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FOOD SAFETY CONSIDERATIONS OF EGGSHELL POWDER FOR FOOD APPLICATIONS: A REVIEW

Suci Apsari Pebrianti[1*], Zahra Naelal Mounaya Insanullah[1], Nadia Raihan[1], Ririn Rosalina Trinita[1]

[1]Food and Agriculture Products Technology, Faculty of Agriculture, Siliwangi University
*Corresponding author: *suciapsaripeb@unsil.ac.id*

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ABSTRACT

Eggshell waste, often seen as an environmental pollutant, is actually a valuable source of calcium carbonate. This makes it a promising candidate for food fortification and preservation. However, ensuring the microbiological and chemical safety of eggshell powder is essential before it can be safely used in food products. This review assesses these safety concerns and offers recommendations for safe application. Eggshells can harbor harmful pathogens such as *Salmonella* spp. and *Escherichia coli,* which are commonly linked to foodborne illnesses. To reduce microbial contamination, several decontamination methods have been investigated, including washing, drying, chlorine dioxide gas treatment, and autoclaving. These methods effectively lower microbial loads, improving the safety of eggshell powder for consumption. Chemical analyses typically show no significant contamination of eggshell powder with toxic heavy metals like lead or cadmium. Acute toxicity studies indicate low toxicity levels; for example, the eggshell membrane has an LD_{50} greater than 2000 mg/kg body weight in mice, and the powder shows an LD_{50} above 5000 mg/kg in rats. Sub-chhronic toxicity studies generally report no harmful effects on body weight or hematological parameters. However, some reversible biochemical changes were observed, such as altered cholesterol and LDL in females and creatinine levels in males, along with mild, reversible histopathological changes in heart and kidney tissues. These findings highlight the need for further research. In conclusion, rigorous decontamination is critical. While eggshell powder shows low acute toxicity and potential as a food fortification, more studies are needed to confirm its long-term safety.

1. Introduction

The Environmental Protection Agency (EPA) has identified eggshell waste as the 15th most significant pollution hazard in the food industry while the European Commission regards eggshell waste as a hazardous material (Waheed et al. 2020). Around 86.7 million metric tonnes of eggs were produced globally in 2020, demonstrating the significant demand for eggs across the globe (Guyonnet 2023). This high level of egg consumption directly correlates with the generation of large amounts of eggshell waste. Without proper treatment, the majority of eggshell waste is disposed of in landfills, where the decaying eggshells contribute to environmental pollution. Therefore, managing eggshell waste poses environmental challenges but also offers an opportunity to repurpose eggshells as a valuable resource.

Eggshell waste should no longer be treated as mere waste but rather recognized as a valuable natural source of calcium. Eggshell waste can be converted into powder rich in calcium containing 80-95% calcium offers a promising solution as a natural and highly concentrated calcium source (Pebrianti et al. 2023; Wijinindyah et al. 2023; Brun et al. 2013).

Calcium deficiency is a prevalent dietary concern that leads to numerous health complications, including stunting in children. Calcium-fortified foods have emerged as an effective technique to enhance calcium consumption in at-risk populations (Sari et al. 2016; Ramadhani et al. 2019; Ismawati et al. 2020; Jayusman et al. 2021).

Utilizing eggshell powder in calcium-fortified foods can both reduce waste and help address calcium deficiency in populations. However, ensuring the safety of eggshell powder for human consumption through proper processing and compliance with food safety standards is essential to protect consumer health.

Besides its application in calcium fortification, eggshell waste also has potential as a natural food preservative. The addition of preservatives is important for extending product shelf life, preventing spoilage, and maintaining original quality for as long as possible. Due to its high calcium carbonate content, eggshell powder can act as a preservative in certain food applications by neutralizing acidity and inhibiting microbial growth (Martin-Diana et al. 2007; Ningrum et al. 2024).

This article will review the food safety aspects of eggshell powder, with a primary focus on microbiological hazards, as well as physical and chemical risks. The aim of this study is to evaluate the safety of eggshell powder as a food additive, and to provide recommendations for its safe use in food products. In this article, the term "eggshell" refers specifically to chicken eggshells.

2. Methods

This article was prepared using a literature review method, which involved collecting, analyzing, and synthesizing information from various relevant library sources. The literature reviewed includes scientific journals, books, and reports, with keywords such as eggshell, eggshell powder, eggshell fortification, eggshell as a food additive, and food safety of eggshell. The sources were accessed and selected through databases including Google Scholar, ResearchGate, PubMed, and Wiley.

