105 (2026) 106523

Contents lists available at ScienceDirect

Poultry Science

journal homepage: www.elsevier.com/locate/psj

Recent advancements to improve drinking water quality in poultry farms

Karim El-Sabrout [a,*], Giovanni Buonaiuto [b], Damiano Cavallini [b], Birendra Mishra [c]

[a] Department of Poultry Production, Faculty of Agriculture, Alexandria University, Alexandria 21545, Egypt
[b] Department of Veterinary Medical Sciences, University of Bologna, 40064 Bologna, Italy
[c] Department of Human Nutrition, Food and Animal Sciences, University of Hawaii at Manoa, 1955 East-West Road, Honolulu, HI 96822, United States

ARTICLE INFO

Keywords:
Electrolyzed water
Health
ORP
Productive performance
Sustainability

ABSTRACT

Water quality is paramount to poultry health and production, as birds consume approximately twice the amount of water as feed. Poor water quality, characterized by high microbial loads, undesirable pH, or elevated mineral content, can interfere with digestion, reduce bird performance, and decrease the efficacy of water-administered medications and vaccines. Traditional, single-strategy water treatments, such as basic chlorination or simple physical filtration alone, are often insufficient to meet the rigorous biosecurity and performance demands of modern commercial poultry operations. Advanced water-quality improvement approaches and technologies, including acidification (e.g., adding organic acids) and physical treatments (e.g., ionization), are therefore integral to biosecurity and successful water management. Hence, the current review discusses these recent treatments and offers a comprehensive perspective on their integration into sustainable and circular water management strategies in poultry farms, for their widespread commercial adoption. Furthermore, it demonstrates the importance of applying the Precision Livestock Farming strategies on poultry drinking water to ensure optimal water sanitization levels are maintained, thereby guaranteeing consistent water hygiene and directly enhancing overall flock productivity.

Introduction

As industrialization and urbanization accelerate globally, the quality of water resources has deteriorated due to increasing contamination from several pollutants (such as heavy metals, organic substances, nanomaterials, pharmaceuticals, and industrial wastes), posing serious risks to ecosystem integrity and animal/ human health (Wang et al., 2024; Nishmitha et al., 2025). Within poultry production systems, drinking water quality is a multidimensional concept encompassing microbiological safety, physicochemical characteristics (e.g., pH and Oxidation-Reduction Potential (ORP)), and functional attributes (Ejiohuo et al., 2025) that influence water intake, nutrient utilization, and overall flock performance (Ebrahimi et al., 2024). However, improving the quality of drinking water in poultry farms is crucial for bird health, optimal performance, and the reduction of disease transmission, as water is the most essential nutrient for birds, consumed at a rate of 1.5 to 2 times more than feed. It acts as a primary thermoregulatory agent, facilitating heat dissipation through evaporative cooling (panting) to maintain a body temperature of approximately 41°C. Beyond temperature control, water serves as the essential medium for enzymatic reactions and the hydrolysis required for digestion, while simultaneously acting as the vehicle for nutrient transport and the elimination of metabolic waste (uric acid) (Orakpoghenor et al., 2021; Adomako et al., 2024).

Among the various dimensions of water quality, microbiological contamination remains one of the most critical challenges in poultry drinking water systems (Münster and Kemper, 2024). Recent scientific literature has documented different strategies for mitigating enteric pathogens, such as *Escherichia coli* and *Salmonella* species, which frequently contaminate poultry drinking water systems (Mustedanagic et al., 2023; Mantzios et al., 2023; Ogundipe and Obe, 2025). This frequent isolation highlights a significant challenge in maintaining optimal water quality on poultry farms and presents a direct concern for food safety due to the potential for bird colonization and subsequent carcass contamination during processing. Additionally, traditional disinfection processes are inherently limited; therefore, not all methods can successfully eliminate the entire spectrum of pathogenic microbes (Singh et al., 2020). However, recent water-treatment approaches and technologies focus heavily on managing key physicochemical parameters and eliminating microbial contamination. They also focus on a

* Corresponding author.
E-mail address: kareem.badr@alexu.edu.eg (K. El-Sabrout).

https://doi.org/10.1016/j.psj.2026.106523
Received 2 December 2025; Accepted 26 January 2026
Available online 27 January 2026

multi-faceted approach to drinking water quality improvement, moving beyond traditional chlorination to sustainability and efficiency (Ebrahimi et al., 2024; Mohamed et al., 2025; Khattak et al., 2025).

Scientific studies consistently underscore the importance of regular water quality analysis, at the source and the end of the line, to diagnose issues like mineral buildup or biofilm formation (El-Katcha et al., 2018; van Bel et al., 2019; Ebrahimi et al., 2024). Notably, a biofilm is a structured, sessile consortium of microorganisms, including bacteria, fungi, and algae, that adheres to submerged surfaces. Within water distribution systems, these communities develop into a resilient 'slime layer' on pipe interiors, where microbes are shielded by a self-produced extracellular polymeric substance (EPS) matrix (Erdei-Tombor et al., 2024). Implementing protocols like regular flushing of water lines and using cleaning agents between flocks is essential to prevent biofilm reestablishment, which is often accelerated by the organic carriers in additives like vitamins and electrolytes (Ogundipe and Obe, 2025). The impact of physicochemical quality, such as high levels of salts (e.g., sodium, sulfates, chlorides), is continually studied and shown to negatively affect poultry health and performance (Ebrahimi et al., 2024; Raut et al., 2025).

Traditional disinfection methods, such as using chlorine (sodium hypochlorite), remain common, but they face limitations; specifically, prolonged exposure of bacteria to sub-lethal concentrations of chlorine has been linked to the emergence of chlorine tolerance in certain bacterial strains, which, in some cases, may also contribute to cross-resistance to antibiotics, besides these methods present operational challenges for untrained staff and generate hazardous by-products that jeopardize environmental safety (Micciche et al., 2018; Walczak et al., 2025; Wang et al., 2025). Furthermore, relying only on the small amount of disinfectants remaining in the pipes is not enough to manage microbial risks. This is because biofilms in the pipes act as a shield for dangerous bacteria, such as Legionella, which is able to remain in water as free-living planktonic bacteria or to grow within biofilms that adhere to the water pipes, preventing the disinfectant from reaching and killing them. Therefore, some disinfection methods fail to manage the risk when biofilms are present (Sciuto et al., 2021; Siponen et al., 2025).

In parallel, the physicochemical composition of drinking water plays a decisive role in shaping poultry health and performance (Khattak et al., 2025). Elevated concentrations of dissolved salts, such as sodium, sulfates, and chlorides, as well as inappropriate pH levels, have been repeatedly associated with impaired growth, reduced feed efficiency, and increased physiological stress in birds (Ebrahimi et al., 2024; Raut et al., 2025). For this reason, regular monitoring of water quality at both the source and the point of use is strongly recommended to detect mineral buildup, scaling, and early biofilm development before they negatively affect flock performance (El-Katcha et al., 2018; van Bel et al., 2019; Ebrahimi et al., 2024). These observations highlight the need for water treatment strategies that simultaneously address microbiological and physicochemical risks.

Conventional filtration systems like sand filters remain important for removing suspended solids and turbidity. However, to combat emerging contaminants such as microplastics and pharmaceutical residues, advanced treatment technologies are being explored, including enhanced filtration combined with activated carbon, and advanced oxidation processes (Kathi and Mahmoud, 2024; Wang et al., 2024; Puteri et al., 2025; Nishmitha et al., 2025).

Accordingly, recent advancements in poultry drinking water management have shifted toward holistic and multi-barrier approaches that combine microbiological control with optimization of physicochemical parameters. The use of organic acids in drinking water is a common and scientifically supported practice. These weak acids, such as acetic acid, work by lowering the water pH (a target of 6.0 to 6.8 is often preferred) and partially dissociating inside bacterial cells, leading to microbial death (Hamid et al., 2018; Chukwudi et al., 2025). This acidification process not only destroys vegetative pathogens in the water but also continues to work in the bird's digestive tract, lowering the intestinal pH. This in turn enhances protein digestibility, feed conversion, and weight gain, and helps in controlling enterobacteria like *E. coli* and *Salmonella* (Khan and Iqbal, 2016; Metwally et al., 2020).

Similarly, emerging disinfectants such as Slightly Acidic Electrolyzed Water (SAEW), whose main component is hypochlorous acid (HOCl), have been scientifically evaluated as a highly potent, safe, and residue-free disinfectant (Tu et al., 2024; Li et al., 2024). They have demonstrated superior efficacy against a broad spectrum of pathogens, particularly through their ability to disrupt and remove biofilms from water distribution systems (Galgano et al., 2023; de Rezende et al., 2023; Li et al., 2024; Tu et al., 2024; Yue et al., 2024; Zhang et al., 2025). Studies, such as one conducted on laying hens, showed that continuous addition of SAEW with an available chlorine concentration (ACC) of 0.3 mg/L achieved a significantly ($P < 0.05$) higher inhibition rate (99.90%) against bacteria compared to conventional disinfectants (Li et al., 2024). Furthermore, SAEW is effective at reducing intestinal pH, which can enhance mineral digestion and absorption, improving the gut microbiota environment (Hamid et al., 2018; Shi et al., 2025; Zhang et al., 2025).

Chlorine Dioxide (ClO_2) is a powerful oxidizer that is effective against a broad spectrum of pathogens and, critically, at breaking down and eliminating biofilm in water lines. Research has demonstrated that a ClO_2 treatment regimen, starting with a shock treatment to eradicate existing bio-slime followed by a continuous low-concentration treatment, can drastically reduce bacterial populations, leading to improved flock health, reduced disease incidence, and enhanced performance parameters like body weight and feed conversion ratio (Sultan et al., 2014; Yue et al., 2024; Mzinyathi et al., 2025). Peracetic Acid (PAA), a mixture of acetic acid and hydrogen peroxide, is another strong oxidizing agent used to disinfect water lines. It is noted for its ability to eliminate biofilms and effectively control a wide range of waterborne pathogens, thus improving the overall sanitary status and bacteriological quality of the drinking water (Galgano et al., 2023; de Rezende et al., 2023; Ogundipe and Obe, 2025).

Newer technologies are emerging to address the challenges of current contaminants and system inefficiencies, and ensure a reliable and sustainable supply of clean, safe water globally (Table 1). Extensive global research is focused on advancing conventional technologies of water treatment to achieve sustainable, safe production (Elhenawy et al., 2024; Nambi Katu, 2025). The recent advancements, such as water electrolysis, focusing on powerful and targeted disinfection alongside integrated water management, provide the scientific basis for significantly improving the quality of drinking water and, consequently, the health and productivity of poultry flocks (Li et al., 2024; Mohamed et al., 2025). Notably, the strategic application of organic acids is a prevalent technique, as they not only reduce microbial load by lowering the water's pH, optimizing the environment for disinfectants, but also confer benefits to the birds' gut health, such as enhanced nutrient digestibility (Ali et al., 2020; Hamid et al., 2018; Chukwudi et al., 2025) (Table 2). Mechanically, technologies such as ultrafiltration (UF) and reverse osmosis (RO) systems provide robust, physical barriers to remove suspended solids, protozoa, and fine contaminants, ensuring a foundational level of water purity, particularly when using well or surface water sources (Kumar and Baskaran, 2020; Obayomi et al., 2024). More recently, the integration of Precision Livestock Farming (PLF) systems have begun to incorporate real-time water quality monitoring, leveraging sensors to track parameters like pH, temperature, and ORP, allowing for the immediate and automated adjustment of treatment processes to maintain optimal water sanitization, thereby ensuring consistent water quality and improving flock performance (Tzanidakis et al., 2023; Papakonstantinou et al., 2024).

In this context, the current comprehensive review specifically addresses 'water quality' through three primary lenses: microbiological safety (e.g., *E. coli* and *Salmonella* counts), chemical composition (e.g., pH and hardness), and functional attributes (e.g., biofilm prevention and nutrient digestibility). This review has also analyzed the spectrum of

Table 1
Comparative overview of drinking water treatment strategies used in poultry farms.

Treatment/ Approach	Mechanism/Process	Effectiveness & Outcomes	Additional Notes/ Impacts	References
Chlorination (Chlorine, NaDCC)	Addition of chlorine-based compounds (e.g., sodium dichloroisocyanurate, sodium hypochlorite) to waterlines for disinfection.	- Reduces *E. coli, Salmonella, S. aureus*, and molds in waterlines. - At 30–50 mg/L NaDCC, a significant reduction in harmful bacteria and improved broiler performance. - Chlorinated water reduces cecal bacteria and *Salmonella* contamination. - However, biofilm can reestablish by end of grow-out, and byproducts may be harmful.	- 30 mg/L NaDCC recommended for cost-effectiveness. - Byproducts of conventional chlorination can be harmful to animals.	(Mustedanagic et al., 2023), (Zou et al., 2023), (Wang et al., 2023), (Raut et al., 2024), (Edet et al., 2024)
Hydrogen Peroxide (H_2O_2)	Oxidative sanitizer; breaks down to water and oxygen, suitable for high organic matter.	- Residuals up to 100 ppm are safe for birds. - Improved body weight gain and feed conversion ratio. - Enhanced amino acid digestibility. - Rapid antimicrobial action.	- No negative impact on early bird performance. - Used for cleaning water with high organic content.	(Mustedanagic et al., 2023), (Biswas et al., 2025)
Peracid-based Sanitizers (PAB)	Use of peracetic acid and related compounds for waterline sanitation.	- Superior efficacy against *Salmonella, E. coli*, and *Bacillus* (planktonic and biofilm forms) compared to peroxide- and hypochlorite-based sanitizers. - Eliminated biofilms at MIC in mixed-species cultures.	- Recommended for pre-harvest pathogen control and food safety.	(Ogundipe and Obe, 2025)
Electrolyzed Water (EW/SAEW/ NEW)	Electrolysis produces water with antimicrobial properties (slightly acidic or neutral pH, available chlorine).	- Up to 3% NEW (12 mg Cl/L) improved water quality, reduced *E. coli*, and lowered mortality. - SAEW (0.3 mg/L ACC) showed 99.9% inhibition rate, superior to conventional methods. - Improved feed conversion, daily gain, and reduced feed gain ratio. - No adverse effects on egg/meat quality or bird health.	- SAEW is residue-free, energy-efficient, and has sustained antimicrobial effect. - Recommended for daily management.	(Rahman et al., 2023), (Li et al., 2024)
Physical Flushing	High-pressure water or air is used to flush waterlines.	- Convenient and quick, but must be repeated frequently. - High utility costs, labor, and low biofilm removal.	- Often combined with chemical disinfectants for better results.	(Mustedanagic et al., 2023), (Edet et al., 2024)
Combined Chemical & Mechanical	Chemical (ClO_2, peracetic acid) plus mechanical (high-pressure air pump) treatment.	- Did not reduce aerobic mesophilic counts below acceptable limits. - No significant reduction in Enterobacteriaceae or Pseudomonadaceae. - Specialized contractors are more effective than farmers.	- Regular monitoring and consistent treatment are crucial.	(Mustedanagic et al., 2023)
Water Ionization/ Electrolysis	Electric field or electrolysis modifies water chemistry (pH, ORP, mineral content).	- Ionized water (negative ORP, lower TDS) increased water intake, body weight, antioxidant capacity, and reduced DNA damage. - Enhanced growth hormone and IGF-1 expression.	- Recommended for improving productivity and health.	(Khalil et al., 2025)
Slightly Acidic Electrolyzed Water	Continuous addition to waterlines (0.3 mg/L ACC).	- Higher inhibition rate (99.9%) and sustained effect compared to conventional methods. - Improved egg weight, yolk color, fecal normal rate, and reduced water footprint. - No negative impact on eggshell quality.	- Easy preparation, residue-free, energy-efficient. - Recommended for daily use.	(Li et al., 2024)
Water Quality Monitoring & Management	Regular testing and adjustment of water parameters (pH, TDS, minerals, microbial load).	- Essential for maintaining bird health, immune competence, and productivity. - Poor water quality can exacerbate disease and reduce vaccine effectiveness. - Microbial contamination increases along distribution system, especially in warm seasons.	- Targeted monitoring and management are necessary. - Clean water supports vaccine efficacy and flock health.	(Farooq et al., 2025), (Farooq et al., 2026), (Boas et al., 2025), (Ogundipe et al., 2025)
Advanced Wastewater Treatment	Advanced oxidation processes, constructed wetlands, and membrane filtering.	- Designed to reduce antibiotic residues and ARGs in poultry wastewater. - More effective than conventional methods for ARG reduction.	- Important for environmental protection and AMR control.	(Aminudin et al., 2026)
Water Conservation & Reuse	Rainwater harvesting, water recycling, and automated systems.	- Reduces reliance on freshwater, environmental impact, and operational costs. - Modern systems have reduced water use in poultry production.	- Supports sustainability in poultry farming.	(Bist et al., 2024)

