (QA) because consumers apply little or no processing. We performed a structured Scopus review (2015–2026; search date: 19 October 2025) with VOSviewer bibliometrics to map QA tools and emerging directions. The corpus comprised 1,813 peer-reviewed items. Co-occurrence and overlay analyses indicate a dominant operational focus on shelf-life and post-process stability driven by packaging (MAP, active/edible coatings), temperature control (validation, rapid cooling), and microbiological verification (e.g., *Listeria*), supported by environmental monitoring. A stable "core toolkit" underpins these practices: HACCP with prerequisite programs, ISO 22000-based FSMS, and GFSI-benchmarked schemes (BRCGS, IFS, FSSC 22000, SQF), often alongside ISO 9001. At process level, SPC and FMEA – plus, to a lesser extent, Six Sigma and QbD – target critical operations. System acronyms are under-represented in keywords, suggesting fuller visibility in texts. Digitalisation is rising: sensor-enabled cold-chain monitoring, blockchain pilots for traceability, and predictive analytics, with scalability challenges for SMEs.
Keywords: Food safety management systems (FSMS), HACCP, Modified atmosphere packaging (MAP), Ready-to-eat foods (RTE), Shelf-life, Statistical process control (SPC)

1. INTRODUCTION

The ready-to-eat (RTE) market is highly sensitive to quality and food safety failures because these products reach consumers with minimal or no further processing. This necessitates the use of rigorous yet cost-effective quality and safety assurance instruments across the entire value chain (Yi et al., 2024). The importance of quality in the food sector has intensified in recent years – on the one hand due to rising consumer expectations for convenience, sensory quality, "clean labels," and supply-chain transparency, and on the other hand owing to tightening regulatory requirements and competitive pressure (Dora et al., 2012; Bai et al., 2025). The globalization of supply chains and the rapid deployment of new technologies (e.g., packaging innovations, environmental sensors, analytical tools) introduce additional complexity that calls for increasingly sophisticated QA methods and tools to manage risk "from farm to fork" (Dhal & Kar, 2025).

In the RTE segment, critical risk points particularly include: thermal processing and its validation, rapid cooling, management of high- and low-microbiological-risk (hygienic) zones, allergen control, packaging integrity and seal tightness, as well as maintenance of microbiological and sensory stability throughout the declared shelf-life. Effective implementation of QA instruments – both system-level (HACCP; GMP/GHP programmes; food safety management systems based on ISO 22000/FSMS and GFSI-benchmarked standards) and operational (SPC, FMEA, internal and external audits, process validation/verification, and environmental monitoring programmes) – is crucial for mitigating the risk of foodborne illness and maintaining consumer trust (Okpala & Korzeniowska, 2021). Evidence from recent industry studies indicates that integrating classical preventive approaches with risk analysis and process-improvement tools materially strengthens the effectiveness of HACCP systems, particularly in the context of hazards specific to RTE products (Siddique et al., 2025; Szczyrba & Ingaldi, 2024; Szczyrba & Dziuba, 2023).

At the operational level, RTE manufacturers increasingly deploy process-improvement methodologies (Lean, e.g., Value Stream Mapping in packaging lines (Klimecka-Tatar, 2017), FMEA, SPC) to reduce the frequency of potentially hazardous events, stabilize critical quality parameters, and shorten response times to deviations (Szczyrba & Szataniak, 2024). This corroborates findings from other manufacturing sectors on the positive impact of Lean tools – such as 5S and TPM – on accident reduction and safety enhancement (Ulewicz & Lazăr, 2019). In parallel, quality and safety management are co-shaped by consumer preferences and packaging design – the Kano-identified packaging attributes influence perceived quality and purchase decisions, and thus must be incorporated into product design and attribute verification (Szczyrba & Szataniak, 2023).

