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Food Industry Wastewater Management System for Land Application: A Systematic Literature Review

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Abstract

Research Objective: This study aimed to systematically evaluate food-industry wastewater treatment, water reuse, resource recovery, and the directness of evidence supporting agricultural land application. **Methodology:** A systematic literature review following PRISMA was conducted using Google Scholar, ScienceDirect, and PubMed. Publications from 2016 to 2026 were considered. Of 280 records identified, 70 duplicates were removed, 210 records were screened, 45 full-text articles were assessed, and 12 studies were included. Evidence was categorized according to study design, treatment or reuse endpoint, directness to land application, and reported environmental outcomes. **Results:** The included studies described anaerobic treatment, membrane bioreactors, Zero Liquid Discharge, adsorption, process-control systems, composting, liquid organic fertilizer production, and irrigation-efficiency approaches. Most studies evaluated treatment performance, discharge compliance, industrial water reuse, or resource recovery. Only one field study directly assessed soil and crop heavy-metal outcomes. Therefore, the evidence indicates potential for land application under specified treatment and monitoring conditions, but it does not establish universal safety across wastewater types, soils, crops, or operating settings. **Conclusion:** Integrated treatment and resource-recovery strategies can support water conservation and circular production. Agricultural land application should be based on applicable quality standards and site-specific monitoring of salinity, nutrients, pathogens, heavy metals, soil accumulation, and crop uptake.

Keywords: *food-industry wastewater; water reuse; land application; resource recovery; systematic literature review*

INTRODUCTION

Rapid population growth and social development have led to the intensification of food production. Land use has become more intensive, and therefore the application of modern agrotechnical measures, the use of artificial fertilizers, and other plant protection products are carried out to increase crop yields. However, at the same time, these practices contribute to additional pollution of water streams and groundwater (Ćirović et al., 2025). Water footprint management in the food industry has now become a crucial issue, equally important as the carbon footprint. Currently, the world is facing complex challenges in which global population growth, urbanization, and rapid economic development are driving a surge in consumer demand for food products (Icheme, 2025).

The food production sector is highly dependent on water, with approximately 70% of the world's total freshwater extraction used specifically for agriculture, while another 20% is absorbed by the manufacturing and processing industries. The combination of climate change, population expansion, and socioeconomic demands has made the threat of water scarcity and water stress increasingly widespread. Water availability and rainfall patterns are predicted to become increasingly unpredictable, ultimately bringing significant consequences for the stability of global food production. Without effective management and efficient use of water in food and beverage production chains worldwide, this crisis could trigger massive geopolitical and social impacts, ranging from rising food prices, hunger, and pollution to potential regional conflicts (Icheme, 2025).

In the context of food and beverage processing, minimizing the use of raw materials, such as water and energy, to achieve the highest level of production is an implementation of manufacturing best practices (Icheme, 2025). The food industry is one of the major consumers of water. The amount of water used varies significantly across the food and beverage industry depending on the type of sector, process parameters, unit size, and cleaning processes applied. Wastewater generated in the food industry may originate from processing units, rinsing and cleaning activities, and by-product streams, including solid and liquid waste. Practical water-use reduction strategies can be achieved by recycling and reusing treated water and recovering valuable materials. To achieve these strategies, the implementation of efficient wastewater treatment methods is required (Abdel-Fatah, 2023).

Food industry wastewater that is not properly managed, when discharged into the environment, can negatively affect the quality of surface water and groundwater. Food industry wastewater containing organic substances, nutrients, and hazardous chemicals may infiltrate groundwater or flow into surface water bodies such as rivers, lakes, and oceans. In addition to affecting the quality of water used by humans, this can also damage aquatic ecosystems. Nutrient runoff from food industry waste can trigger eutrophication, leading to algal blooms and potentially reducing dissolved oxygen levels in water, which may cause mass mortality of aquatic organisms. Furthermore, groundwater contamination by toxic substances and pathogens can pose a serious threat to human health, especially for communities that depend on groundwater as a source of drinking water (Afifah et al., 2025).