NaDCC: Sodium Dichloroisocyanurate; TDS: total dissolved solids; ORP: Oxidation-reduction potential; MIC: Minimum Inhibitory Concentration; SAEW: Slightly Acidic Electrolyzed Water; NEW: Neutral Electrolyzed Water; AMR: Antimicrobial Resistance; ARG: Antibiotic Resistance Gene.

Table 2
Summary of studies on the effects of organic acids in poultry drinking water.

Species	Dose or concentration[1]	Reported beneficial effects[2]	References
Broiler, Ross 308, 1-42 days	OAB, 2 ml/L	Bp	Saad et al., 2024
Broiler, Ross 308, 1-42 days	OAB, 480 mmol/L	Cc	Szott et al., 2022
Broiler, Ross 308, 1-35 days	OAB, 0.2 ml/L	SC	Ferreira et al., 2022
Broiler, Arbor Acres, 1-42 days	OAB, 2%	WI,	Zhang et al., 2022
Broiler, Arbor Acres, 1-42 days	OAB, 0.05, 0.10, 0.15, 0.20%	BW, DWG, WI	Guo et al., 2021
Broiler, Arbor Acres, 1-42 days	HMTB, 0.05, 0.10, 0.15, 0.20%	BW, DWG, WI	Guo et al., 2021
Broiler, ISA JA57, 1-42 days	Fa, 2 and 3%	FI, CY	Al-Mutairi et al., 2020
Broiler, ISA JA57, 1-42 days	Ba, 2 and 3%	FI, CY	Al-Mutairi et al., 2020
Laying hens, Isa Brown, 20-48 weeks	OAB, 1 ml/L	EcC, BW, Eq	Bouassi et al., 2020
Broiler, Arbor Acres, 1-35 days	Fa, 1%	WG, WI	Metwally et al., 2020
Broiler, Arbor Acres, 1-35 days	La, 1%	WG, WI	Metwally et al., 2020
Broiler, Arbor Acres, 1-35 days	Pa, 1%	WG, WI	Metwally et al., 2020
Broiler, Arbor Acres, 1-35 days	Ca, 1%	WG	Metwally et al., 2020
Broiler, Arbor Acres, 1-35 days	OAB, 1%	WG, WI	Metwally et al., 2020
Broiler, Cobb 500, 1–35 days	Fa, 1 ml/L	SC	Bourassa et al., 2018
Broiler, Lohmann, 1-49 days	Acv, 10, 20, 30 ml/L	Ci	Hayajneh et al., 2018
Broiler, Cobb 500, 1–35 days	OAB, 4 ml/L	BW, BSAA	El-Katcha et al., 2018
Broiler, Cobb 500, 1–35 days	Ca, Nr	BW, FCR	Abdelrazek et al., 2016
Broiler, Cobb 500, 1–35 days	Aa, Nr	BW	Abdelrazek et al., 2016
Broiler, Ross 308, 1-42 days	OAB, 0.35 ml/L	FI, DWG, EcC,	Eftekhari et al., 2015
Broiler, Hubbard, 22-42 days	OAB, 0.5, 1, 1.5 and 2 ml/L	BW, FCR, CY, EcC, SC	Sultan et al., 2015
Broiler, Ross 308, 1-42 days	OAB, 0.5%	FI, FCR, Sr, Bp	Marin Flamand et al., 2014
Laying hens, Hy-Line W-98, 68-76 weeks	Fa, 0.5, 1 and 1.5 ml/L	Ep, EW, FCR, Eq	Abbas et al., 2013
Broiler, Ross 308, 1-42 days	Ha, 150, 300 and 450 ppm	DWG, FI, Mc, Mmc	Ozturk et al., 2010
Egg-type chicken, 2-21 days	Ma, 0.05, 0.10, 0.15%	EcC	Moharrery and Mahzonieh, 2005
Broiler, Ross, 1-56 days	Ma, 0.05, 0.10, 0.15%	EcC	Moharrery and Mahzonieh, 2005

[1] OAB: Organic Acid Blend; OIAB:Organic and Inorganic Acid Blend; Fa: Formic acid; BA: Butyric acid; PA: Propionic acid; Acv: Apple cider vinegar; Ha: Humic acid; Ma: Malic acid; La: Lactic acid; Ca: Citric acid; Aa: Acetic acid; Sa: Salicylic acid; Ta: Tartaric acid; HMTB: 2-hydroxy-4-methylthiobutyric acid;.

[2] BW: body weight; FCR: Feed conversion rate; CY: carcass yield; EcC: *E. coli* count, SC: Salmonella count; BSAA: blood serum antioxidant activity; Bp: Blood parameters; Cc: *Campylobacter* counts; FI: Feed intake; Ci: Coccidiosis infestation; Sr: Survival rate; DWG: Daily weight gain; Mc: Meat color; Mmc: Meat mineral composition; WI: Water intake; WG: Weight gain; Ep: Egg production; EW: Egg weight; Eq: Egg quality.

existing and emerging strategies for optimizing poultry drinking water quality. It details the efficacy and application of conventional chemical treatments, including various forms of chlorination and acidification, alongside advanced physical and oxidative approaches such as ionization and ozonation systems. The findings underscore that a multi-barrier approach, tailoring treatment to the specific source water challenges, yields the most reliable results for preventing biofilm formation and pathogen transmission. Ensuring this optimal water quality is paramount for flock health, welfare, and productivity, directly impacting feed conversion ratios and disease management efforts. Additionally, this review will serve as a valuable resource for water-treatment systems in poultry farms, offering structured comparisons of efficacy, cost-effectiveness, and operational complexity. Moving forward, continued industry focus must shift toward sustainable, automated, and sensor-driven monitoring solutions to ensure real-time water parameter stability and support the long-term economic viability of poultry production globally.

Traditional approaches for water quality improvement

Prior to the widespread implementation of modern water-testing equipment, physical treatments, and automated watering systems, poultry farmers depended on a variety of traditional methodologies to ensure the water provided to their birds was safe, clean, and conducive to healthy growth. These practices were fundamentally grounded in practical experience, acute observational skills, the utilization of natural materials, and preventive hygiene measures. Although these traditional approaches may have lacked the precision and scientific rigor of contemporary techniques, they frequently proved effective in reducing the incidence of waterborne diseases and enhancing the productivity of small-scale and backyard poultry operations, particularly in rural and resource-limited contexts (Chander et al., 2012; Schneider et al., 2016; Ebrahimi et al., 2024; Bist et al., 2024; Nambi Katu, 2025); noting that while larger conventional poultry growers increasingly adopt advanced membrane technologies, such as RO, traditional approaches like chlorination and mechanical filtration remain the foundational standards for water quality improvement. The traditional practices employed for water quality control in poultry farms can be categorized into several key areas, as follows.

Chlorination and disinfection

Chlorine-based disinfection is a widely adopted, cost-effective, and broad-spectrum antimicrobial practice in animal husbandry (Tyski et al., 2024; Slattery and Garvey, 2025). The primary disinfecting agent is hypochlorous acid (HOCl), which is formed when chlorine sources, such as sodium hypochlorite (NaOCl), are introduced to water. The efficacy of chlorine, however, is highly dependent on water pH, as HOCl is the most potent sanitizer and is predominant at lower pH values (e.g., pH 4.5 to 6.0), while the less effective hypochlorite ion (OCl^-) is favored at alkaline pH (Yaqub et al., 2021; Raut et al., 2024). Notably, the germicidal efficacy of (OCl^-) is estimated to be approximately 80 to 100 times lower than that of HOCl because its negative electrical charge is repelled by the similarly charged lipid bilayer of bacterial cell walls, which hinders penetration and slows the oxidation of internal cellular components (Giarratana and Reiner, 2022; Sil et al., 2025). Consequently, to maximize biocidal efficiency and control biofilms, water must be acidified to a range of pH 6.0–7.0, shifting the chemical equilibrium toward the more reactive HOCl form. However, recent studies confirm that treating drinking water with sodium hypochlorite can significantly ($P < 0.05$) reduce bacterial contamination, subsequently leading to a decrease in performance-inhibiting issues for chickens (Raut et al., 2024; Li et al., 2025). A recommended range for a free chlorine residual in poultry drinking water is typically 2-5 ppm at the drinker line to inhibit microbial growth (Maharjan et al., 2016; Raut et al., 2024). High concentrations of free chlorine residual (e.g., 20 ppm or more) can negatively impact water consumption due to palatability issues.

Acidification

Water acidification involves adding organic (e.g., formic, lactic, or citric acid) or inorganic acids (e.g., phosphoric or sulfuric acid) to the drinking water to maintain a pH typically between 3.8 and 4.5 (Abdelrazek et al., 2016; Al-Mutairi et al., 2020; Arce-Menocal et al., 2021). This method is beneficial for poultry health and performance through several scientific mechanisms. Firstly, the lowered pH creates an unfavorable environment for the growth of pathogenic bacteria like *Escherichia coli* and *Salmonella spp*. in the water line, an effect which can be synergistically combined with sanitizers like chlorine (Hreško Šamudovská et al., 2018; Ali et al., 2020; Zhang et al., 2022). Secondly, water acidification can decrease the pH of the intestinal tract, which favors the growth of beneficial gut microbiota and can improve the activation of digestive enzymes, such as pepsin, leading to enhanced nutrient utilization and overall performance (Ali et al., 2020; Zhang et al., 2025). Experimental studies have demonstrated that the combination of acidifiers and sanitizers is more effective in improving body weight gain and feed conversion ratio in broilers than either treatment alone (Adil et al., 2020; Sharifuzzaman et al., 2025).

Flushing

Flushing is a mechanical water management practice involving the rapid movement of water through the drinking lines, primarily serving to physically remove deposits, sediment, and organic matter (Mustedanagic et al., 2023; LeChevallier et al., 2024). This procedure is crucial for controlling the development of biofilm. Biofilms harbor pathogenic and opportunistic bacteria, such as *Pseudomonas* spp. and *Campylobacter* spp., and continually contaminate the drinking water (van Bel et al., 2019; Waegenaar et al., 2025). Regular flushing, ideally daily during the starter period and at least one to two times per week afterward, is essential to minimize biofilm buildup and maintain water quality (Suchomel et al., 2013; LeChevallier et al., 2024). Furthermore, high-pressure flushing is a core component of the thorough cleaning and sanitation protocol between flocks, often utilized in conjunction with chemical cleaners (acid and base) to remove both organic debris and mineral scale, thereby ensuring that chemical disinfectants can effectively reach and inactivate any remaining microorganisms (Jafari et al., 2024; Waegenaar et al., 2025).

Recent technologies for water quality improvement

In response to current water quality challenges, particularly the contamination in some regions, the poultry industry has experienced substantial technological progress in recent years, with innovative water treatment approaches complementing refinements in traditional practices. These advancements encompass a wide spectrum of technologies, including physical treatment systems and intelligent monitoring & control platforms. The following sections provide a detailed overview of these recent and emerging technologies, synthesizing current evidence and emphasizing innovations that are transforming water quality management into modern poultry facilities.

Advanced water treatment integration now utilizes Advanced Oxidation Processes (AOPs) to achieve the mineralization of recalcitrant organic pollutants through hydroxyl radical generation. This is often complemented by nanotechnology, which exploits the high specific surface area of engineered nanomaterials for selective molecular adsorption. Furthermore, advanced membrane filtration, specifically Nanofiltration (NF) and RO, provides critical desalination and solute rejection through a combination of size-exclusion and solution-diffusion mechanisms (Cardoso et al., 2021; Kurian, 2021; Kumari and Kumar, 2023).

Filtration systems

Filtration remains one of the most universally applicable physical water treatment methods, serving as the first line of defense against suspended solids, sediments, and particle-associated microorganisms that can impair water quality (Cescon and Jiang, 2020; Ross et al., 2025). It also helps prevent operational issues within drinking water distribution networks. Traditional sand and multimedia filtration systems continue to play a key role in water management, achieving removal efficiencies of 85-95% for particles larger than 10 μm (Puteri et al., 2025). These conventional filters have evolved considerably through the adoption of automated backwashing mechanisms, which reduce labor requirements while maintaining consistent filtration performance during extended operation (Piche et al., 2019). Such automation is particularly valuable in large-scale commercial settings, where manual maintenance would be economically and logistically unfeasible.