Amid volatile demand and increasing supply-chain complexity, food organizations – including SMEs – also adopt agile management approaches that can facilitate the implementation and maintenance of QA systems and a strong food-safety culture (Dziuba & Szczyrba, 2023; Sharp & Synodinos, 2024). Comparable challenges linked to the deployment of new technologies under the Agriculture 4.0 paradigm (AI, IoT) and their implications for safety systems are likewise examined in the context of primary production, e.g., livestock farming (Pilarczyk & Ulewicz, 2024).

Responsible production, apart from using methods appropriate for production engineering (Krupnik-Worek et al., 2025), should also include relations related to social space (Hanada, 2025; Hargreaves-Mendes & Marmolejo-Duarte, 2025).

These conditions point to the need for a comprehensive, up-to-date review of the quality-assurance instruments and methods employed by ready-to-eat producers. These conditions point to the need for a comprehensive, up-to-date review of the quality-assurance instruments and methods used by ready-to-eat manufacturers, together with an assessment of their implementation maturity, limitations, and development pathways.

2. METHODOLOGY OF RESEARCH

The study takes the form of a systematic literature review combined with a bibliometric analysis performed in VOSviewer. The methodological objective was to identify and map the quality-assurance (QA) instruments and methods employed by ready-to-eat (RTE) manufacturers, as well as to capture the temporal dynamics and co-occurrence of topics over time.

Scopus (Elsevier) served as the primary database. Scopus was selected due to its broad multidisciplinary coverage, high-quality indexing of peer-reviewed journals, and advanced bibliometric functionalities. It is also one of the most frequently used databases in systematic literature reviews and bibliometric studies in food science and quality management, which supports the comparability and reliability of the results.

The search was conducted on 19 October 2025 and covered the years 2015–2026. The inclusion of the year 2026 results from the Scopus indexing practice, whereby articles available online ahead of print are assigned to forthcoming volumes and publication years. Consequently, a limited number of records labeled as 2026 were already visible in the database at the time of the search.

English-language original research and review articles were included. Editorial materials, errata, and conference papers were excluded, unless preliminary content screening indicated a substantively relevant contribution to RTE and QA issues. The search strategy was developed in the TITLE-ABS-KEY field using Boolean operators, domain-specific RTE keywords, and terms describing system-level and operational QA instruments.

The core query encompassed variants of RTE product descriptors (“ready-to-eat,” “ready to eat,” RTE, “prepared meal*,” “convenience food*,” “chilled meal*,” “ready meal*,” “minimally processed food*,” “fresh-cut,” “ready-to-serve”) in conjunction (AND) with quality-systems terminology (“quality assurance,” “quality control,” HACCP, “ISO 22000,” FSMS, GFSI, BRC/BRCGS, IFS, SQF, FSSC 22000, GMP/GHP, “prerequisite program*,” PRP*, SPC, Six Sigma, FMEA, QbD, “environmental monitoring,” “rapid microbiological method*,” “predictive microbiology,” “shelf-life,” “challenge test*,” “thermal process validation,” “cooling validation,” “allergen management,” “traceability,” “blockchain,” “digital twin*,” IoT, “data-driven,” “predictive analytic*”).

Additionally, a production- and technology-context qualifier was applied (manufactur*, process*, packaging, “modified atmosphere”/MAP, “cold chain,” “temperature abuse,” “hygienic design,” sanitation, CIP) to filter out purely consumer-focused studies with no implications for manufacturing QA. An exclusion filter removed common sources of false positives (e.g., “animal feed,” “pet food,” “veterinary diet*,” “parenteral,” “intravenous,” “ready-to-use”/RTU, “clinical nutrition”).

Following export of results from Scopus (CSV and RIS/BibTeX formats), a two-stage screening was carried out: (i) preliminary title-and-abstract selection; and (ii) full-text assessment to confirm compliance with the inclusion criteria (RTE as the primary object of study; an unambiguous link to QA/FSMS; reference to production, packaging, or cold-chain stages; process validation/verification, allergen control, rapid methods, SPC/FMEA/Six Sigma/QbD in the RTE context). Publications on clinical nutrition, supplements, RTU pharmaceuticals, and papers without practical implications for the QA toolkit were excluded. Duplicates were removed during record consolidation.