Although wastewater treatment has received substantial attention, the literature often combines four distinct endpoints: compliance for discharge to water bodies, internal industrial reuse, agricultural land application, and recovery of wastewater by-products. These endpoints require different evidence. Treatment performance expressed as BOD, COD, or TSS removal does not by itself demonstrate long-term safety for soil, crops, or the food chain. Evidence for land application should also consider salinity, nutrient loading, pathogens, heavy metals, soil accumulation, crop uptake, and local regulatory requirements. A review that distinguishes these endpoints is therefore needed to support technically appropriate and environmentally responsible decisions.

This systematic review aimed to evaluate and synthesize evidence on food-industry wastewater management for land application and circular resource use. Specifically, it examined: (1) the treatment and resource-recovery technologies reported in the literature; (2) whether the reported endpoint was discharge compliance, industrial reuse, resource recovery, or direct land application; (3) the directness and strength of the evidence supporting soil and agricultural use; and (4) the operational trade-offs and monitoring requirements that should guide implementation.

METHODS

Design and information sources

This study used a systematic literature review design and followed the PRISMA stages of identification, screening, eligibility assessment, and inclusion. Secondary evidence was retrieved from Google Scholar, ScienceDirect (Elsevier), and PubMed. The eligibility window was revised to 2016-2026 to match the publication years of the studies included in the final synthesis (Cabrera et al., 2023).

Search strategy

Searches combined Indonesian and English terms. The principal English search string was: ("food industry wastewater" OR "agro-industrial wastewater") AND ("wastewater treatment" OR "water reuse") AND ("land application" OR "soil infiltration" OR irrigation). The Indonesian search string was: ("air limbah industri pangan" OR "air limbah agroindustri") AND ("sistem pengelolaan" OR "pengolahan air limbah") AND ("pemanfaatan air ke tanah" OR irigasi). Syntax was adapted to the functions of each database. Reference lists of potentially eligible articles were also checked for additional relevant studies.

Eligibility and study selection

Studies were included when they: (1) were published in Indonesian or English between 2016 and 2026; (2) were available in full text; (3) addressed wastewater or treatment by-products from food-processing or closely related industrial contexts; and (4) reported extractable findings relevant to treatment performance, discharge compliance, water reuse, land application, soil or crop outcomes, or circular resource recovery. Duplicates, inaccessible full texts, studies without relevant reuse or land-application outcomes, and reports with insufficient methodological or outcome information were excluded. Community-service and technical-planning studies were retained only when they provided extractable implementation evidence; mixed-industry studies were retained only when they contributed directly relevant evidence on agricultural reuse or contaminant control. These sources were treated as indirect or contextual evidence rather than as equivalent to controlled field studies.

Data extraction, appraisal, and synthesis. For each included study, the authors extracted the industrial context, study design, treatment or management approach, measured outcomes, intended reuse endpoint, and relevance to land application. A structured descriptive appraisal considered four domains: study design, directness to land application, use of measured environmental outcomes, and transferability to other wastewater, soil, and crop conditions. Field and laboratory studies with measured outcomes were interpreted more strongly than technical-planning or community-service reports. Because the designs, wastewater types, interventions, and outcomes were heterogeneous, no meta-analysis was performed. Findings were synthesized narratively and organized into treatment diversification, water circularity, resource recovery, and evidence directly supporting land application.

RESULTS

The search identified 280 records. After removal of 70 duplicates, 210 titles and abstracts were screened and 165 records were excluded. Forty-five full-text articles were assessed; 33 were excluded because the full text was unavailable (n = 5), the study did not address land, soil, reuse, or relevant circular-resource outcomes (n = 18), or the methods and outcomes were insufficient for extraction (n = 10). Twelve studies were included in the qualitative synthesis (Figure 1).