Filtration systems serve as a critical defense against operational failure in poultry drinking water systems by mitigating the accumulation of suspended solids, mineral scale, and biological fouling. Scientifically, unfiltered water acts as a carrier for silt and sand that mechanically interfere with the precision seating of nipple drinker pins, resulting in "leakers" that increase litter moisture and ammonia emissions (Piccirillo et al., 2024; Ibrahim et al., 2025). Furthermore, these particulates provide a physical substrate for the attachment and proliferation of biofilms—complex communities of microorganisms such as *E. coli*—which can restrict flow and harbor pathogens (Maes et al., 2019; Ogundipe et al., 2024). High mineral content, specifically calcium and magnesium, leads to the precipitation of $CaCO_3$ (scale), which narrows pipe diameters and reduces the volumetric flow rate available to the flock during peak metabolic demand (Watkins, 2018). By removing these abrasive and reactive elements, filtration maintains the structural integrity of the delivery system and ensures the biochemical stability of administered vaccines and medications, which might otherwise be inactivated by mineral binding or oxidation (Saleh et al., 2023).

The introduction of membrane-based filtration technologies has further expanded the capabilities of physical water treatment (Shehata et al., 2023). Microfiltration systems, operating with pore sizes from 0.1 to 10 μm, effectively remove bacteria, protozoa, and suspended solids from source water (Bottino et al., 1991). These systems are especially beneficial in poultry farms that rely on surface water sources characterized by high bacterial loads and variable turbidity. Ultrafiltration, employing membranes with pores between 0.01 and 0.1 μm, provides enhanced removal of viruses, colloidal particles, and macromolecular compounds (Shehata et al., 2023).

Nanofiltration and reverse osmosis (RO) technologies, although less commonly implemented due to their higher capital and operational costs, are increasingly used in facilities facing severe water quality issues (Azmi et al., 2025). Nanofiltration membranes (0.001-0.01 μm) effectively remove multivalent ions, dissolved organic matter, and trace contaminants commonly present in groundwater and surface water (Mohammad et al., 2015; Boo et al., 2018). RO systems provide the highest purification level among pressure-driven membrane processes, achieving up to 99% removal of dissolved solids, salts, and a wide range of contaminants (Tayeh, 2024). In poultry operations where source water exhibits excessive hardness, high total dissolved solids (TDS), or contamination by agricultural chemicals (Saleh et al., 2023), RO can transform marginal water sources into potable supplies suitable for birds. Modern agricultural RO systems are now equipped with energy recovery devices and optimized parameters to minimize concentrate production and reduce the environmental footprint of the reject stream (Tayeh, 2024).

The main constraints to broader adoption of advanced membrane technologies in poultry facilities are economic and operational. Membrane systems require higher upfront investment than conventional filtration, and ongoing expenses for cleaning, replacement, and concentrate disposal must be carefully weighed against their performance benefits (Ayach et al., 2024; Osman et al., 2024). Membrane fouling (the unwanted accumulation of organic and inorganic substances, such as fats, proteins, minerals, and microorganisms, on the surface or within the pores of a filtration system) remains a persistent technical challenge, often requiring pretreatment to extend operational lifespan. Nevertheless, continuous improvements in membrane materials and process optimization are driving cost reductions and enhancing system efficiency, making these technologies increasingly viable across diverse scales of poultry production.

Ultraviolet radiation disinfection

Ultraviolet (UV) disinfection is one of the most widely adopted non-chemical water treatment methods, owing to its proven efficacy, operational simplicity, and lack of chemical residues (Ashok and Khedikar, 2016). The germicidal mechanism of UV radiation relies on the absorption of Ultraviolet-C (a specific subtype of ultraviolet light characterized by its short wavelength and high energy) energy (254 nm) by microbial nucleic acids, inducing thymine dimers in DNA and similar photoproducts in RNA (Akhila et al., 2021). These alterations disrupt genetic integrity and inhibit microbial replication. Unlike some chemical disinfectants, UV treatment does not produce viable but non-culturable cells, ensuring complete inactivation of target microorganisms (Görlitz et al., 2024). UV doses of $\geq$40 mJ cm^2 typically achieve >4 log (99.99%) reduction in enteric bacteria, like *Escherichia coli* (González et al., 2023; Moonsub et al., 2024). González et al. (2023) reported that the UV system has been shown to be effective in inactivating microorganisms, but there are concerns about the possibility of reactivation, which compromises the safety of the treated water.

Ozone treatment

Ozone has emerged as an increasingly attractive alternative to conventional chlorination for water treatment, offering powerful oxidizing capacity, broad-spectrum antimicrobial activity, and complete decomposition to molecular oxygen without leaving persistent chemical residues (Kakhki et al., 2021). Ozone exerts antimicrobial effects through direct oxidation of cellular lipids, proteins, and nucleic acids, rapidly inactivating bacteria, viruses, fungi, and protozoa at concentrations much lower than those required for equivalent inactivation by chlorine-based disinfectants (Rosenblum et al., 2012).

Ozone for water treatment is produced on-site, most commonly via corona discharge systems that convert oxygen into ozone through high-voltage electrical discharge (Ebihara et al., 2011). Although on-site generation requires higher initial investment, it eliminates the need for chemical storage, transport, and handling, offering operational and safety advantages appreciated by many producers.

Beyond direct microbial inactivation, ozone is highly effective in biofilm prevention and removal, addressing one of the most persistent challenges in poultry water distribution systems (Bialoszewski et al., 2011). Despite these considerable advantages, ozone treatment systems exhibit several operational and safety considerations. The short half-life of ozone in water (typically 20 min, depending on temperature) means it decomposes rapidly after application, leaving no residual disinfecting capacity within the distribution network (Varol, 2022). As a result, ozone treatment is best suited for systems with short distribution lines or may require supplementary disinfection (e.g., low-level chlorination) to maintain microbial control throughout the system. Water parameters (including pH, temperature, and organic content) strongly influence ozone stability and efficacy (Galdeano et al., 2018). Therefore, baseline water quality characterization and periodic monitoring are essential for ensuring consistent performance.

Hydrogen peroxide

Hydrogen peroxide (H_2O_2) has gained increasing prominence as an alternative disinfectant for poultry drinking water due to its strong oxidative properties, broad-spectrum antimicrobial activity, and environmentally benign decomposition products (Biswas et al., 2025). Its mode of action involves the generation of reactive oxygen species (ROS), particularly hydroxyl radicals, which oxidize lipids, proteins, and nucleic acids, leading to microbial cell death (Abdelshafy et al., 2024). In aqueous systems, these radicals are produced through iron-catalyzed decomposition reactions that impart strong biocidal potential against bacteria, fungi, and viruses. Food-grade hydrogen peroxide, typically supplied as a 35% solution and diluted to 25–50 mg/L in drinking water, provides effective microbial control while decomposing completely into water and oxygen, leaving no harmful residues or halogenated by-products (Clark et al., 2009).

From an operational standpoint, hydrogen peroxide offers several advantages compared with chlorine-based disinfectants. It demonstrates superior storage stability when protected from light and stored in opaque, chemically compatible containers, thereby ensuring consistent dosing over extended periods (Madanská et al., 2004). Furthermore, stabilized formulations, often enhanced with silver ions or metal catalysts, extend antimicrobial activity and permit lower effective concentrations, improving cost efficiency without compromising biocidal performance (Davoudi et al., 2012; Martin et al., 2015). Despite these advantages, potential safety concerns associated with excessive hydrogen peroxide exposure should be recognized. Reactive hydroxyl radicals can induce oxidative stress and tissue injury in animals at elevated concentrations. Experimental studies on some livestock, including birds, have shown that H_2O_2 exposure can impair intestinal morphology and barrier function (Yin et al., 2015; Romeu et al., 2023; Zhong et al., 2023). Similarly, intraperitoneal administration of H_2O_2 in broilers increased oxidative stress biomarkers such as reactive oxygen species and malondialdehyde while reducing antioxidant defenses, including glutathione peroxidase activity (Chen et al., 2021). These findings underscore the need to maintain free residuals within the EPA-recommended range of 25-50 ppm to ensure microbial safety without adverse physiological effects.

Recent field observations suggest that the inclusion of hydrogen peroxide in poultry drinking systems at practical concentrations does not significantly affect growth performance or amino acid digestibility during early grow-out stages (Biswas et al., 2025). Hydrogen peroxide–based disinfectants generally exhibit limited biofilm penetration and removal capacity compared with ozone or chlorine dioxide. In systems where biofilm accumulation is already established, this limitation may necessitate mechanical cleaning, high-concentration shock treatments with alternative oxidants, or complete system sanitization before routine peroxide-based disinfection can be implemented (Chowdhury et al., 2025). Regular monitoring of hydrogen peroxide residuals, although less common than chlorine residual testing due to the lack of simple field methods, provides valuable assurance of system performance and early detection of organic overload or equipment malfunction that could impair disinfection efficacy (Maharjan et al., 2015; Han et al., 2025). However, systematic studies addressing its physiological and zootechnical impacts remain limited and warrant further investigation.

Emerging physical technologies

Beyond the previous systems, several innovative physical water treatment technologies are under development for water applications. They represent the foundational approach to improving water quality in poultry operations. They primarily function through the mechanical removal of particulate matter, turbidity, and microbial contaminants without the addition of chemical substances (Cho and Kim, 2022). These technologies have gained significant attention, particularly in production systems where regulations restrict the use of chemical disinfectants or where compliance with organic certification standards is required.

Non-thermal plasma

Non-thermal plasma (NTP), often called "cold plasma," is an emerging technology in water treatment that functions as a highly potent Advanced Oxidation Process (AOP) (Barjasteh et al., 2021;

Santalunai et al., 2025). Unlike traditional boiling (which uses heat) or chlorination (which uses chemical additives), NTP uses high-voltage electricity to ionize gas near or within water, creating a state of matter rich in highly reactive particles. It is one promising approach, producing reactive oxygen and nitrogen species through electrical discharges that create a partially ionized gas near ambient temperature (Yang et al., 2023). These species (including hydroxyl radicals, ozone, hydrogen peroxide, and nitrogen oxides) exert potent antimicrobial activity via membrane oxidation, protein denaturation, and DNA disruption (Yang et al., 2023). Cold atmospheric plasma can be applied directly to water surfaces or within flow-through reactors, offering flexibility in design (Velasquez et al., 2024). Preliminary studies have shown promising results for biofilm control and degradation of emerging contaminants, though commercial systems tailored for continuous water treatment remain at an early stage (Kumar et al., 2021). Further optimization is required regarding energy efficiency, system scalability, and safety management related to reactive species production.

Magnetized water

Magnetized water (MW) involves passing water through a magnetic field, which theoretically alters the physical properties of the water, such as potentially reducing the size of water molecule clusters, increasing its solubility for nutrients and minerals, and raising the pH to a slightly alkaline level (El-Sabrout and El-Hanoun, 2019; Kırkpınar et al., 2023). MW treatment represents a non-chemical and increasingly studied approach aimed at improving water quality and animal performance through the application of magnetic fields to drinking water systems (El-Sabrout and El-Hanoun, 2019; Ahmed and El-Hamed, 2020). The process relies on exposing water to a static or electromagnetic field (typically generated by neodymium, iron, or boron magnets) either as the water flows through magnetic tubes or by immersing a magnetized device directly into the water (Cho and Lee, 2005; Amiri and Dadkhah, 2006; Mohammadnezhad et al., 2022). These magnets are usually coated with protective layers such as epoxy, nickel, or copper to prevent corrosion and maintain stability under acidic conditions. During magnetization, the strength of the magnetic field and the configuration of the magnetic device (e.g., linear or circular arrangement) determine the degree of induced water modification (Zaidi et al., 2014). Water is generally passed through the magnetic field at a controlled, low velocity to ensure sufficient exposure and minimize turbulence (Sanchez et al., 2025). In some systems, the water circulates in a closed loop for repeated exposure, maintaining the induced magnetic properties for several hours after treatment, typically between 6 and 12 h, although residual effects can persist for longer depending on the system design (Hassan et al., 2018). The magnetization process is proposed to alter several physicochemical characteristics of water. Exposure to magnetic fields can reduce the clustering of water molecules by weakening hydrogen bonding, leading to smaller molecular aggregates with greater mobility and solubility potential (Otsuka and Ozeki, 2006; Cai et al., 2009). Magnetically treated water also exhibits reduced surface tension, which may enhance penetration and diffusion across cellular membranes (Moussa et al., 2025). Collectively, these changes could improve hydration, nutrient transport, and metabolic efficiency in biological systems (Shamsaldain and Rawee, 2020). In practice, magnetization systems are typically installed inline within the water distribution network, allowing the continuous passage of water through a magnetic field before reaching the drinkers (Moussa et al., 2025). Reported effects include reduced scale formation due to altered calcium carbonate crystallization, enhanced dissolution of minerals, and improved hydration and metabolic efficiency in livestock (Shamsaldain and Rawee, 2020; Youssef, 2025).

Studies indicate that MW can positively influence poultry production by enhancing growth rate, feed efficiency, immunity, and egg quality, while also reducing the incidence of certain pathogenic microbes (El-Hanoun et al., 2017; Jassim and Aqeel, 2017; El-Sabrout and Hanafy, 2017; Soliman et al., 2021). These technologies represent emerging, eco-friendly alternatives to conventional chemical sanitization, focusing on optimizing the water's structure and intrinsic properties to support animal health and productivity. The main findings from published studies on the use of magnetized drinking water in poultry are summarized in Table 3, highlighting reported effects on growth performance, feed efficiency, hematological traits, and antioxidant status.

Several studies have examined the magnetization effects on water and feed intake, growth performance, carcass characteristics, hematological and biochemical parameters, reproductive performance, and egg quality across different bird species and experimental conditions (Mahmoud et al., 2017; Radha and Sardary, 2021; Yusuf et al., 2022). Notably, El-Hanoun et al. (2017) found that geese given MW at 4000 gauss exhibited increased ($P < 0.05$) water intake compared with birds consuming untreated water. Conversely, Al-Mufarrej et al. (2005), Al-Fadul (2006), and Mahmoud et al. (2017) observed reduced water consumption in broilers when MW was supplied, which McMahon (2009) attributed to modifications in surface tension, viscosity, and solubility that affect hydration behavior. Regarding feed intake, Gholizadeh et al. (2008) and Kırkpınar et al. (2023) reported that MW increased feed intake in broilers, whereas Al-Hassani and Amin (2012) found no significant differences in Cobb-500 chicks treated with MW at 500 gauss for 5-15 min. However, El-Katcha et al. (2018) noted a numerical increase in feed intake in broilers when MW treatment was repeated every six hours. The impact on body weight gain has been generally positive. Mahmoud et al. (2017) observed improved weight

Table 3
Summary of studies on the effects of magnetized water on poultry species.