Data for VOSviewer were prepared by normalizing fields and creating a thesaurus file that merged synonyms and term variants (e.g., “HACCP” ↔ “hazard analysis and critical control points”; “ISO-22000” ↔ “ISO 22000”; “BRC” ↔ “BRCGS”; “FSMS” ↔ “food safety management system”; “MAP” ↔ “modified atmosphere packaging”; “IoT” ↔ “internet of things”; “RTE” ↔ “ready-to-eat”). Highly generic keywords (“food,” “quality,” “safety”) were removed from keyword lists when they dominated and blurred the thematic structure. We also adopted a conceptual distinction between management, control, inspection, and testing to guide term normalization and interpretation (Knop, 2020). Co-occurrence

analysis was performed primarily on author keywords, and secondarily on index keywords, using full counting and an initial minimum occurrence threshold of ≥5 (calibrated via sensitivity analysis). Results were presented as: cluster maps, overlay visualizations (average year of occurrence), and density visualizations. For co-citation, “sources” and “cited references” were analyzed with thresholds of ≥10 and ≥20 citations, respectively (adjusted to corpus size), enabling identification of the core literature (HACCP/FSMS, rapid methods, cold chain, process improvement). Bibliographic coupling (documents, organizations, countries) and co-authorship (authors/organizations/countries) were applied to identify research schools and collaboration networks. Map layout parameters (VOS, force-based) were kept at defaults, with no manual repositioning in the final visualizations.

Limitations stemming from the use of a single database (Scopus) were acknowledged; key conclusions were triangulated with full-text querying and contextual checks. The datasets (included records, VOSviewer input files, thesaurus.csv, and analysis settings) are provided in the supplementary materials to enable replication and longitudinal comparison.

„(TITLE-ABS-KEY("ready-to-eat" OR "ready to eat" OR RTE OR "prepared meal" OR "convenience food*" OR "chilled meal*" OR "ready meal*" OR "minimally processed food*" OR "fresh-cut" OR "ready-to-serve"))*

AND

(TITLE-ABS-KEY("quality assurance" OR "quality control" OR HACCP OR "ISO 22000" OR "food safety management system" OR FSMS OR GFSI OR BRC OR BRCGS OR IFS OR "FSSC 22000" OR SQF OR GMP OR GHP OR "prerequisite program*" OR PRP* OR "statistical process control" OR SPC OR "Six Sigma" OR FMEA OR "quality by design" OR QbD OR "environmental monitoring" OR "rapid microbiological method*" OR "predictive microbiology" OR "shelf-life" OR "challenge test*" OR "thermal process validation" OR "cooling validation" OR "allergen management" OR traceability OR blockchain OR "digital twin*" OR IoT OR "data-driven" OR "predictive analytic*"))*

AND

(TITLE-ABS-KEY(manufactur OR process* OR packaging OR "modified atmosphere" OR MAP OR "cold chain" OR "temperature abuse" OR "hygienic design" OR sanitation OR "cleaning-in-place" OR CIP))*

AND NOT TITLE-ABS-KEY("animal feed" OR "pet food" OR "veterinary diet" OR parenteral OR intravenous OR "ready-to-use" OR RTU OR "clinical nutrition")*

AND (PUBYEAR > 2014 AND PUBYEAR < 2027)

AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re"))

AND (LIMIT-TO(LANGUAGE,"English"))”

In summary, the adopted methodology enables a transparent and reproducible identification of quality assurance instruments applied in the ready-to-eat sector. The combination of systematic literature review principles with VOSviewer-based bibliometric analysis allows both quantitative mapping of research trends and qualitative interpretation of QA-related themes. This methodological framework supports the achievement of the research objectives and ensures the robustness of the results.