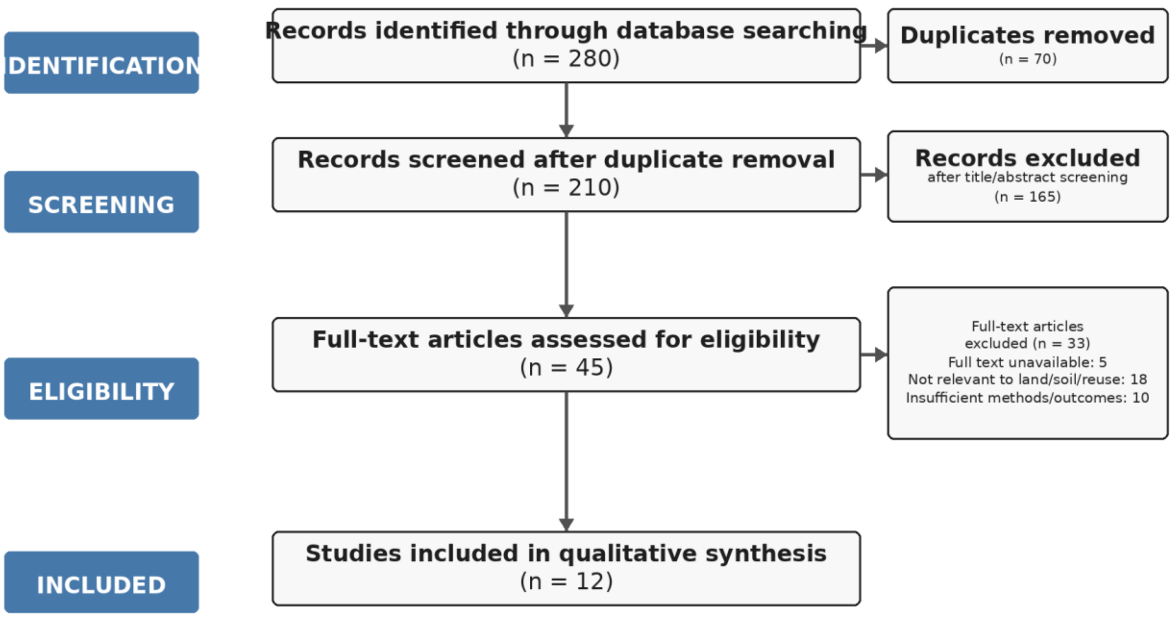

Figure 1. PRISMA flow of article identification and selection

Table 1. Characteristics, findings, and reuse relevance of the included studies

No.	Author(s)	Title	Study design	Main findings	Reuse or land-application relevance and evidence limitations
1	Sukindrawati & Kartika (2022)	Community Service Innovation in the Construction of a Tofu Wastewater Treatment Installation Producing Biogas as an Alternative Fuel	Community-service implementation report	A Tofu Wastewater Treatment Installation was successfully constructed and significantly reduced the pollution load of wastewater, making the water safe and suitable for discharge into drainage channels or rivers.	The installation reduced the reported pollution load and supported discharge management. Soil, crop, pathogen, salinity, and long-term land-application outcomes were not directly measured.
2	Yulistika et al. (2025)	Analysis and Design of a Tofu Industrial Liquid Waste Treatment System Using the Classification–Decision Tree Method	Model-Based Systems Engineering (MBSE) design study	The treatment system was successfully modeled into four main stages: pre-treatment, anaerobic treatment, aerobic treatment, and control using a biotope pond.	The model supports automated decisions on whether effluent is suitable for discharge or requires reprocessing. Field performance and agricultural land-application safety were not evaluated.
3	Yuliastuti & Cahyono (2020)	Study of Liquid Waste Management in the Iodized Consumption Salt Industry	Qualitative and quantitative descriptive study	Liquid waste from the salt industry originates from the washing process of raw salt materials and visually appears yellowish-white because it contains fine salt particles. Laboratory test results showed that the wastewater characteristics had very high pollution levels and exceeded the standard quality threshold based on East Java Governor Regulation No. 72/2013, Class II.	Recirculation and periodic reuse can reduce clean-water demand and wastewater volume. The study addressed process-water reuse rather than agricultural land application.
4	Munratiwar & Ray (2020)	Sustainable Management of Water and Wastewater in the Food Industry for a ZLD System	Case study and water-management system modeling	The integration of rainwater harvesting systems with ZLD technology proved effective in independently meeting the	The case study and model indicate potential for internal reuse, irrigation, and landscaping. Direct soil and crop monitoring and the energy and cost