Species	Magnetic field strength	Reported beneficial effects[1]	References
Broiler	10000 G	Lq, Aq	Yusuf et al., 2022
Laying hens	1000 G	Ue, Ss, St, Eq, ECC	Radha and Sardary, 2021
Laying hens	1500 G	Ue, Ss, St, Eq, ECC	Radha and Sardary, 2021
Laying hens	2000 G	Ue, Ss, St, Eq, ECC	Radha and Sardary, 2021
Broiler	13,200 G	EcC, BW, FCR	Soliman et al., 2021
Japanese Quail	500 G	Bp	Al-Hilali, 2018
Japanese Quail	1000 G	Bp	Al-Hilali, 2018
Broiler	NR	BW, FCR, Bp	El-Katcha et al., 2018
Laying hens	2000 G	EW, FCR, BW, Eq, Bp	Hassan et al., 2018
Laying hens	3000 G	EW, FCR, BW, Eq, Bp	Hassan et al., 2018
Egyptian male geese	4000 G	Bp, AI, SQ	El-Hanoun et al., 2017
Egyptian female geese	4000 G	BW, Ep, FCR, WI, Ef; H, Eq, Cp	El-Hanoun et al., 2017
Pekin ducks	NR	Bp	El-Katcha et al., 2017
Broiler	NR	BW, FI	Mahmoud et al., 2017
Broiler	1000 G	Bp	Jassim and Aqeel, 2017
Broiler	500 G	BW, FI, CY,	Al-Hassani and Amin, 2012
Broiler	5000 G	BW, Ci	Elmusharaf et al., 2010
Broiler	500 G	WI	Al-Mufarrej et al., 2005

[1] Lq: litter quality; Aq: Air quality; St: Shell thickness; Bp: Blood parameters; Ep: Egg production; Ef; Egg fertility; H: Hatchability; Cp: Chicks performances, M: Mortality; BW: Body weight, FCR: Feed conversion rate; CY: carcass yield; EcC: *E. coli* count, Ci: Coccidiosis infestation;; EW: Egg weight; Ue: Undesirable egg%; Ss: Shell strength; ECC: Egg Chemical Composition; AI: Antioxidant indices; SQ: Semen quality; NR: Not reported.

gain in Sasso broilers. Likewise, Baker et al. (2024) found that magnetization of drinking water significantly ($P < 0.025$) enhanced the growth rate and final body weight of broiler chickens. Moreover, El-Katcha et al. (2017) reported improved growth performance in Pekin ducklings and final body weight increases of approximately 19.6% in geese receiving MW, respectively. According to Gholizadeh et al. (2008), broilers consuming MW (6000 gauss) yielded about 200 g more meat than controls. Nonetheless, some studies found no significant differences, as reported by Al-Hassani and Amin (2012) and El-Katcha et al. (2018), who noted that repeated MW treatment produced only minor, non-significant gains in final weight and feed efficiency. Such discrepancies have been attributed to differences in strain, magnetization strength, water flow rate, and device type (Mahmoud et al., 2017). Feed conversion ratio (FCR) has shown consistent improvement under MW treatment, with significant reductions reported by Mahmoud et al. (2017) in broilers and by El-Hanoun et al. (2017) in geese. However, El-Katcha et al. (2017 and 2018) observed that repeated MW treatment only numerically improved FCR, protein efficiency ratio, and performance index in broilers and ducks. Livability and mortality responses to MW are variable: Gholizadeh et al. (2008) noted reduced mortality in MW-treated broilers, whereas Mahmoud et al. (2017) found slightly higher mortality (3.27% vs. 2.22%) in MW groups. Keirs et al. (2005) reported that applying a magnetic field reduced mortality by nearly 48% in commercial layers, but Mitre (2018), El-Sabrout and Hanafy (2017), and Al-Hassani and Amin (2012) observed no significant effects on mortality or viability in various poultry strains. Although MW has been proposed to influence liver function and gut physiology, Gilani et al. (2014) observed no significant differences in intestinal or bone morphology between MW-treated and control groups.

Oxidative balance and antioxidant status appear to be positively affected by MW. Shah and Nagarajan (2013), Hafizi et al. (2014), and Ebrahim and Azab (2017) reported decreased malondialdehyde (MDA) and nitric oxide (NO) concentrations, along with increased superoxide dismutase (SOD) activity in tissues of MW-treated birds. El-Katcha et al. (2018) demonstrated that frequent MW treatment significantly ($P < 0.05$) enhanced total antioxidant capacity (TAC) and SOD activity, while reducing hydrogen peroxide levels. Notably, the balance between MDA, SOD, and NO serves as a critical determinant of health and growth performance, particularly under environmental or pathological stress. MDA is a primary byproduct of lipid peroxidation; elevated concentrations indicate severe oxidative damage to cell membranes, which is directly correlated with reduced body weight gain, increased FCR, and compromised intestinal integrity in broilers (Wang et al., 2013; Mishra and Jha, 2019; Mohamed et al., 2025). To counteract such damage, SOD acts as the first line of enzymatic defense by neutralizing superoxide radicals, while NO plays a dualistic role: while basal levels are vital for vasodilation and immunomodulation (Surai et al., 2019; Desbruslais and Wealleans, 2022; Oke et al., 2024).

Furthermore, MW improved immune status by elevating antibody titers against Newcastle disease vaccine at 35 days and reducing total intestinal bacterial counts by approximately 10% in the jejunum and 27% in the colon (El-Katcha et al., 2018). El-Nagar et al. (2024) found that MW (14500 gauss) significantly ($P < 0.05$) reduced total bacterial counts, while Anne et al. (2016) demonstrated that magnetic fields (2-10 mT for 6 h) inhibited *E. coli* growth by up to 82.2%. Elmusharaf et al. (2010) observed that a weak electromagnetic field (5 μT for 30 min/day) protected broilers from coccidiosis, suggesting that MW may serve as an alternative to anticoccidial drugs. Abdel-Azeem et al. (2023) confirmed positive effects of MW (≤1 Tesla) on hematological traits and intestinal villus morphology in Japanese quail. These effects may stem from increased mineral solubility and improved nutrient transport across cell membranes (Attia et al., 2015), along with enhanced water quality and reduced bacterial load (Sargolzehi et al., 2010; El-Nagar et al., 2024).

El-Hanoun et al. (2017) found that MW (4000 gauss) improved hatchability in geese, likely via enhanced immunity and reproductive health. MW also strengthened immune responses and intestinal integrity in Pekin ducks (El-Katcha et al., 2017) and reduced Salmonella prevalence in broilers (El-Katcha et al., 2018). In contrast, Al-Mufarrej et al. (2005) reported no significant effect on immune parameters at 500 gauss. Kırkpınar et al. (2023) documented increased serum total protein and globulin levels in broiler chickens given MW, while Al-Hilali (2018) observed significant ($P < 0.05$) increases in hemoglobin, red and white blood cell counts, and packed cell volume in Japanese quail. Reductions in serum cholesterol, triglycerides, and very-low-density lipoproteins, along with elevated HDL concentrations, indicate improved lipid metabolism and cardiovascular health (Al-Hilali, 2018). These metabolic improvements may be linked to enhanced mineral solubility and oxygen transport, facilitating nutrient utilization and tissue oxygenation (Al-Daraji and Aziz, 2008). Jassim and Aqeel (2017) reported marked decreases in blood glucose, cholesterol, and triglycerides in Ross broilers consuming MW (1000 gauss), while El-Katcha et al. (2017) found that MW increased HDL and reduced LDL in Pekin ducklings. Yacout et al. (2015) also noted higher white blood cell counts, potentially reflecting increased immunoglobulin levels and bone marrow activity. Gilani et al. (2014) confirmed that MW (6500 gauss) caused no adverse blood biochemical changes.

Carcass characteristics were variably affected, as Gholizadeh (2008) observed increased meat fat content, whereas El-Hanoun et al. (2017) reported higher ($P < 0.05$) dressing percentages and reduced abdominal fat in geese receiving MW (4000 gauss), accompanied by improved renal and hepatic function. Kırkpınar et al. (2023) demonstrated that dressing yield can be affected by high magnetization of drinking water, while Al-Mufarrej et al. (2005) reported no significant differences at 500 gauss. Gilani et al. (2014) showed that MW (6500 gauss) enhanced jejunal villus height and muscle layer thickness, suggesting improved nutrient absorption capacity. Reproductive and egg quality parameters also benefit from MW. El-Hanoun et al. (2017) observed increased egg number (+18.7%), egg weight (+4.3%), egg mass (+24.7%), eggshell thickness (+10.5%), and yolk percentage (+8.3%) in geese provided with MW. El-Sabrout and El-Hanoun (2019) reported that field strengths exceeding 1000 gauss per month enhanced eggshell thickness by approximately 9% in hens. Similarly, El-Sabrout and Hanafy (2017) found that MW (14,500 gauss) improved shell quality in Lohmann Brown hens without significantly affecting egg yield, whereas Al-Kuhla et al. (2023) mentioned that MW treatment can increase egg production. El-Sabry et al. (2018) noted higher albumen and yolk heights ($P \leq 0.01$) in eggs from hens given MW (3000 gauss). These findings suggest that MW enhances calcium availability, supporting eggshell formation (Verma, 2011) and maintaining bone calcium and phosphorus balance during laying (El-Sabrout and Hanafy, 2017; El-Sabry et al., 2018). Likewise, Hassan et al. (2018) showed that MW (2000 gauss) improved eggshell strength and overall performance in Gimmizah chickens. Darsi et al. (2017) observed that MW (0.65 Tesla) increased egg strength, possibly through altered limestone solubility. Reproductive traits were also enhanced, Al-Daraji and Aziz (2008) reported improved semen quality and volume in Hy-Line roosters exposed to MW (500-2000 gauss), and El-Hanoun et al. (2017) found that MW (up 4000 gauss) improved geese fertility (+9%), hatchability (+11.6%), and number of hatched goslings alongside elevated estrogen and progesterone concentrations. Collectively, these findings indicate that MW exerts broad physiological and productive benefits in poultry, though variations in experimental design, magnetic field strength, and treatment duration may explain inconsistencies among studies.

Ionized water

The use of ionized drinking water in poultry production, typically referring to alkaline electrolyzed water (AEW), is an emerging practice studied for its potential effects on bird health and productive performance. The ionization process, often achieved via electrolysis, alters the water's physicochemical properties, which are hypothesized to confer biological benefits (Ezzat et al., 2023; Khalil et al., 2025). Notably, ionized water, produced via electrolysis to achieve a slightly alkaline pH and a negative ORP, is suggested to offer antioxidant properties and function as a mild disinfectant, reducing concentrations of pathogenic bacteria, Total Dissolved Solids (TDS), and algae within the water (Mohamed et al., 2025). Scientifically, this is believed to contribute to improved physiological status, health/immunity, and growth performance in poultry, including better feed conversion ratios and higher final body weights (Shihab et al., 2019; Ezzat et al., 2023; Khalil et al., 2025).

Mohamed et al. (2025) demonstrated that ionization processes, particularly electrolysis, can influence key water quality parameters. Scientific literature suggests that the resulting alkaline ionized water often exhibits a negative ORP, indicating antioxidant properties. This altered state is proposed to enhance the water's biological activity and fluid dynamics, theoretically improving its absorption and participation in metabolic processes within the bird. Furthermore, the ionization technique has been associated with a reduction in microbial contaminants such as heterotrophic plate counts, total dissolved solids (TDSs), and algal counts, contributing to a cleaner and safer drinking source for the flock.

Regarding ionized drinking water's impact on birds' performance, several studies, primarily focused on broiler chickens, have investigated the effects of ionized water on performance metrics. Positive results have been reported, including higher final body weights and improved feed conversion ratios (FCR) compared to control groups receiving tap water (Mohamed et al., 2025; Khalil et al., 2025). These improvements are sometimes linked to the alkaline nature of the water, which may positively influence digestive physiology and nutrient metabolism. From an immunological standpoint, the consumption of ionized water has been correlated with enhanced immune responses. Research has shown increases in blood parameters indicative of better health, such as hemoglobin, total protein, globulin, and specific immunoglobulins (IgG, IgM) (Shihab et al., 2019; Mohamed et al., 2025). The negative ORP and associated antioxidant capacity may play a role by contributing to a higher TAC and a reduction in lipid peroxidation markers (like MDA), thereby mitigating oxidative stress and supporting overall physiological resilience against challenges.

However, the question remains: which is better, drinking alkaline or acidic water? According to recent research, a slightly alkaline pH, especially with a negative ORP, from electrolysis devices improves some productive and physiological traits in poultry birds (Jassim and Aqeel, 2017; Shihab et al., 2019; Mohamed et al., 2025). On the other hand, several scientific studies overwhelmingly favor slightly acidic water over alkaline water for enhancing poultry gut health and nutrient digestibility (Zhang et al., 2025; Shah et al., 2025). Acidification of drinking water supports the bird's natural digestive physiology by lowering the pH in the crop and proventriculus, which activates essential proteolytic enzymes like pepsin that require an acidic environment to efficiently break down proteins into absorbable amino acids. Furthermore, a low water pH acts as a chemical barrier against pathogenic bacteria, such as *Salmonella* and *E. coli*, while simultaneously promoting the proliferation of beneficial, acid-tolerant microflora like *Lactobacillus spp.* that improve intestinal morphology (e.g., increased villus height).

Digitization and smart systems

Poultry industry 4.0 technologies refer to the integration of "smart" digital approaches into the poultry value chain to create a highly automated, data-driven, and interconnected production environment. The integration of these technologies is leading to smarter, more adaptive, and efficient water treatment plants. Real-time monitoring & control system uses Internet of Things (IoT) sensors to continuously monitor water quality, flow, and equipment health, allowing for immediate process adjustments. Additionally, Artificial Intelligence (AI) and Big Data are employed for predictive maintenance, optimizing chemical dosing, and managing energy consumption to lower operational costs and improve reliability. Hence, modern PLF strategies have increasingly integrated real-time water quality surveillance as a core component of flock management. By deploying advanced sensors to continuously track critical variables, specifically pH, temperature, and ORP, these systems enable the automated, instantaneous modulation of water treatment protocols. This closed-loop approach ensures optimal sanitization levels are maintained, thereby guaranteeing consistent water hygiene and directly enhancing overall flock productivity (Tzanidakis et al., 2023; Papakonstantinou et al., 2024).

The advancement of PLF technologies signifies a shift from traditional observational management to data-driven proactive interventions, where real-time water quality monitoring serves as a critical biological "early warning system." While the integration of pH, temperature, and ORP sensors is scientifically robust for optimizing sanitization, current research highlights that the majority of these advanced "closed-loop" systems remain in the prototype or early commercialization stages, with widespread literature still focused on experimental rather than large-scale field data (Prakash, 2025; Hassoon et al., 2025). The transition from research to practice is currently hindered by high initial capital costs and technical challenges such as sensor drift, the need for frequent calibration, and rural internet connectivity gaps.