3. Results and discussions

3.1. *Microbial contamination and outbreaks associated with egg*

It is possible for eggshell to serve as human pathogen carriers. Fecal matter exposure in nesting habitats, contact with wash water during handling, or packaging can all result in contamination. Consequently, the shell surface may harbor pathogens such as *Salmonella* spp., *Escherichia coli* O157:H7, *Yersinia enterocolitica*, *Aeromonas*, *Enterobacter, Serratia, Listeria monocytogenes, Citrobacter braakii, Klebsiella, Pseudomonas, Rahnella aquatilla* from eggshells and egg contents (Adesiyun et al. 2006; Kilonzo-Nthenge et al. 2016). Some microbial species, such as *Buttiauxella agrestis*, *Salmonella*, *Flavimonas oryzihabitans*, and *Stenotrophomonas maltophilia* were detected solely on the surface of the eggshells. This finding implies that shell contamination does not always result in contamination of the egg's internal contents by the same microorganisms (Kilonzo-Nthenge et al. 2016).

Eggs and egg-based products have been linked to foodborne outbreaks globally, often due to contamination with various *Salmonella* species. The types of *Salmonella* detected in eggs, whether on the shell or in the internal contents, may vary across countries or regions. This variation depends on several factors, including the type and quality of feed, the condition of the housing and nesting areas, hygiene during egg handling, and the type of packaging used (Bermudez-Aguirre et al. 2025).

The common *Salmonella* serotypes such *S. Typhimurium*, *S. Enteritidis*, *S. Infantis*, *S. Hadar*, *S. Typhi*, and *S. Heidelberg, S. Tennessee,* and *S. Kentucky* have been identified in both eggshells and egg contents (Alegria-Moran et al. 2017; Kingsbury et al. 2019; Gast et al. 2021; Christidis et al. 2020; Godinez-Oviedo et al. 2020). Various microbial serotypes detected on eggshells in several countries are summarized in **Table 1**.

Several incidents of egg recalls from the market have occurred due to microbial contamination, particularly involving *Salmonella*. One of the most recent cases took place in January 2025 in Canada, where eggs from several distributors were pulled from the market. These actions were prompted by concerns over public health risks linked to bacterial contamination. Such recalls are critical in preventing the spread of foodborne illnesses, especially when the source of contamination involves common and widely consumed food items like eggs (Government of Canada 2025).

Outbreaks of salmonellosis also occurred at two restaurants in Korea. The outbreaks were caused by *Salmonella Enteritidis*, and the source of the infections was suspected to be contaminated eggs (Eun et al. 2024). Another notable case involved a *Salmonella Enteritidis* outbreak that was confirmed to have contaminated eggs as of October 17, 2024. This outbreak led to 93 reported infections across 12 U.S. states, underscoring the widespread impact such contamination can have (Centers for Disease Control and Prevention 2024).

The EFSA (European Food Safety Authority) report covering the period from September 2, 2021, to January 11, 2022, showed that there were 272 cases of *Salmonella Enteritidis* outbreaks caused by the consumption of eggs or egg-containing products. This incident led to the withdrawal of fresh eggs from farms

Table 1. Microbial serotype detected in eggshells in various country.

Country	Serotype	References
Korea	*S. Infantis* (8.35), *S. Bareilly* (5.0%), *S. Agona* (3.3%), *S. Enteritidis* (1.7%), *S. Montevideo* (1.7%)	Jung & Lee (2024)
Delhi, India	*Escherichia coli* (84%) and *Staphylococcus* spp. (77%)	Verma et al. (2023)
Taiwan	*Staphylococcus* spp. *and Enterobacteriaceae*	Shu-Chen et al. (2023)
Mexico, USA	*Salmonella enteritica* spp.	Godinez-Oviedo et al. (2020)
New Zealand, Australia	*Salmonella Infantis*, *Salmonella Thompson*	Kingsbury et al. (2019)
Italia	*Escherichia coli* (>10^5 cfu/cm^2), *Enterococci faecalis, Enterococci faecium* (>10^3 cfu/cm^2), *Staphylococcus aureus* (>10^2 cfu/cm^2), *Enterobacteriaceae* (10^4 cfu/cm^2)	Pesavento et al. (2017)
Ekosodin village, Nigeria, Afrika	*Enterobacter aerogenes, Escherichia coli, Citrobacter freundii, Bacillus cereus, Enteroccocus faecalis* and *Proteus mirabillis* for the bacterial isolates while the fungi isolates include *Mucor* sp.*, Rhizopus* sp.*, Aspergillus* sp.*, Fusarium* sp. and *Penicillium*	Oviasogie et al. (2016)
Tennessee, USA	*E. coli* (11.9%), *Enterobacter* (9.1%), *Serratia* (11.5%), *Citrobacter braakii* (0.4%), *Klebsiella* (2.4%), *Pseudomonas* (0.8%), *Rahnella aquatilla* (1.2%), *Buttiauxella agrestis* (0.8%), *Salmonella* (3.6%), *Flavimonas oryzihabitans* (0.8%), *Stenotrophomonas maltophilia* (1.2%)	Kilonzo-Nthenge et al. (2016)

linked to the outbreak from circulation, redirecting them for use in heat-treated egg products. The source of contamination was suspected to originate from the packaging area and farm enclosures. Similarly, in December 2020, an egg recall was also carried out in Newfoundland and Labrador, Canada, for the same reason (Canadian Food Inspection Agency 2020).