3. RESULTS AND DISCUSION

The Scopus search yielded a corpus of 1,813 publications (articles and reviews) from 2015–2026. A clear upward trend is evident after 2018, with local maxima in 2021 (207) and 2024 (211); the value for 2026 stands at 5 records as of 19 October 2025, reflecting early-access publications assigned to forthcoming volumes rather than a complete publication year. The most frequent publication venues were: Acta Horticulturae (117), Foods (91), Food Control (60), Journal of Food Processing and Preservation (55), Postharvest Biology and Technology (50), LWT (43), Food Packaging and Shelf Life (37), Food Chemistry (31), International Journal of Food Microbiology (27), and Innovative Food Science and Emerging Technologies (26).
Within the corpus, 4,436 unique author keywords (8,732 total occurrences) and 7,021 unique index keywords (24,264 occurrences) were identified.
The analysis was performed in VOSviewer (unit of analysis: author keywords; counting method: full counting; initial threshold: ≥5 occurrences; the cluster map is presented in the VOSviewer Figure 1).

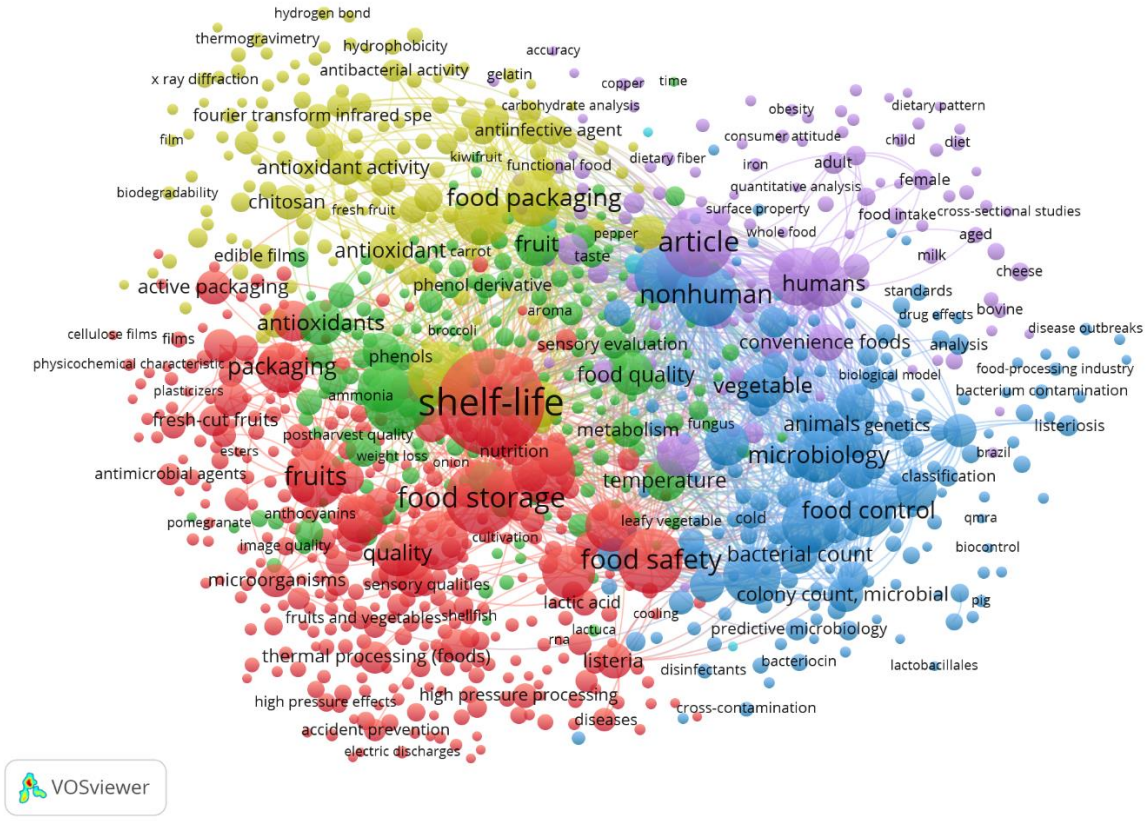

Fig. 1. Thematic clusters of QA research in RTE foods – author-keyword network (VOSviewer; Scopus 2015–2026).