Evaluating the cost-effectiveness and efficacy of treatment strategies

The most common treatment, chlorination, remains popular because it is the cheapest option and provides a "residual" effect that keeps killing germs as water moves through the pipes. However, its efficacy is highly dependent on water pH; if the water is even slightly alkaline, chlorine loses its power. On the other hand, advanced oxidation (like Ozone or UV) is far more effective at killing tough pathogens that chlorine misses, but these systems require a much higher initial investment and offer no protection once the water leaves the treatment device.

Acidification occupies a "middle ground" in terms of cost. While more expensive than basic chlorine, it provides a dual benefit: it sanitizes the water and improves the bird's internal gut health. By lowering the pH, it helps the birds digest protein more efficiently and creates an environment where "bad" bacteria like Salmonella cannot survive. For producers, the extra cost of the acid is often recovered through better feed conversion ratios (FCR) and a reduced need for expensive antibiotics.

Advanced technologies like ionization and PLF sensors involve the highest upfront costs but offer the most consistency. Ionization is increasingly valued for its ability to reduce physiological stress in birds, which can lead to higher meat yields. Meanwhile, PLF tools (like real-time pH and ORP sensors) act as an insurance policy. By providing 24/7 monitoring, they prevent "silent" failures in water quality that typically go unnoticed with manual testing, ensuring that the money spent on treatments is actually resulting in clean water at the drinker line.

Ultimately, the most cost-effective strategy for a modern poultry farm is rarely a single treatment, but an integrated approach. Combining low-cost filtration with precision dosing of acids or sanitizers ensures the highest level of biosecurity. While the initial price tag for these technologies is higher, the long-term economic return is found in more uniform bird weights, lower mortality rates, and more sustainable water use, making them essential for high-performance commercial operations.

Conclusion

Improving poultry drinking water quality is optimally achieved through the integration and synergy of multiple treatment strategies, rather than relying on a single method. A holistic approach recognizes that contaminants often interact and require diverse interventions. For example, using a physical strategy like filtration can effectively reduce suspended solids and microbial load, making subsequent chemical disinfection (e.g., using stabilized chlorine or peracetic acid) more efficient by decreasing the organic matter and biofilms that consume the disinfectant. Concurrently, implementing a nutritional strategy, such as controlled acidifiers, helps to modulate the pH of the water and the bird's gut flora, thereby inhibiting the proliferation of specific pathogens (e.g., Salmonella and *E. coli*) and mitigating the risk of scaling from mineral deposits. This combination, where physical removal enhances chemical efficacy, and biological/chemical modification promotes gut health and inhibits recontamination, results in a multiplicative benefit that far exceeds the sum of the individual contributions, leading to demonstrably improved flock health, performance, and biosecurity. Furthermore, the implementation of advanced electrolyzed water technologies, such as magnetization and ionization, modifies the water's physicochemical characteristics. These changes are believed to confer biological benefits superior to standard tap water, demonstrating the potential to enhance bird health and productivity.

Data availability

The supplementary data can be available from the first and corresponding author upon a reasonable request.

Funding

This research article has no funds.

CRediT authorship contribution statement

Karim El-Sabrout: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Giovanni Buonaiuto:** Writing – original draft, Data curation, Conceptualization. **Damiano Cavallini:** Resources, Formal analysis, Data curation. **Birendra Mishra:** Writing – original draft, Supervision, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Disclosures

The authors declare that there is no known conflict of interest associated with this publication.

Acknowledgments

All the authors of this manuscript are grateful to their respective universities and institutes for their technical assistance and valuable support in completing this review article.

References

Abbas, G., Khan, S.H., Rehman, H., 2013. Effects of formic acid administration in the drinking water on production performance, egg quality and immune system in layers during hot season. Avian Biol. Res. 6 (3), 227–232. https://doi.org/10.3184/175815513X13740707043279.

Abdel-Azeem, A.S., Tantawy, S.S.H., Hassan, H.A., Abdel-Latif, A.M., Elzayat, M.Y.F., Abdel-Azim, A.M., 2023. Effect of magnetized water on blood indices and histomorphometric parameters of intestinal sections of Japanese quail. Anim. Biotechnol. 34 (4), 1331–1341. https://doi.org/10.1080/10495398.2021.2023558.

Abdelrazek, H.M.A., Abuzead, S.M.M., Ali, S.A., El-Genaidy, H.M.A., Abdel-Hafez, S.A., 2016. Effect of citric and acetic acid water acidification on broiler's performance with respect to thyroid hormones levels. Adv. Anim. Vet. Sci. 4 (5), 271–278. https://doi.org/10.14737/journal.aavs/2016/4.5.271.278.

Abdelshafy, A.M., Hu, Q., Luo, Z., Ban, Z., Li, L., 2024. Hydrogen peroxide from traditional sanitizer to promising disinfection agent in food industry. Food Rev. Inter. 40 (2), 658–690. https://doi.org/10.1080/87559129.2023.2191690.

Adil, S., Banday, M.T., Sheikh, I.U., Khan, A.A., Baba, I.A., Zaffer, B., 2020. Effect of water acidification and sanitation on performance, gut microbial population and carcass characteristics of broiler chicken. J. World Poult. Res. 10 (2), 391–396. https://doi.org/10.36380/jwpr.2020.46.

Adomako, K., Kwadwo, T., Benni, D., Kwaning, J., Asante, N., Nyaaba, A., Abdulai, S., Appoh, S., 2024. Effect of different sources of drinking water on the growth performance, carcass characteristics, and hematological indices of broiler chickens. Ghan. J. Anim. Sci. 15 (1), 44–52. https://doi.org/10.4314/gjansci.v15i1.5.

Ahmed, N.H., El-Hamed, N., 2020. Impact of magnetic water treatment technology on water parameters, growth performance and blood parameters of the Nile Tilapia (*Oreochromis niloticus*). Egypt. J. Aquat. Biol. Fish. 24, 645–655. https://doi.org/10.21608/ejabf.2020.126947.

Akhila, P.P., Sunooj, K.V., Aaliya, B., Navaf, M., Sudheesh, C., Sabu, S., Sasidharan, A., Mir, S.A., George, J., Mousavi Khaneghah, A., 2021. Application of electromagnetic radiations for decontamination of fungi and mycotoxins in food products: a comprehensive review. Trends Food Sci. Technol. 114, 399–409.

Al-Daraji, H.J., Aziz, A., 2008. The use of magnetically treated water for improving semen traits of roosters. Al-Anbar J. Vet. Sci. 1, 79–92.

Al-Fadul, M., 2006. The Effect of Magnetically Treated Water and Diet on the Performance of the Broiler Chicks, 2006. Department of Poultry Production, Faculty of Poultry Production, University of Khartoum, Sudan. Master Thesis.

Al-Hassani, D., Amin, G., 2012. Response of some productive traits of broiler chickens to magnetic water. Inter. J. Poult. Sci. 11, 158–160. https://doi.org/10.3923/ijps.2012.158.160.

Al-Hilali, A.H., 2018. Effect of magnetically treated water on physiological and biochemical blood parameters of Japanese quail. Int. J. Poult. Sci. 17, 78–84.

Ali, A.M., Elagrb, H.M., Hamoud, M.M., Gamal, A.M., Mousa, M.R., Nasr, S.A.E., ElShater, M.A.H., Laban, S.F., Zahran, O.K., Ali, M.M., 2020. Effect of acidified drinking water by organic acids on broiler performance and gut health. Adv. Anim. Vet. Sci. 8 (12), 1301–1309.

Al-Kuhla, A.A., 2023. The effect of magnetized water on growth and quality improvement of poultry. J. Glob. Innov. Agric. Sci. 11, 607–610. https://doi.org/10.22194/JGIAS/23.1097.

Al-Mufarrej, S., Al-Batshan, H., Shalaby, M., Shafey, T., 2005. The effects of magnetically treated water on the performance and immune system of broiler chickens. Inter. J. Poult. Sci. 4, 96–102.

Al-Mutairi, H.M.S., Hussein, E.O.S., Jar El Nabi, A.R., Swelum, A.A., Abd El-Hack, M.E., Taha, A.E., Al-Mufarrej, S.I., 2020. Does the consumption of acidified drinking water affect growth performance and lymphoid organs of broilers? Sustainability 12 (8), 3093. https://doi.org/10.3390/su12083093.

Aminudin, M., Amalina, F., Ab Hamid, M., Sulaiman, S., Azfa, N., Razak, A.S., 2026. Environmental and public health risks of antibiotic resistance gene pollution in poultry systems: sustainability impact, transmission pathways, and mitigation strategies. Microbe, 100658. https://doi.org/10.1016/j.microb.2026.100658. In press.

Amiri, M.C., Dadkhah, A.A., 2006. On reduction in the surface tension of water due to magnetic treatment. Colloids Surf. A Physicochem. Eng. Aspects 278 (1), 252–255.

Anne, T., Francis, N., Silas, K., 2016. Effects of magnetic flux density on the population of Escherichia coli in river Njoro water. Int. J. Phys. 4, 113–118.

Arce-Menocal, J., Roa-Flores, M., López-Coello, C., Ávila- González, E., Herrera-Camacho, J., Cortes-Cuevas, A., 2021. Use of organic acids in water and its effect on productive performance in broiler chicks. Abanico Veterinario 10, 1–17.

Ashok, A., Khedikar, I., 2016. Overview of water disinfection by UV technology -A review. Int. J. Sci. Technol. Eng. 2, 213–219.

Attia, Y.A., Abd El-Hamid, A.E., Al-Hanoun, A.M., Al-Harthi, M.A., Abdel-Rahman, G.M., Abdella, M.M., 2015. Responses the fertility semen quality, blood constituents, immunity and antioxidant status of rabbit buck to type and magnetizing of water. Ann. Anim. Sci. 15, 387–407.

Ayach, J., El Malti, W., Duma, L., Lalevée, J., Al Ajami, M., Hamad, H., Hijazi, A., 2024. Comparing conventional and advanced approaches for heavy metal removal in wastewater treatment: an In-depth review emphasizing filter-based strategies. Polymers 16 (14), 1959.

Azmi, L.S., Jabit, N., Ismail, S., Ku Ishak, K.E.H., Abdullah, T.K., 2025. Membrane filtration technologies for sustainable industrial wastewater treatment: a review of heavy metal removal. Desalin. Water Treat. 323, 101321. https://doi.org/10.1016/j.dwt.2025.101321.

Baker, A.T., Ojo, O.I., Dinka, M.O., Rwanga, S., 2024. Impact of magnetised water on Nigeria broiler chicken performance and growth rate. J. Digital Food Energy Water Syst. 5 (2), 43–55. https://doi.org/10.36615/c71ezb59.

Barjasteh, A., Dehghani, Z., Lamichhane, P., Kaushik, N., Choi, E.H., Kaushik, N.K., 2021. Recent progress in applications of non-thermal plasma for water purification, bio-sterilization, and decontamination. Appl. Sci. 11 (8), 3372.

Bialoszewski, D., Pietruczuk-Padzik, A., Kalicinska, A., Bocian, E., Czajkowska, M., Bukowska, B., Tyski, S., 2011. Activity of ozonated water and ozone against *Staphylococcus aureus* and *Pseudomonas aeruginosa* biofilms. Medical Science Monitor. Int. Med. J. Exp. Clin. Res. 17 (11), BR339–BR344. https://doi.org/10.12659/msm.882044.

Bist, R.B., Bist, K., Poudel, S., Subedi, D., Yang, X., Paneru, B., Mani, S., Wang, D., Chai, L., 2024. Sustainable poultry farming practices: a critical review of current strategies and future prospects. Poult. Sci. 103 (12), 104295.

Biswas, B.K., Hoque, M.R., Raut, R., Tabler, T., Taylor-Bowden, T., Nahashon, S., Maharjan, P., 2025. Applied research note: understanding varying levels of hydrogen peroxide residuals in poultry drinking water in early broiler growth performance. J. Appl. Poult. Res. 34 (4), 100577. https://doi.org/10.1016/j.japr.2025.100577.

Boas, D.M., Júnior, W.L., Nascimento, J.C., Leite, C.C., Matos, J.R., Paz, F., Sant'Ana, A. S., Guimarães, A.G., 2025. Incidence of *Escherichia coli* in drinking water: a comparative study of indoor and outdoor sources over four years across Bahia, Brazil. Hygiene Environ. Health Adv. 15, 100121. https://doi.org/10.1016/j.heha.2025.100121.

Boo, C., Wang, Y., Zucker, I., Choo, Y., Osuji, C.O., Elimelech, M., 2018. High performance nanofiltration membrane for effective removal of perfluoroalkyl substances at High water recovery. Env. Sci. Technol. 52 (13), 7279–7288.