No.	Author(s)	Title	Study design	Main findings	Reuse or land-application relevance and evidence limitations
				operational water needs of the food industry, especially in water-scarce areas.	burden of ZLD were not reported in the synthesis.
5	Wattimena & Nisa (2024)	Treatment of Sludge from the Wastewater Treatment Plant of a Cake and Snack Industry Using the Composting Method	Experimental composting study	The final characteristics of the organic fertilizer produced from the sludge composting process showed very good physical quality, namely blackish-brown color, coarse texture, a natural earthy odor, and dry moisture levels.	The study supports sludge-to-compost resource recovery, but assessment was mainly based on physical characteristics. Nutrient composition, pathogens, contaminants, and agronomic field performance require further evaluation.
6	Nurdiana et al. (2023)	Alternative Technology for Treating Industrial Wastewater Using Plant Media	Community-service implementation report	Communities and business actors successfully understood how to process coconut fiber waste, which was initially of no value, into a productive planting medium known as cocopeat. The characteristics of coconut fiber proved effective as an absorbent for liquid waste or excess water because it has a porous structure rich in essential nutrients, such as potassium.	The community program demonstrates reuse of coconut waste as an absorbent planting medium. Wastewater-quality improvement and safety for soil or crops were not quantified.
7	Muhamad et al. (2021)	Treatment of Wastewater from a Food and Beverage Industry Using Conventional Wastewater Treatment Integrated with a Membrane Bioreactor System: A Pilot-Scale Case Study	Pilot-scale quantitative experimental method	The integrated conventional–MBR system showed very high pollutant removal efficiency.	The pilot system achieved high pollutant removal and supports non-process industrial reuse. Agricultural irrigation and long-term soil effects were not studied.

No.	Author(s)	Title	Study design	Main findings	Reuse or land-application relevance and evidence limitations
8	Syafruddin et al. (2026)	Village Community Empowerment: Utilization of Appropriate Technology in Automatic Drip Irrigation Systems and Processing Durian Peel Waste into Economically Valuable Products	Community-service implementation report	The implementation of an automatic drip irrigation system successfully increased the efficiency of residual watering water use by up to 40%, while also reducing labor operational costs.	The program supports irrigation efficiency and circular agriculture. It provides contextual implementation evidence rather than direct evidence on treated food-industry wastewater quality or land-application safety.
9	Aprilianti et al. (2025)	Planning of a Wastewater Distribution System and Wastewater Treatment Plant for the Aren Sago Flour Industry in Plajan Village	Quantitative technical-planning study	Household-scale aren sago industries in Plajan Village produce liquid waste with concentrated pollutant parameters exceeding official government quality standards.	The planning study addresses prevention of untreated discharge. Because the system was not evaluated as an operating treatment plant, performance and land-application outcomes remain unverified.
10	Panhwar et al. (2022)	Utilization of Treated Industrial Wastewater and Accumulation of Heavy Metals in Soil and Okra Vegetable	Field experimental study	Laboratory wastewater treatment successfully purified wastewater significantly by reducing COD and BOD levels to meet Sindh Environmental Quality Standards (SEQS).	This field experiment provides the most direct evidence on treated wastewater, soil, crops, and heavy metals. Findings apply to the wastewater mixture, treatment process, crop, and conditions studied and should not be generalized without local validation.
11	Hartiani & Suprianik (2024)	Utilization of Tofu Liquid Waste as an Effort to Preserve the Environment and Improve the Community Economy in Taman Village, Grujungan District, Bondowoso Regency	Qualitative descriptive Community-Based Research	An anaerobic fermentation process for 8–10 days successfully converted tofu liquid waste into Liquid Organic Fertilizer. Success indicators included a change in fertilizer color to brownish-black and the disappearance of a strong foul odor, replaced by a distinctive fermented	The community-based study supports conversion of tofu wastewater into liquid fertilizer using qualitative indicators. Nutrient balance, pathogens, heavy metals, application rate, and long-term soil or crop outcomes were not quantified.

No.	Author(s)	Title	Study design	Main findings	Reuse or land-application relevance and evidence limitations
				aroma similar to tapai.	
12	Elkhatib et al. (2025)	Effective Elimination of Lead from Polluted Wastewater Utilizing a Novel Nanocomposite Derived from Byproducts of the Drinking Water Industry	Laboratory experimental study	The nanocomposite structure proved highly stable and could be regenerated using dilute acid for reuse up to six cycles without significant decline in adsorption performance.	The laboratory study demonstrates lead adsorption and sorbent regeneration. It is indirect evidence because it did not evaluate food-industry effluent or agricultural field application.