Four stable thematic clusters were obtained, corresponding to the map colors (Fig. 1):

- **Cluster A – "Shelf-life & storage/processing" (red):** anchored by shelf-life (the most frequent term), food storage, thermal processing (foods), microorganisms,

fruits/fresh-cut, temperature. This cluster links the RTE literature with fresh/"minimally processed" plant products, cooling validation, and control of storage parameters.

- **Cluster B – "Packaging, edible and active coatings" (green):** food packaging, modified atmosphere packaging (MAP), edible coating/edible films, active packaging, antioxidant activity, chitosan, phenols/antioxidants. This is the dominant branch focusing on extending shelf-life and controlling sensory quality of RTE via packaging materials and bioactive coatings.
- **Cluster C – "Microbiology and safety control" (blue):** food safety, food control, bacterial/colony count, predictive microbiology, contamination/cross-contamination, *Listeria monocytogenes*, disinfectants, biocontrol, lactic acid/Lactobacillales. This cluster covers validation and verification of control measures typical for RTE (post-process contamination, hygienic zoning, monitoring).
- **Cluster D – "Epidemiological/nutritional perspective" (purple; peripheral to QA):** humans/nonhuman, diet/dietary pattern, cross-sectional studies, milk/cheese. This is a more biomedical/nutritional layer that sits at the periphery of the QA core on the map.

In the author keywords, the highest frequencies were observed for: "shelf life/shelf-life," fresh-cut, food safety, *Listeria monocytogenes*, modified atmosphere packaging, ready-to-eat, packaging, edible coating, active packaging, minimal(ly) processing, and storage/postharvest. In the index keywords, control/technology categories predominate (e.g., food packaging, quality control, food microbiology, food contamination), which confirms the technical profile of the reviewed corpus.

The place of "QA instruments" within the keywords

Within the author keywords, system-level concepts (e.g., HACCP, ISO 22000, FSMS, BRCGS/IFS/SQF, PRP, SPC, FMEA, QbD) appear only sporadically (e.g., HACCP ~10 occurrences; GMP ~3; Six Sigma ~2; ISO 22000 incidental), whereas the shelf-life–packaging–microbiology axis is very prominent. This suggests that research in 2015–2026 focused primarily on operational tools (validation of thermal/cooling processes, MAP, coatings, microbiological monitoring) and shelf-life extension strategies, while management systems (FSMS, GFSI-benchmarked standards) were less often foregrounded in metadata as keywords. The same tendency is visible in the index keywords layer, where categories such as "quality control/food control/food packaging" are strongly represented, but the names of standards are rare.

Temporal trends and emerging topics

In the overlay visualization (average year of occurrence), newer-toned elements (shifted toward the blue–green periphery of the map) include terms linked to digitization and analytics (e.g., machine learning, predictive analytics, sensor, traceability), whereas traditional motifs (shelf-life, packaging, fresh-cut, *Listeria*) form a persistent core of the literature. Although terms such as blockchain, digital twin, and IoT are infrequent in the keywords, their appearance after 2020 indicates the onset of Industry 4.0 integration with QA in RTE (especially cold-chain monitoring and batch traceability).

Implications for the review of QA instruments in RTE

1. Dominance of packaging and shelf-life: The core of the corpus concerns shelf-life extension via MAP, edible/active coatings, bioactive inputs (e.g., chitosan,

phenolics), and storage/cooling management. These are unambiguously operational QA instruments.

2. Strong microbiological strand: *Listeria monocytogenes*, bacterial/colony counts, post-process contamination, and cross-contamination constitute a second pillar aligned with verification and monitoring in risk-based systems (HACCP/PRPs), even if the system names themselves do not dominate the keywords.
3. Relative weakness of system-level metadata: The low frequency of standards acronyms (HACCP/ISO 22000/GFSI) in keywords suggests that system implementation is more often described in article bodies (case studies, audits, validations) than tagged in metadata. This justifies the need for full-text review of selected papers to assess the actual scope of FSMS application in RTE.
4. Digitization – early stage: Isolated occurrences of traceability, blockchain, digital twin, and machine learning point to an emerging research direction (prediction of spoilage/pathogen risk, cold-chain monitoring). In industrial practice, the potential of these tools is growing, but the evidence base in the RTE literature remains moderate.