Bottino, A., Capannelli, G., Petit-bon, P., Cao, N., Pegoraro, M., Zoia, G., 1991. Pore size and Pore-size distribution in microfiltration membranes. Sep. Sci. Technol. 26 (10–11), 1315–1327.
Bouassi, T., Libanio, D., Mesa, M.D., Oke, O.E., Gil, A.H., Tona, K., Ameyapoh, Y., 2020. Supplementation with liquid whey and ACIDAL® ML in drinking water affect gut pH and microflora and productive performance in laying hens. Br. Poult. Sci. 62, 138–146.
Bourassa, D.V., Wilson, K.M., Ritz, C.R., Kiepper, B.K., Buhr, R.J., 2018. Evaluation of the addition of organic acids in the feed and/or water for broilers and the subsequent recovery of *Salmonella Typhimurium* from litter and ceca1. Poult. Sci. 97 (1), 64–73.
Cai, R., Yang, H., He, J.S., Zhu, W., 2009. The effects of magnetic fields on water molecular hydrogen bonds. J. Mol. Struct. 938, 15–19.
Cardoso, I.M.F., Cardoso, R.M.F., da Silva, J.C.G.E., 2021. Advanced oxidation processes coupled with nanomaterials for water treatment. Nanomaterials 11 (8), 2045.
Cescon, A., Jiang, J.Q., 2020. Filtration process and alternative filter Media material in water treatment. Water 12, 3377.
Chander, M., Ghosh, S., Mukherjee, R., 2012. Improving water quality for livestock health and productivity: lessons from indigenous knowledge. Ind. J. Trad. Knowl. 11 (2), 258–263.
Chen, Z., Xing, T., Li, J., Zhang, L., Jiang, Y., Gao, F., 2021. Hydrogen peroxide-induced oxidative stress impairs redox status and damages aerobic metabolism of breast muscle in broilers. Poult. Sci. 100 (2), 918–925. https://doi.org/10.1016/j.psj.2020.11.029.
Cho, Y.I., Kim, H.S., 2022. Chapter 8 - nonchemical methods to control scale and deposit formation. In: Amjad, Z., Demadis, K.D. (Eds.), Water-Formed Deposits. Elsevier, pp. 167–193.
Cho, Y.I., Lee, S.H., 2005. Reduction in the surface tension of water due to physical water treatment for fouling control in heat exchangers. Int. Commun. Heat Mass Transf. 32 (1–2), 1–9.
Chowdhury, M.A.H., Reem, C.S.A., Ashrafudoulla, M., Rahman, M.A., Shaila, S., Jie-Won Ha, A., Ha, S.D., 2025. Role of advanced cleaning and sanitation techniques in biofilm prevention on dairy equipment. Compr. Rev. Food Sci. Food Saf. 24 (3), e70176. https://doi.org/10.1111/1541-4337.70176.
Chukwudi, P., Umeugokwe, P.I., Ikeh, N.E., Amaefule, B.C., 2025. The effects of organic acids on broiler chicken nutrition: a review. Anim. Res. One Health. 3, 43–53.
Clark, T., Dean, B., Watkins, S.E., 2009. Evaluation of different hydrogen peroxide products for maintaining adequate sanitizing residual in water. https://poultry-science.uark.edu/_resources/pdf/avianadvice_spr09.pdf.
Darsi, E., Kermanshahi, H., Nasiry, M.H., Golian, A., Golizadeh, M., 2017. Effects of magnetized water on in-vitro calcium carbonate solubility and eggshell breaking strength. J. Agric. Sci. Technol. 19 (7), 1495–1505.
Davoudi, M., Ehrampoush, M.H., Vakili, T., Absalan, A., Ebrahimi, A., 2012. Antibacterial effects of hydrogen peroxide and silver composition on selected pathogenic enterobacteriaceae. Inter. J. Environ. Health Eng. 1 (1), 23. https://doi.org/10.4103/2277-9183.96148.
de Rezende, H.C., de Lima, M., Santos, L.D., 2023. Peracetic acid application as an antimicrobial and its residual (HEDP): a holistic approach on the technological characteristics of chicken meat. Poult. Sci. 102 (10), 103003.
Desbruslais, A., Wealleans, A.L., 2022. Oxidation in poultry feed: impact on the bird and the efficacy of dietary antioxidant mitigation strategies. Poultry 1, 246–277. https://doi.org/10.3390/poultry1040022.
Ebihara, K., Stryczewska, H., Ikegami, T., Mitsugi, F., Pawlat, J., 2011. On-site ozone treatment for agricultural soil and related applications. Przeglad Elektrotechniczny 7, 141–152.
Ebrahim, S., Azab, E., 2017. Biological effects of magnetic water on human and animals. Biomed. Sci. 3, 78–85.
Ebrahimi, N.A., Nobakht, A., İnci, H., Palangi, V., Suplata, M., Lackner, M., 2024. Drinking water quality management for broiler performance and carcass characteristics. World 5, 952–961.
Edet, U.O., Joseph, A., Bassey, D., Bassey, I.N., Bebia, G.P., Mbim, E., Ogar, A.Y., 2024. Risk assessment and origin of metals in chicken meat and its organs from a commercial poultry farm in Akwa Ibom state, Nigeria. Heliyon 10 (17), e36941. https://doi.org/10.1016/j.heliyon.2024.e36941.
Eftekhari, A., Rezaeipour, V., Abdullahpour, R., 2015. Effects of acidified drinking water on performance, carcass, immune response, jejunum morphology, and microbiota activity of broiler chickens fed diets containing graded levels of threonine. Livest. Sci. 180, 158–163.
Ejiohuo, O., Onyeaka, H., Akinsemolu, A., Nwabor, O.F., Siyanbola, K.F., Tamasiga, P., Al-Sharify, Z.T., 2025. Ensuring water purity: mitigating environmental risks and safeguarding human health. Water Biol. Secur. 4, 100341.
El-Hanoun, A.M., Attia, Y.A., Al-Harthi, M.A., Habiba, H.I., Oliveira, M.C., 2017. Magnetized drinking water improves productivity and blood parameters in geese. Revista Colombiana De Ciencias Pecuarias 30, 209–218.
Elhenawy, S., Khraisheh, M., AlMomani, F., Al-Ghouti, M., Selvaraj, R., Al-Muhtaseb, A., 2024. Emerging nanomaterials for drinking water purification: a new era of water treatment technology. Nanomaterials 14 (21), 1707. https://doi.org/10.3390/nano14211707.
El-Katcha, M., Soltan, M., El-Naggar, K., Farfour, H., 2017. Effect of magnetic water treatment and some additives on growth performance, some blood biochemical parameters and intestinal health of growing Pekin ducklings. Alex. J. Vet. Sci. 53, 143.
El-Katcha, M., Soltan, M.A., El-Shobokshy, S.A., Kasser, M., 2018. Impact of water acidification or magnetic treatment on growth performance, health and oxidative status of broiler chicks challenged by *Salmonella enteritidis*. Alex. J. Vet. Sci. 59 (2), 154–154.
Elmusharaf, M.A., Cuppen, J.J., Grooten, H.N.A., Mohamed, H.E., Alhaidary, A., Beynen, A.C., 2010. Exposure of broiler chickens to a weak electromagnetic field reduces the impact of a simulated, commercial Eimeria infection. Am. J. Anim. Vet. Sci. 5 (1), 65–70. https://doi.org/10.3844/ajavsp.2010.65.70.
El-Nagar, S.H., Abdallah, R., Abou Asa, S., Elmadawy, M.A., Abouelenien, F., Elsaidy, N. R., Shukry, M., Abd El-Maksoud, E.M., 2024. The effects of improved water quality with zeolite addition and/or water magnetization on broiler performance, meat quality, and immunity. Alex. J. Vet. Sci. 82, 84–100. https://doi.org/10.5455/ajvs.201849.
El-Sabrout, K., El-Hanoun, A.M., 2019. Does magnetised drinking water influence poultry's health and production? World Poult. Sci. J. 75, 411–416. https://doi.org/10.1017/S0043933919000266.
El-Sabrout, K., Hanafy, M., 2017. Effect of magnetized water on productive traits of laying chickens. Prof. Anim. Sci. 33, 739–742.
El-Sabry, M.I., Charal, J.W., Mcmillan, K.W., Lavergne, T.A., 2018. Does magnetized drinking water affect productivity and egg quality of layers? Egypt. J. Anim. Prod. 55, 117–123.
Erdei-Tombor, P., Kiskó, G., Taczman-Brückner, A., 2024. Biofilm formation in water distribution systems. Processes 12, 280. https://doi.org/10.3390/pr12020280.
Ezzat, H.N., Hussein, M.A., Shihab, I.M., Al-Qazzaz, M.F., 2023. Effect of drinking ionized water on histological changes, bacteria count, and some hematological parameters of Japanese quail. Iraqi J. Agric. Sci. 54 (2), 464–471.
Farooq, M., Ghaffar, A., Perera, A.S., Cork, S., Niu, Y.D., Checkley, S., Abdul-Careem, M. F., 2026. Influence of drinking water quality on immune responses to viral vaccines in layer chickens. Vet. Immunol. Immunopathol. 291, 111035. https://doi.org/10.1016/j.vetimm.2025.111035.
Farooq, M., Khan, U., Adnan, M., Younas, W., Qureshi, N.B., Yasir, Q.M., Cai, Q., Chiu, M., 2025. Global decline of aquatic and terrestrial insects driven by climate change and anthropogenic impacts: the interaction of multiple stressors and disruption of niche conservatism. Biol. Conserv. 308, 111181. https://doi.org/10.1016/j.biocon.2025.111181.
Ferreira, T.S., Ravetti, R., Rubio, M.S., Alves, L.B.R., Saraiva, M.M.S., Benevides, V.P., Lima, T.S., Lima, B.N., Almeida, A.M., Berchieri Jr, A., 2022. Inclusion of organic acids in the drinking water and feed for the control of *Salmonella Heidelberg* in Broilers. Braz. J. Poult. Sci. 24, eRBCA.
Galdeano, M., Wilhelm, A., Goulart, I., Tonon, R., Freitas-Silva, O., Germani, R., Chávez, D., 2018. Effect of water temperature and pH on the concentration and time of ozone saturation. Braz. J. Food Technol. 21. https://doi.org/10.1590/1981-6723.15617.
Galgano, S., Conway, L., Maggio, F.D., Farthing, K., Dalby, N., Fellows, A., Houdijk, J.G. M., 2023. Precursor-derived in-water peracetic acid impacts on broiler performance, gut microbiota, and antimicrobial resistance genes. Poult. Sci. 102 (2), 102368.
Gholizadeh, M., Arabshahi, H., Saeidi, M.R., Mahdavi, B., 2008. The effect of magnetic water on growth and quality improvement of poultry. Middle East J. Sci. Res. 3, 140–144.
Giarratana, N., Reiner, G., 2022. Antimicrobial and tolerability profile of a sprayable hypochlorous acid oxidizing (AOS) solution for wound care. Int. J. Nurs. Health Care Res. 5, 1302. https://doi.org/10.29011/2688-9501.101302.
Gilani, A., Kermanshahi, H., Golian, A., Gholizadeh, M., Mohammadpour, A.A., 2014. Assessment of magnetised drinking water on excreta quality, nutrients digestibility, serum components and histomorphology of digestive tract in broiler chickens. Res. Opin. Anim. Vet. Sci. 4, 120–127. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20143035100.
González, Y., Gómez, G., Moeller-Chávez, G.E., Vidal, G., 2023. UV disinfection systems for wastewater treatment: emphasis on reactivation of microorganisms. Sustainability 15 (14), 11262.
Görlitz, M., Justen, L., Rochette, P.J., Buonanno, M., Welch, D., Kleiman, N.J., Eadie, E., Kaidzu, S., Bradshaw, W.J., Javorsky, E., Cridland, N., Galor, A., Guttmann, M., Meinke, M.C., Schleusener, J., Jensen, P., Söderberg, P., Yamano, N., Nishigori, C., O'Mahoney, P., Manstein, D., Croft, R., Cole, C., de Gruijl, F.R., Forbes, P.D., Trokel, S., Marshall, J., Brenner, D.J., Sliney, D., Esvelt, K., 2024. Assessing the safety of new germicidal far-UVC technologies. Photochem. Photobiol. 100 (3), 501–520. https://doi.org/10.1111/php.13866.
Guo, Y.J., Wang, Z.Y., Wang, Y.S., Chen, B., Huang, Y.Q., Li, P., Tan, Q., Zhang, H.Y., Chen, W., 2021. Impact of drinking water supplemented 2-hydroxy-4-methylthio-butyric acid in combination with acidifier on performance, intestinal development, and microflora in broilers. Poult. Sci. 101 (3), 101661.
Hafizi, L., Gholizadeh, M., Karimi, M., Hosseini, G., Mostafavi-Toroghi, H., Haddadi, M., Rezaiean, A., Ebrahimi, M., Meibod, N.E., 2014. Effects of magnetized water on ovary, pre-implantation stage endometrial and fallopian tube epithelial cells in mice. Iran. J. Reprod. Med. 12 (4), 243–248.
Hamid, H., Shi, H.Q., Ma, G.Y., Fan, Y., Li, W.X., Zhao, L.H., Zhang, J.Y., Ji, C., Ma, Q.G., 2018. Influence of acidified drinking water on growth performance and gastrointestinal function of broilers. Poult. Sci. 97 (10), 3601–3609.
Han, S.H., Yu, J.E., Yang, S.B., Kwon, Y.W., Kim, M., Choi, S.J., Park, J.W., 2025. Comparative analysis of environmental disinfection methods: hydrogen peroxide vaporization versus standard disinfection practices—An experimental study and literature review. J. Clin. Med. 14 (11), 3789.
Hassan, S., Attia, Y., El-Sheikh, A., Abdelkader, A., 2018. Productive, egg quality and physiological responses of Gimmizah chicken as affected by magnetized water of different strengths. Egypt. Poult. Sci. J. 38 (1), 51–64.
Hassoon, O.A., Khader, O.M., Aljuboori, Z.T.H., Furaijl, H.B., Hussein, A.A., Dawie, W. M., Ibrahim, Y.A., Alsalame, H.A.A., 2025. Impact of precision livestock farming on animal welfare and productivity. J. Anim. Health Prod. 13 (S1), 327–335. https://doi.org/10.17582/journal.jahp/2025/13.s1.327.335.