Evidence Classification and Appraisal

The evidence base was heterogeneous. Only one study directly measured treated wastewater, soil, crop, and heavy-metal outcomes under field conditions. Other studies primarily evaluated treatment performance, discharge or internal reuse, resource recovery, system design, or community implementation. Consequently, evidence on pollutant removal and circularity was broader than evidence establishing long-term agricultural safety.

Table 2. Evidence classification, directness, and interpretive limits

Evidence category	Included studies	Primary outcomes	Interpretation
Direct field land-application evidence	Panhwar et al. (2022)	Treatment performance, soil and crop heavy metals	Most direct evidence, but limited to one mixed-industry field setting and specific treatment, soil, and crop conditions.
Treatment, discharge, or industrial-reuse evidence	Sukindrawati & Kartika (2022); Yuliastuti & Cahyono (2020); Munratiwar & Ray (2020); Muhamad et al. (2021); Aprilianti et al. (2025); Elkhatib et al. (2025)	Pollutant reduction, process-water reuse, discharge decisions, contaminant removal	Useful for treatment selection, but mainly indirect for agricultural land application.
Resource-recovery and agricultural by-products	Wattimena & Nisa (2024); Nurdiana et al. (2023); Syafruddin et al. (2026); Hartiani & Suprianik (2024)	Compost, liquid fertilizer, planting media, irrigation efficiency	Supports circular-economy applications; chemical, microbiological, and long-term agronomic outcomes were often limited.
System design and monitoring	Yulistika et al. (2025)	Process configuration and decision-tree monitoring	Supports operational decision-making; field treatment performance and land-application outcomes were not validated.

DISCUSSION

The 12 included studies were organized around three practical themes: diversification of treatment technologies, water circularity through reuse, and recovery of wastewater by-products. However, the appraisal also showed that the evidence was not equally direct. Treatment-efficiency and implementation studies were common, whereas direct evidence on soil, crop, salinity, pathogen, nutrient, and long-term heavy-metal outcomes was limited. The findings should therefore be interpreted according to the endpoint and design of each study.

Diversification of Food Industry Wastewater Treatment Technologies

Food-industry wastewater characteristics differ substantially among subsectors and require context-specific treatment. In tofu processing, anaerobic systems can reduce organic loads and recover biogas, while fermentation can convert wastewater into liquid organic fertilizer. These approaches support pollution control and resource recovery, but reports based on discharge suitability, odor reduction, color change, or community implementation should not be interpreted as complete evidence of agricultural safety. Verification should include effluent quality, pathogen control, nutrient loading, salinity, and the intended soil and crop conditions (Sukindrawati & Kartika, 2022; Hartiani & Suprianik, 2024).

Resource-recovery options such as liquid fertilizer, compost, and cocopeat may reduce waste volume and return organic matter or nutrients to productive use. Nevertheless, physical indicators such as color, texture, odor, and moisture are insufficient on their own to confirm product quality. Before agricultural use, recovered products should be characterized for nutrient content, maturity or stability, pathogens, salinity, and potentially hazardous contaminants, and their application rates should be matched to crop and soil requirements.

For larger-scale food and beverage industries, conventional treatment integrated with a membrane bioreactor can produce high-quality effluent and support non-process reuse. Advanced adsorption materials may also remove specific contaminants such as lead. These technologies have different operational trade-offs. Membrane systems require energy, fouling control, cleaning, and membrane replacement, whereas adsorption systems require regeneration and safe management of contaminant-rich residuals. Laboratory contaminant-removal performance also requires field validation before it can be applied to complex food-industry effluent or agricultural irrigation (Muhamad et al., 2021; Elkhatib et al., 2025).

Operational monitoring is essential because treatment performance can vary with influent composition, flow, loading, temperature, pH, maintenance, and operator capacity. Monitoring should be linked to the intended endpoint: discharge parameters for environmental release, process-quality requirements for industrial reuse, and additional soil- and crop-protection parameters for land application.