Overall, the results indicate that quality assurance research in the RTE sector is dominated by operational instruments related to shelf-life, packaging, and microbiological control, while system-level frameworks remain less visible in bibliometric metadata. These findings justify the need for integrated analyses combining bibliometric methods with full-text assessment to capture the actual maturity of FSMS implementation.

4. CONCLUSIONS

This review – based on a Scopus query (2015–2026) and VOSviewer keyword co-occurrence analysis – shows that research on quality assurance in the ready-to-eat (RTE) segment focuses primarily on operational instruments: shelf-life extension via packaging and coatings (MAP, edible/active coatings), storage/cooling management, and microbiological control (including post-process hazards and *Listeria monocytogenes*). The literature core is thus formed by “near-process” technologies and validations that directly translate into the stability and safety of RTE products.

It should be noted that publication counts for the terminal year (2026) are partial and should be interpreted as indicative of emerging trends rather than annual output.

At the same time, the formal system layer (HACCP, ISO 22000/FSMS, GFSI standards: BRCGS/IFS/SQF/FSSC 22000) is less visible in metadata (keywords), suggesting that system practices are more often implied than foregrounded in publication descriptors. Consequently, robust inference about FSMS implementation maturity requires full-text verification and a review of case studies, rather than bibliometrics alone.

Emerging yet still moderately represented threads of QA digitization (traceability, IoT, machine learning, predictive analytics, with sporadic blockchain/digital twin) indicate that the RTE sector is at an early stage of Industry 4.0 integration, particularly in cold-chain monitoring and spoilage/pathogen risk prediction. Challenges remain especially salient for SMEs: data interoperability, costs and capabilities, and demonstrated return on investment. In light of the above, we recommend a research–implementation agenda for the RTE sector:

1. Integrate FSMS with data analytics – architectures that link HACCP/PRPs with sensors and predictive models (as a “single risk map”).

2. Standardize data and indicators – harmonized models (e.g., for time/temperature, environmental hygiene, packaging integrity) and outcome-oriented effectiveness metrics (incident-based KPIs).
3. Validate under real-world conditions – comparative studies of RMMs and predictive algorithms on RTE production lines, reporting sensitivity/specificity and impacts on QA decision-making.
4. Economics of quality – cost–benefit analyses (TCO/ROI) for digital QA instruments in SMEs, with models for scalable deployment.
5. Competencies and safety culture – training programs that combine FSMS fundamentals with analytics and interpretation of process data.

In summary, ready-to-eat products require a combination of proven operational instruments (shelf-life, packaging, microbiology), mature management systems, and a new data layer. Such a three-pillar model (FSMS + operations + data/AI) best addresses the complexity of modern RTE supply chains, minimizes the risk of hazardous events, and supports durable consumer trust.

REFERENCES

Bai, Y., Jiang, D., & Pretorius, L. (2025). Trends in sustainable agricultural supply chain management. Polish Journal of Management Studies, 31(1), 25-44. DOI: 10.17512/pjms.2025.31.1.02

Dora, M., Kumar, M., Van Goubergen, D., Molnar, A., & Gellynck, X. (2013). Food quality management system: Reviewing assessment strategies and a feasibility study for European food small and medium-sized enterprises. Food Control, 31(2), 607–616. DOI: 10.1016/j.foodcont.2012.12.006

Dhal, S. B., & Kar, D. (2025). Leveraging artificial intelligence and advanced food processing techniques for enhanced food safety, quality, and security: a comprehensive review. Discover Applied Sciences, 7(1). DOI: 10.1007/s42452-025-06472-w

Dziuba, S. & Szczyrba, A. (2023). Agile management in Polish organic food processing enterprises. Production Engineering Archives, 29(1), 2023. 101-107. DOI: 10.30657/pea.2023.29.12