Hayajneh, F.M.F., Jalal, M., Zakaria, H., Abdelqader, A., Abuajamieh, M., 2018. Anticoccidial effect of apple cider vinegar on broiler chicken: an organic treatment to measure antioxidant effect. Polish J. Vet. Sci. 21 (2), 361-369-361–369.
Hreško Šamudovská, A., Demeterová, M., Skalická, M., Bujňák, L., Naď, P., 2018. Effect of water acidification on some morphological, digestive and production traits in broiler chickens. Bulgar. J. Vet. Med. 21, 269–278.
Ibrahim, A., Khalefa, H.S., Moubarak, S.T., 2025. Evaluation of the physicochemical and microbiological quality of water in Egyptian poultry farms: a correlational analysis of water quality parameters. Alex. J. Vet. Sci. 87, 19–27. https://doi.org/10.5455/ajvs.271857.
Jafari, M., Asadi, E., Fakheri Fard, A., 2024. Operational management of water quality to prevent physical, chemical, and microbial contaminations in hydroponic cultivation. Water Supply 24 (9), 3046–3060.
Jassim, E.Q., Aqeel, C.h.H., 2017. Effect of alkaline water and /or magnetic water on some physiological characteristics in broiler chicken. J. Entomol. Zool. Stud. 5, 1643–1647.
Kakhki, S., Khiadani, M., Naderi, K., Forough, M., Kholghi Oskooei, V., Yektay, S., 2021. Effect of ozonation-based disinfection methods on the removal of antibiotic resistant bacteria and resistance genes (ARB/ARGs) in water and wastewater treatment: a systematic review. Sci. Total Environ. 811, 151404.
Kathi, S., Mahmoud, A.E., 2024. Trends in effective removal of emerging contaminants from wastewater: a comprehensive review. Desalin. Water Treat. 317, 100258. https://doi.org/10.1016/j.dwt.2024.100258.
Keirs, R.W., Peebles, E.D., Sarjeant, W.J., Gerard, P.D., Terner, J.D., 2005. Assessment of the effects of electromagnetic field modification on egg-laying hens in commercial flocks as indicated by production measures. Am. J. Vet. Res. 66 (8), 1425–1429.
Khalil, M., Soliman, F., El-Sabrout, K., Aggag, S., 2025. Impact of using ionized drinking water on growth performance and DNA damage of broiler chicks. Trop. Anim. Health Prod. 57 (9), 497. https://doi.org/10.1007/s11250-025-04715-x.
Khan, S.H., Iqbal, J., 2016. Recent advances in the role of organic acids in poultry nutrition. J. Appl. Anim. Res. 44, 359–369.
Khattak, F., Galgano, S., Pearson, R., Houdijk, J.G.M., Short, F., Leigh, A., 2025. Enhancing key broiler welfare indicators, meat quality, and gut microbiome composition using oxygen-enriched drinking water under commercially relevant housing conditions. Poult. Sci. 104 (10), 105550.
Kırkpınar, F., Ataei, A.H., Işık, Ö., 2023. The effects of the magnetic drinking water in poultry: a review. Bull. Univ. Agri. Sci. Veter. Med. Cluj-Napoca - Anim. Sci. Biotech. 80 (2), 1–8. https://doi.org/10.15835/buasvmcn-asb:2023.0004.
Kumar, S.V., Baskaran, R., 2020. Novel integrated ultrafiltration and reverse osmosis system in high quality drinking water production. Orient. J. Chem. 36 (6), 1243–1247. https://doi.org/10.13005/ojc/360634.
Kumar, A., Škoro, N., Gernjak, W., Puač, N., 2021. Cold atmospheric plasma technology for removal of organic micropollutants from wastewater—A review. Eur. Phys. J. 75 (11), 283. https://doi.org/10.1140/epjd/s10053-021-00283-5.
Kumari, P., Kumar, A., 2023. Advanced Oxidation Process: a remediation technique for organic and non-biodegradable pollutant. Result Surf. Interf. 11, 100122.
Kurian, M., 2021. Advanced oxidation processes and nanomaterials - A review. Clean. Eng. Technol. 2, 100090. https://doi.org/10.1016/j.clet.2021.100090.
LeChevallier, M.W., Prosser, T., Stevens, M., 2024. Opportunistic pathogens in drinking water distribution systems—A review. Microorganisms 12 (5), 916.
Li, J., Wang, Y., Zheng, W., Xia, T., Kong, X., Yuan, Z., Niu, B., Wei, G., Li, B., 2024. Comprehensive evaluation of treating drinking water for laying hens using slightly acidic electrolyzed water. Poult. Sci. 103 (1), 103176. https://doi.org/10.1016/j.psj.2023.103176.
Li, Z., Liu, C., Shao, D., Tan, C., Cao, Y., Deng, S., Lim, T.T., Xu, F., 2025. Low-concentration hypochlorous acid drinking water alleviates broiler gut microbial load while preserving overall growth performance. Toxics 13 (1), 48.
Madanská, J., Vitková, Z., Capková, Z., 2004. Sledovanie stability roztokov peroxidu vodíka [Examination of the stability of hydrogen peroxide solutions]. Ceska a Slovenska farmacie: casopis Ceske farmaceuticke spolecnosti a Slovenske farmaceuticke spolecnosti 53 (5), 261–263.
Maes, S., Vackier, T., Huu, S.N., Heyndrickx, M., Steenackers, H., Sampers, I., De Reu, K., 2019. Occurrence and characterisation of biofilms in drinking water systems of broiler houses. BMC Microbiol. 19 (1), 1–15. https://doi.org/10.1186/s12866-019-1451-5.
Maharjan, P., Clark, T., Frank, M., Martins, B.B., Foy, M.K., Watkins, S.E., 2015. Evaluating different hydrogen peroxide products for residuals and efficacy over time. Inter. J. Poult. Sci. 14, 436–440. https://doi.org/10.3923/ijps.2015.436.440.
Maharjan, P., Clark, T., Kuenzel, C., Foy, M.K., Watkins, S.E., 2016. On farm monitoring of the impact of water system sanitation on microbial levels in broiler house water supplies. J. Appl. Poult. Res. 25, 266–271.
Mahmoud, M.S., Soliman, F.N., Bahie El Deen, M., El Sebai, A., 2017. Effect of magnetic drinking water, feed form and its restricted on Sasso broilers. I. Productive performance. Egypt. Poult. Sci. J. 37, 1069–1082.
Mantzios, T., Tsiouris, V., Kiskinis, K., Economou, V., Petridou, E., Tsitsos, A., Patsias, A., Apostolou, I., Papadopoulos, G.A., Giannenas, I., Fortomaris, P., 2023. Vitro investigation of the antibacterial activity of nine commercial water disinfectants, acidifiers, and glyceride blends against the most important poultry zoonotic bacteria. Pathogens 12, 381.
Marin-Flamand, E., Vázquez-Durán, A., Méndez-Albores, A., 2014. Effect of organic acid blends in drinking water on growth performance, blood constituents and immune response of broiler chickens. J. Poult. Sci. 51, 144–150.
Martin, N.L., Bass, P., Liss, S.N., 2015. Antibacterial properties and mechanism of activity of a novel silver-stabilized hydrogen peroxide. PloS One 10 (7), e0131345.
McMahon, C., 2009. Investigation of the Quality of Water Treated by Magnetic Fields. University of Southern Queensland Faculty of Engineering and Surveying. Undergraduate Thesis.
Metwally, A., Hamoud, M., Laban, S., Nasr, S., Zahran, O., Ali, M., Gamal, A., 2020. Effect of acidified drinking water by organic acids on broiler performance and gut health. Adv. Anim. Vet. Sci. 8 (12), 1301–1309. https://doi.org/10.17582/journal.aavs/2020/8.12.1301.1309.
Micciche, A.C., Rubinelli, P.M., Ricke, S.C., 2018. Source of water and potential sanitizers and biological antimicrobials for alternative poultry processing food safety applications. Front. Sustain. Food Syst. 2, 82. https://doi.org/10.3389/fsufs.2018.00082.
Mishra, B., Jha, R., 2019. Oxidative stress in the poultry gut: potential challenges and interventions. Front. Vet. Sci. 6, 60. https://doi.org/10.3389/fvets.2019.00060.
Mitre, K., 2018. The effect of magnetic water on feed conversion ratio, body weight gain, feed intake and livability of male broiler chickens. Poultry science undergrad honors theses. 5. University of Arkansas, Fayetteville. https://scholarworks.uark.edu/poscuht/5/.
Mohamed, A., Khalil, M., Soliman, F., El-Sabrout, K., 2025. The effect of drinking ionized water on the productive performance, physiological status, and carcass characteristics of broiler chicks. Animals 15 (2), 229. https://doi.org/10.3390/ani15020229.
Mohammad, A.W., Teow, Y.H., Ang, W.L., Chung, Y.T., Oatley-Radcliffe, D.L., Hilal, N., 2015. Nanofiltration membranes review: recent advances and future prospects. Desalination 356, 226–254.
Mohammadnezhad, A., Azizi, S., Sousanabadi Farahani, H., Tashan, J., Habibnejad Korayem, A., 2022. Understanding the magnetizing process of water and its effects on cementitious materials: a critical review. Const. Build. Mater. 356, 129076. https://doi.org/10.1016/j.conbuildmat.2022.129076.
Moharrery, A., Mahzonieh, M., 2005. Effect of malic acid on visceral characteristics and coliform counts in small intestine in the broiler and layer chickens. Inter. J. Poult. Sci. 4, 761–764. https://doi.org/10.3923/ijps.2005.761.764.
Moonsub, K., Seesuriyachan, P., Boonyawan, D., Wattanutchariya, W., 2024. Synergistic effect of plasma-activated water with micro/nanobubbles, ultraviolet photolysis, and ultrasonication on enhanced *Escherichia coli* inactivation in chicken meat. Processes 12 (3), 567.
Moussa, M., Besma, Z., Hachicha, M., 2025. Magnetic water treatment: theory and effects on treated water—A systematic review. Euro-Mediterr. J. Environ. Integr. 10, 2323–2342. https://doi.org/10.1007/s41207-024-00722-w.
Münster, P., Kemper, N., 2024. Long-term analysis of drinking water quality in poultry and pig farms in Northwest Germany. Front. Anim. Sci. 5, 1467287. https://doi.org/10.3389/fanim.2024.1467287.
Mustedanagic, A., Matt, M., Weyermair, K., Schrattenecker, A., Kubitza, I., Firth, C.L., Loncaric, I., Wagner, M., Stessl, B., 2023. Assessment of microbial quality in poultry drinking water on farms in Austria. Front. Vet. Sci. 10, 1254442. https://doi.org/10.3389/fvets.2023.1254442.
Mzinyathi, M., Muthuraj, V., Ajala, E.O., Kakavandi, B., Janse van Rensburg, S., Nkambule, T.T.I., Mamba, G., 2025. Chlorine dioxide drinking water pre-oxidation and disinfection: a review of its effectiveness, mechanisms, and disinfection by-products. Desal. Water Treat. 323, 101340. https://doi.org/10.1016/j.dwt.2025.101340.
Nambi Katu, K., 2025. Water purification technologies: innovations and challenges. R.I.J.E.P.S. 4 (1), 23–29. https://doi.org/10.59298/RIJEP/2025/412329.
Nishmitha, P.S., Akhilghosh, K.A., Aiswriya, V.P., Ramesh, A., Muthuchamy, M., Muthukumar, A., 2025. Understanding emerging contaminants in water and wastewater: a comprehensive review on detection, impacts, and solutions. J. Hazard. Mater. Adv. 18, 100755. https://doi.org/10.1016/j.hazadv.2025.100755.
Obayomi, O.V., Olawoyin, D.C., Oguntimehin, O., Mustapha, L.S., Kolade, O.S., Oladoye, O.P., Oh, S., Obayomi, S.K., 2024. Exploring emerging water treatment technologies for the removal of microbial pathogens. Curr. Res. Biotechnol. 8, 100252.
Ogundipe, T.T., Beitia, S., Obe, T., 2024. Applied Research note: microbial composition of the biofilm of poultry drinking water system. J. Appl. Poult. Res. 33 (2), 100403. https://doi.org/10.1016/j.japr.2024.100403.
Ogundipe, T.T., Beitia, S., Zhang, L., Zhang, X., Obe, T., 2025. Differences in microbial composition of litter and water line biofilm of broiler farms as influenced by water quality history. Poult. Sci. 104 (11), 105832. https://doi.org/10.1016/j.psj.2025.105832.
Ogundipe, T.T., Obe, T., 2025. Effectiveness of sanitizers on different biofilm-forming microorganisms associated with the poultry drinking water system. Poult. Sci. 104 (7), 105122. https://doi.org/10.1016/j.psj.2025.105122.
Oke, O.E., Akosile, O.A., Oni, A.I., Opowoye, I.O., Ishola, C.A., Adebiyi, J.O., Odeyemi, A.J., Adjei-Mensah, B., Uyanga, V.A., Abioja, M.O., 2024. Oxidative stress in poultry production. Poult. Sci. 103 (9), 104003. https://doi.org/10.1016/j.psj.2024.104003.
Orakpoghenor, O., Ejum Ogbuagu, N., Sa'Idu, L., 2021. Effect of Environmental Temperature on Water Intake in Poultry. IntechOpen. https://doi.org/10.5772/intechopen.95695.
Osman, A.I., Chen, Z., Elgarahy, A.M., Farghali, M., Mohamed, I.M., Priya, A., Hawash, H.B., Yap, P., Yap, P., 2024. Membrane Technology for Energy saving: principles, techniques, applications, challenges, and prospects. Adv. Energ. Sustain. Res. 5, 2400011. https://doi.org/10.1002/aesr.202400011.
Otsuka, I., Ozeki, S., 2006. Does magnetic treatment of water change its properties? J. Phys. Chem. B 110, 1509–1512.
Ozturk, E., Ocak, N., Coskun, I., Turhan, S., Erener, G., 2010. Effects of humic substances supplementation provided through drinking water on performance, carcass traits and meat quality of broilers. J. Anim. Physiol. Anim. Nutr. 94 (1), 78–85.

Papakonstantinou, G.I., Voulgarakis, N., Terzidou, G., Fotos, L., Giamouri, E., Papatsiros, V.G., 2024. Precision livestock farming technology: applications and challenges of Animal welfare and climate change. Agriculture 14 (4), 620.

Piccirillo, A., Tolosi, R., Mughini-Gras, L., Kers, J.G., Laconi, A., 2024. Drinking water and biofilm as sources of antimicrobial resistance in free-range organic broiler farms. Antibiotics 13, 808. https://doi.org/10.3390/antibiotics13090808.

Piche, A., Campbell, A., Cleary, S., Douglas, I., Basu, O.D., 2019. Investigation of backwash strategy on headloss development and particle release in drinking water biofiltration. J. Water Process Eng. 32, 100895.

Prakash, J., 2025. Precision poultry farming: a review of sensor technologies and data analytics. Inter. J. Vet. Sci. Anim. Husb. 10 (8), 390–393. https://www.doi.org/10.22271/veterinary.2025.v10.i8f.2643.

Puteri, M.N., Gew, L.T., Ong, H.C., Ming, L.C., 2025. Technologies to eliminate microplastic from water: current approaches and future prospects. Environ. Inter. 199, 109397. https://doi.org/10.1016/j.envint.2025.109397.

Radha, G., Sardary, S., 2021. Effects of using magnetic water on egg quality and biochemical composition in commercial layers. IOP Conf. Series Earth Environ. Sci. 761, 012106. https://doi.org/10.1088/1755-1315/761/1/012106.

Rahman, S.M., Islam, S.M., Kong, D., Xi, Q., Du, Q., Yang, Y., Oh, D., Wang, J., Han, R., 2023. Controlling microbial population in livestock and poultry industry using electrolyzed water as an emerging technology for ensuring food safety. Food Control 152, 109843. https://doi.org/10.1016/j.foodcont.2023.109843.

Raut, R., Biswas, B.K., Taylor-Bowden, T., Kilonzo-Nthenge, A., Pokharel, B., Tabler, T., Nahashon, S.N., Maharjan, P., 2025. Effects of chronic exposure of specific water quality parameters in poultry drinking water on dietary amino acid digestibility and early broiler performance. Poult. Sci. 104 (2), 104835.

Raut, R., Kilonzo-Nthenge, A., Aniume, T., Basnet, A., Watkins, S., Maharjan, P., 2024. Impacts of on-farm water sanitation practices on microbial hygiene in poultry waterlines and efficacy of sodium hypochlorite-based product on foodborne pathogens. J. Appl. Poult. Res. 33 (3), 100425. https://doi.org/10.1016/j.japr.2024.100425.

Romeu, M.J., Morais, J., Vasconcelos, V., Mergulhão, F., 2023. Effect of hydrogen peroxide on cyanobacterial biofilms. Antibiotics 12, 1450. https://doi.org/10.3390/antibiotics12091450.