Water Efficiency in the Food Sector and the Zero Liquid Discharge (ZLD) Concept

Water circularity strategies can reduce dependence on freshwater by combining source reduction, internal reuse, rainwater harvesting, and treatment appropriate to the required water quality. The included evidence described Zero Liquid Discharge systems and irrigation-efficiency approaches. These strategies may conserve water, but their feasibility depends on industry scale, local water scarcity, energy supply, technical capacity, and the quality requirements of the intended reuse endpoint.

Zero Liquid Discharge combines membrane and thermal processes to maximize water recovery and minimize liquid discharge. Its potential benefits include reduced groundwater extraction and greater internal water reuse. However, ZLD is capital- and energy-intensive and transfers contaminants into concentrated brines or solid residues that still require appropriate management. Therefore, ZLD should be presented as one option within a treatment train rather than as a universally appropriate solution (Munratiwar & Ray, 2020).

Decision-support and automated monitoring can improve consistency in effluent classification and reduce human error. Nevertheless, a digital classification system is only as reliable as its sensors, calibration, decision thresholds, maintenance, and validation data. Automated decisions should therefore supplement, rather than replace, laboratory verification and regulatory oversight (Yulistika et al., 2025).

Contribution to Soil and Agricultural Sustainability Through Land Application

The direct evidence supporting land application was limited. Panhwar et al. (2022) reported that treated mixed industrial wastewater met the study standards and did not produce hazardous heavy-metal accumulation in the evaluated soil and okra crop under the reported conditions. This finding supports conditional feasibility, not universal safety. The remaining studies mainly addressed treatment performance, discharge, internal reuse, or resource recovery and did not directly evaluate long-term soil accumulation, crop uptake, pathogens, salinity, or nutrient imbalance.

For agricultural implementation, treated effluent and recovered products should be assessed against applicable standards and a site-specific management plan. At minimum, monitoring should consider pH, electrical conductivity or salinity, sodium-related soil risks, nutrients, organic load, pathogens, relevant heavy metals, irrigation rate, soil accumulation, and crop uptake. Monitoring frequency and parameters should be adapted to the wastewater source, treatment process, soil, crop, climate, and duration of application.

Strengths and Limitations

This review provides an integrative overview of treatment, water circularity, and by-product recovery across diverse food-industry contexts. Its main limitation is the small and heterogeneous evidence base, which included field experiments, laboratory studies, modeling, technical planning, and community-service reports. Only one study directly assessed soil and crop heavy-metal outcomes, and several studies were only indirectly related to agricultural land application. Differences in wastewater composition, treatment scale, regulatory standards, and reported outcomes prevented quantitative pooling. The findings should therefore guide technology screening and research priorities rather than serve as a universal declaration of land-application safety.

CONCLUSION

The reviewed evidence indicates that biological, physicochemical, membrane-based, adsorption, and resource-recovery approaches can improve food-industry wastewater management and support water conservation and circular production. The strength and relevance of evidence differ by endpoint: several studies support pollutant reduction, discharge management, industrial reuse, ZLD, composting, or liquid-fertilizer production, while direct evidence on agricultural soil and crop safety remains limited.

Land application should therefore be undertaken only after treatment performance has been verified against applicable standards and site-specific risks have been assessed. Future research should compare technologies using consistent influent and effluent data and should measure salinity, nutrients, pathogens, heavy metals, soil accumulation, crop uptake, operational costs, energy demand, and long-term agronomic outcomes. Automated monitoring may strengthen quality control, but it should be validated and combined with laboratory testing and regulatory supervision.

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Ethical Approval Statement: This study used a systematic literature review method and therefore did not require ethical approval because it only analyzed secondary data that had been previously published and was publicly available. In addition, the researchers did not conduct direct intervention involving human or animal subjects; therefore, there were no ethical risks in data collection.

Informed Consent Statement: This study used only secondary data derived from previous research articles that had been published in various databases, including Google Scholar, ScienceDirect, and PubMed. This study did not directly involve human subjects for data collection, such as through interviews, observation, or questionnaire completion; therefore, the informed consent procedure was not relevant to be applied.

Data Availability Statement: This systematic literature review used secondary data from published national and international articles. The included-study data and evidence classifications are presented in Tables 1 and 2. Searches were conducted in Google Scholar, ScienceDirect (Elsevier), and PubMed for publications from 2016 to 2026.

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Conflict of Interest: There is no conflict of interest.

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