Hanada, K.B. (2025). The Void of Mies: Unfolding Unbuilt Projects of Mies van der Rohe. Technical Transactions, 122, art. e2025001. DOI: 10.37705/TechTrans/e2025001

Hargreaves-Méndez, A. & Marmolejo-Duarte, C. (2025). Does Urban Design Influence the Perception of Safety? An Analysis of the Green Axis of Consell de Cent in Barcelona. Technical Transactions, 122, art. e2025005. DOI: 10.37705/TechTrans/e2025005

Klimecka-Tatar, D. (2017). Value Stream Mapping as Lean Production tool to improve the production process organization – case study in packaging manufacturing. Production Engineering Archives, 17(17), 40–44. DOI: 10.30657/pea.2017.17.09

Knop, K. (2020). Indicating and analysis the interrelation between terms – visual: management, control, inspection and testing. Production Engineering Archives, 26(3), 110–120. DOI: 10.30657/pea.2020.26.22

Krupnik-Worek, J., Skoczypiec, S. & Habel, J. (2025). Artificial Intelligence overview for optimizing production scheduling in a picture framing company. Technical Transactions, 122, art. e2025006. DOI: 10.37705/TechTrans/e2025006

Okpala, C. O. R., & Korzeniowska, M. (2021). Understanding the Relevance of Quality Management in Agro-food Product Industry: From Ethical Considerations to Assuring Food Hygiene Quality Safety Standards and Its Associated Processes. Food Reviews International, 39(4), 1879–1952. DOI: 10.1080/87559129.2021.1938600

Szczyrba, A. & Ingaldi, M. (2024). Implementation of the FMEA Method as a Support for the HACCP System in the Polish Food Industry. Management Systems in Production Engineering, 32(3), 2024. 357-371. DOI: 10.2478/mspe-2024-0034

Szczyrba A., Dziuba Sz.,(2023). Good Manufacturing Practices for Quality and Safety Management in the Food Industry, Materials Research Proceedings, 34, 288-297, 2023 DOI: 10.21741/9781644902691-34

Szczyrba A., Szataniak E., (2024). The Impact of Lean Tools on the Reduction of Potentially Dangerous Events, Materials Research Proceedings, 45, 205-212, 2024 DOI: 10.21741/9781644903315-24

Szczyrba, A. & Szataniak, M. (2023). Decoding Consumer Preferences in Food Packaging with the Kano Model. System Safety: Human - Technical Facility - Environment, 5(1), 2023. 83-92. DOI: 10.2478/czoto-2023-0010

Siddique, A., Gupta, A., Sawyer, J. T., Huang, T.-S., & Morey, A. (2025). Big data analytics in food industry: a state-of-the-art literature review. Npj Science of Food, 9(1). DOI: 10.1038/s41538-025-00394-y

Sharp, K. L., & Synodinos, C. (2024). Going green: unpacking generation Y's shift towards organic food in South Africa. Polish Journal of Management Studies, 30(2), 264-281. DOI: 10.17512/pjms.2024.30.2.16

Pilarczyk, M. & Ulewicz, R. (2024). The Impact of Agriculture 4.0 on Workplace Safety in Animal Handling. System Safety: Human - Technical Facility - Environment, 6(1), 2024. 60-68. DOI: 10.2478/czoto-2024-0008

Ulewicz, R. & Lazar, L.V. (2019). The Effect of Lean Tools on the Safety Level in Manufacturing Organisations. System Safety: Human - Technical Facility - Environment, 1(1), 2019. 514-521. DOI: 10.2478/czoto-2019-0066

Yi, L., Wang, W., Diao, Y., Yi, S., Shang, Y., Ren, D., Ge, K., & Gu, Y. (2024). Recent advances of artificial intelligence in quantitative analysis of food quality and safety indicators: A review. TrAC Trends in Analytical Chemistry, 180, 117944. DOI: 10.1016/j.trac.2024.117944