Rosenblum, J., Ge, C., Bohrerova, Z., Yousef, A., Lee, J., 2012. Ozonation as a clean technology for fresh produce industry and environment: sanitizer efficiency and wastewater quality. J. Appl. Microbiol. 113 (4), 837–845.

Ross, T.T., Alim, M.A., Rahman, A., 2025. Simple and effective filtration system for drinking water production from harvested rainwater in rural areas. J. Environ. Manag. 373, 123887.

Saad, M.H., Hameed, S.S., Ali, A.J., 2024. Effect of some essential oil and organic acids on blood picture, lipid profile and intestinal health in broiler chickens. Iraqi J. Agric. Sci. 55 (6), 2006–2011.

Saleh, N.A., Ayoub, M.A., Nossair, M.A., Alqhtani, A.H., Swelum, A.A., Khojah, H., Gamal, M., Imam, M.S., Khafaga, A.F., Arif, M., Abd El-Hack, M.E., 2023. Influence of water quality and pollution on broiler's performance, vaccine and antibiotic efficiencies – A review. Ann. Anim. Sci. 23 (4), 1021–1036. https://doi.org/10.2478/aoas-2023-0023.

Sanchez, D., Herrera-Peraza, E., Navarro-Gomez, C., Sanchez-Navarro, J.R., 2025. Assessing the potential of magnetic water treatment of groundwater for calcium carbonate scale mitigation in drinking water distribution networks. Water 17 (9), 1265.

Santalunai, S., Pakprom, J., Charoensiri, W., Thongsopa, C., Thosdeekoraphat, T., Janpangngern, P., Chaipanya, P., Santalunai, N., Santalunai, S., 2025. Utilizing non-thermal plasma technology for coolant contaminant removal: an efficiency and dielectric properties investigation. Heliyon 11, e44073.

Sargolzehi, M.M., Rokn-Abadi, M.R., Naserian, A.A., 2010. The effects of magnetic water on milk and blood components of lactating Saanen goats. Int. J. Nutr. Metab. 1 (1), 57–62.

Schneider, A.F., Almeida, D., Moraes, A.N., Picinin, L., Oliveira, Gewehr, C.E., 2016. Chlorinated drinking water for lightweight laying hens. Arquivo Brasileiro De Medicina Veterinaria E Zootecnia 68, 1690–1696.

Sciuto, E.L., Laganà, P., Filice, S., Scalese, S., Libertino, S., Corso, D., Faro, G., Coniglio, M.A., 2021. Environmental management of Legionella in domestic water systems: consolidated and innovative approaches for disinfection methods and risk assessment. Microorganisms 9 (3), 577.

Shah, A.A., Mehmood, S.M., Raziq, F., Khan, M.T., Ullah, A., Abbas, Y., Hassan, S.K., Ahmad, S., Manzoor, S., Khan, K., 2025. Effect of water at different pH levels adjusted with organic and inorganic acidifiers on the growth performance, blood biochemistry, carcass yield, and meat physicochemical properties of broilers. Turk. J. Vet. Anim. Sci. 49 (5), 189–198. https://doi.org/10.55730/1300-0128.4390.

Shah, D., Nagarajan, N., 2013. Luteal insufficiency in first trimester. Indian J. Endocrinol. Metab. 17 (1), 44–49.

Shamsaldain, Q.Z., Rawee, E.A., 2020. Effect of magnetic water on productive efficiency of Awassi sheep. Iraqi J. Vet. Sci. 26, 129–135. https://doi.org/10.33899/ijvs.2020.166887.

Sharifuzzaman, M., Mun, H.S., Ampode, K.M.B., Lagua, E.B., Park, H.R., Kim, Y.H., Hasan, M.K., Yang, C.J., 2025. Optimizing broiler growth, health, and meat quality with citric acid- assessing the optimal dose and environmental impact: citric acid in broiler health and production. Poult. Sci. 104 (2), 104668.

Shehata, N., Egirani, D., Olabi, A.G., Inayat, A., Abdelkareem, M.A., Chae, K.J., Sayed, E.T., 2023. Membrane-based water and wastewater treatment technologies: issues, current trends, challenges, and role in achieving sustainable development goals, and circular economy. Chemosphere 320, 137993.

Shi, Z., Xi, L., Wei, R., Shi, Z., Xu, Z., Gao, S., Liang, X., Zhang, Y., Ye, Z., Cheng, P., 2025. Effect of slightly acidic electrolyzed water in drinking water on the intestinal morphology and gut microbiota in early weaned piglets. Front. Anim. Sci. 6, 1593059. https://doi.org/10.3389/fanim.2025.1593059.

Shihab, I.M., Ezzat, H.N., Hussein, M.A., 2019. Effect of using ionized water on some productive and physiological performance of Japanese quails. Poult. Sci. 98, 5146–5151.

Singh, R., Bhadouria, R., Singh, P., Kumar, A., Pandey, S., Singh, V. K., .2020. Nanofiltration technology for removal of pathogens present in drinking water. Chapter 21 - Waterborne pathogens (Elsevier eBooks), 463–489. https://doi.org/10.1016/b978-0-12-818783-8.00021-9.

Sil, T., Malyshev, D., Aspholm, M., Magnus, A., 2025. Boosting hypochlorite's disinfection power through pH modulation. BMC Microbiol. 25, 101. https://doi.org/10.1186/s12866-025-03831-w.

Siponen, S., Ikonen, J., Gomez-Alvarez, V., Hokajärvi, A.M., Ruokolainen, M., Jayaprakash, B., Kolehmainen, M., Miettinen, I.T., Pitkänen, T., Torvinen, E., 2025. Effect of pipe material and disinfectant on active bacterial communities in drinking water and biofilms. J. Appl. Microbiol. 136 (1), lxaf004. https://doi.org/10.1093/jambio/lxaf004.

Slattery, M., Garvey, M., 2025. Chlorine disinfection byproducts: a public health concern associated with dairy food contamination. Dairy 6 (2), 18.

Soliman, E.S., Hamad, R.T., Hassan, R.A., 2021. Moderations in performance, immunity, tissue architecture, and vaccine viability induced by water magnetization in broiler farms. Vet. World 14, 1695–1710.

Suchomel, M., Diab-Elschahawi, M., Kundi, M., et al., 2013. Influence of pre- and post-usage flushing frequencies on bacterial water quality of non-touch water fittings. BMC Infect. Dis. 13, 402.

Sultan, A., Ullah, I., Khan, S., Khan, R.U., Ul Hassan, Z., 2014. Impact of chlorine dioxide as water acidifying agent on the performance, ileal microflora and intestinal histology in quails. Arch. Anim. Breed. 57, 31. https://doi.org/10.7482/0003-9438-57-031.

Sultan, A., Ullah, T., Khan, S., Khan, R., 2015. Effect of organic acid supplementation on the performance and ileal microflora of broiler during finishing period. Pak. J. Zool. 47, 635–639.

Surai, P.F., Kochish, I.I., Fisinin, V.I., Kidd, M.T., 2019. Antioxidant defence systems and oxidative stress in poultry biology: an update. Antioxidants 8 (7), 235. https://doi.org/10.3390/antiox8070235.

Szott, V., Peh, E., Friese, A., Roesler, U., Kehrenberg, C., Ploetz, M., Kittler, S., 2022. Antimicrobial effect of a drinking water additive comprising four organic acids on Campylobacter load in broilers and monitoring of bacterial susceptibility. Poult. Sci. 101 (12), 102209.

Tayeh, Y.A., 2024. A comprehensive review of reverse osmosis desalination: technology, water sources, membrane processes, fouling, and cleaning. Desalin. Water Treat. 320, 100882. https://doi.org/10.1016/j.dwt.2024.100882.

Tu, M., Zang, Y., Mo, Q., Yuan, X., Shu, D., Zhang, G., Hu, J., Li, Y., Liu, R., Bing, S., Zang, Y., 2024. Effect of combined electrolyzed reduced water and slightly acidic electrolyzed water spraying on the control of Salmonella, eggshell quality, and shelf life of eggs during storage. Poult. Sci. 103 (9), 104012.

Tyski, S., Bocian, E., Laudy, A.E., 2024. Animal health protection - assessing antimicrobial activity of veterinary disinfectants and antiseptics and their compliance with European standards: a narrative review. Polish J. Microbiol. 73 (4), 413–431.

Tzanidakis, C., Simitzis, P., Panagakis, P., 2023. Precision livestock farming (PLF) systems: improving sustainability and efficiency of animal production. In: García Márquez, F.P., Lev, B. (Eds.), Sustainability. International Series in Operations Research & Management Science, Sustainability. International Series in Operations Research & Management Science, 333. Springer, Cham. https://doi.org/10.1007/978-3-031-16620-4_15.

van Bel, N., Hornstra, L.M., van der Veen, A., Medema, G., 2019. Efficacy of flushing and chlorination in removing microorganisms from a pilot drinking water distribution system. Water 11 (5), 903. https://doi.org/10.3390/w11050903.

Varol, K., 2022. Determination of maximum ozone concentrations and half-life of ozone in some drinking water and high quality pure water produced in new system devices. Fresenius Environ. Bull. 31, 2285–2294.

Velasquez, J.A., Bao, Y., Huang, J.Y., 2024. Atmospheric cold plasma as a novel approach to remediating microplastics pollution in water. Environ. Poll. 356, 124390.

Verma, S.S., 2011. Magnetic water treatment. Chem. Bus. J. 1, 13–16.

Waegenaar, F., Pluym, T., Vermeulen, E., De Gusseme, B., Boon, N., 2025. Impact of flushing procedures on drinking water biostability and invasion susceptibility in distribution systems. Appl. Environ. Microbiol. 91 (6), e0068625.

Walczak, Ł.J., Kwiatkowska, M., Twarowski, B., Kubacka, M., Paluch, J., Herbet, M., 2025. Disinfectant-induced bacterial resistance and antibiotic cross-resistance-mechanisms and clinical relevance. Clin. Exp. Medi. 26 (1), 26. https://doi.org/10.1007/s10238-025-01950-2.

Wang, H., Gao, X., Zuo, Y., 2024. Research and application of water treatment technologies for emerging contaminants (ECs): a pathway to solving water environment challenges. Water 16 (13), 1837. https://doi.org/10.3390/w16131837.

Wang, H., Zhong, X., Shi, W., Guo, B., 2013. Study of malondialdehyde (MDA) content, superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) activities in chickens infected with avian infectious bronchitis virus. Afr. J. Biotechnol. 10 (45), 9213–9217. https://doi.org/10.4314/ajb.v10i45.

Wang, J., Vaddu, S., Bhumanapalli, S., Mishra, A., Applegate, T., Singh, M., Thippareddi, H., 2023. A systematic review and meta-analysis of the sources of Salmonella in poultry production (pre-harvest) and their relative contributions to the microbial risk of poultry meat. Poult. Sci. 102 (5), 102566. https://doi.org/10.1016/j.psj.2023.102566.

Wang, Y., Zhang, Z., Xia, M., Zhang, X., Lan, R., Wei, B., Liu, Y., Lu, Y., Fan, G., 2025. Mechanism and risk control of chlorine-resistant bacteria in drinking water supply systems: a comprehensive bibliometric analysis. Water 17 (7), 956. https://doi.org/10.3390/w17070956.

Watkins, S., 2018. Water: the Most Important Nutrient for Your Birds. University of Arkansas. https://poultry-science.uark.edu/_resources/pdf/July2018_AvianAdvice.pdf. access 15 January 2026.

Yacout, M.H., Hassan, A.A., Khalel, M.S., Shwerab, A.M., Abdel-Gawad, E.I., Abdel-Kader, Y.I., 2015. Effect of magnetic water on the performance of lactating goats. J. Dairy Vet. Anim. Res. 2 (5), 159–170.

Yang, Y., Wang, Y., Wei, S., Wang, X., Zhang, J., 2023. Effects and mechanisms of non-thermal plasma-mediated ROS and its applications in animal husbandry and biomedicine. Int. J. Mol. Sci. 24 (21), 15889.

Yaqub, M., Woo, C.H., Lee, W., 2021. Optimization of hypochlorous acid generation by HCl electrolysis through response surface methodology and artificial neural networks. J. Environ. Chem. Eng. 9, 105826.

Yin, J., Duan, J., Cui, Z., Ren, W., Li, T., Yin, Y., 2015. Hydrogen peroxide-induced oxidative stress activates NF-κb and Nrf2/Keap1 signals and triggers autophagy in piglets. RSC Adv. 5 (20), 15479–15486.

Youssef, E., 2025. Advancements in magnetized water technology: enhancing crop yields, drought tolerance, and environmental sustainability: a review. Egypt. J. Agron. 47 (3), 655–662.

Yue, C., Yuya, H., Zhihuan, L., Zimo, W., Jianying, F., 2024. Study on the disinfection effect of chlorine dioxide disinfectant (ClO_2) on dental unit waterlines and its in vitro safety evaluation. BMC Oral Health 24 (1), 648. https://doi.org/10.1186/s12903-024-04391-7.

Yusuf, K.O., Akande, O.S., Baiyeri, M.R., 2022. Effect of drinking magnetized water on offensive odour from poultry droppings of broiler chicken. Environ. Res. Eng. Manag. 78 (3), 119–128.

Zaidi, N.S., Sohaili, J., Muda, K., Sillanpää, M., 2014. Magnetic field application and its potential in water and wastewater treatment systems. Sep. Purif. Rev. 43, 206–240. https://doi.org/10.1080/15422119.2013.794148.

Zhang, B., Du, L., Yu, T., Zhang, K., Zhao, R., Yang, C., Song, X., 2025. Impact of drinking water supplemented with complex acidifiers on production performance, egg quality, physiological and biochemical indicators, and microbial flora of BIAN chickens. Life 15 (11), 1700. https://doi.org/10.3390/life15111700.

Zhang, H., Guo, Y., Wang, Z., Wang, Y., Chen, B., Du, P., Zhang, X., Huang, Y., Li, P., Michiels, J., Chen, W., 2022. Acidification of drinking water improved tibia mass of broilers through the alterations of intestinal barrier and microbiota. Anim. Biosci. 35 (6), 902–915. https://doi.org/10.5713/ab.21.0455.

Zhong, Y., Ma, T., Fu, Z., Chen, A., Yu, J., Huang, Y., Fu, J., 2023. Effects of hydrogen peroxide-induced oxidative stress on intestinal morphology, redox status, and related molecules in squabs. Animals 13 (4), 749. https://doi.org/10.3390/ani13040749.

Zou, Q., Meng, W., Wang, C., Wang, T., Liu, X., Li, D., 2023. Sodium dichloroisocyanurate: improving broiler health by reducing harmful microbial levels in the waterline. Front. Vet. Sci. 10, 1234949. https://doi.org/10.3389/fvets.2023.1234949.