Another report related to *Salmonella* outbreaks in eggs occurred between May 1, 2015, and October 31, 2018, with a total of 838 confirmed cases and 371 probable cases reported in 18 countries across the European Union and the European Economic Area. Food trace-back investigations based on meals consumed by infected individuals at various food establishments identified eggs from Poland as the source of contamination, which was later confirmed as the vehicle of transmission in the outbreak (Pijnacker et al. 2019).

The reports emphasize the critical importance of implementing stringent sanitary and hygienic protocols during egg handling to prevent contamination by pathogenic microorganisms. Moreover, the data indicate that eggshells pose an inherent microbiological hazard, including potential contamination by bacteria such as *Salmonella* spp. Therefore, it is imperative to apply targeted decontamination techniques during the processing of eggshell powder. These interventions aim to achieve a significant reduction in microbial load, ensuring that the final product meets established microbial safety criteria before its utilization as a food additive

3.2. *Microbial contamination risks and reduction strategies in eggshell powder*

As explained in the previous sub-chhapter, the production and use of eggshell powder pose potential risks of microbial contamination, which can compromise product safety and consumer health. Considering that eggshell powder has been widely fortified in various food products such as pudding (Pebrianti et al. 2023), ice cream (Hasan et al. 2023), jelly candies and jelly (Novelina et al. 2020; Younas et al. 2021), chicken nuggets (Merta et al. 2020), tekwan as a local food from South Sumatra, Indonesia (Telisa et al. 2022), snack bars (Handayani et al. 2022), and bakery products (Afzal 2020; Arnold et al. 2022; Shahnila et al. 2022), therefore identifying and controlling these risks is essential to ensure the quality of products derived from eggshell powder. Eggshell powder is produced through several main steps, including dry cleaning, washing, soaking in an acid solution, drying, and size reduction through grinding or milling. Among these stages, certain steps such as washing or cleaning and drying serve a crucial role in eliminating microbial contaminants.

Utilizing eggshell powder without prior treatment resulted in significant microbial proliferation, with a total bacterial count reaching 9.0 × 10^6 CFU/g, while no yeast or mold growth was detected (Hasan et al. 2015). According to Kilonzo-Nthenge et al. (2016), the bacterial loads are often higher on unclean eggs compared to washed ones. A study conducted by Shu-Chen et al. (2023) in Taiwan demonstrated similar findings, showing that the presence of *Staphylococcus* spp. and *Enterobacteriaceae* on unwashed chicken eggshells was 93.81% and 13.33%, respectively. In contrast, washed eggs showed significantly lower prevalence rates of 66.67% for *Staphylococcus* spp. and 7.02% for *Enterobacteriaceae*. Additionally, the bacterial counts of both groups were substantially higher in unwashed eggs, indicating that the washing process improves the microbial safety and overall quality of the eggs.

An alternative method to prevent *Salmonella* contamination involves thoroughly rinsing eggshells under running tap water, scrubbing them with a household sponge, and then soaking them in a solution made by mixing 10 drops of sodium hypochlorite (a common household bleach) per liter of water (Davis et al. 2008).

Another effective cleaning method involves multiple washes in chlorinated water, followed by boiling in deionized water for 30 minutes (Hassan, 2015). In another report, Kim et al. (2016) showed that the use of chlorine dioxide gas (ClO_2) can be an efficient alternative to enhance the microbiological safety of eggshell-based products. Inactivation using ClO_2 gas under wet conditions is more effective in eliminating *Salmonella Enteritidis* and *Salmonella Gallinarum* compared to dry conditions. Under wet conditions, exposure for 30 minutes at ClO_2 concentrations of 20 ppm, 40 ppm, and 80 ppm resulted in a bacterial population reduction of more than 4 log for *S. Enteritidis*. For *S. Gallinarum*, similar effectiveness was observed at concentrations of 40 ppm and 80 ppm.

Eggshell powder is processed through drying at temperatures ranging from 65°C to 160°C for durations between 90 minutes and 24 hours (Aditya et al. 2021; Pebrianti et al. 2023). This heat treatment significantly improves the microbiological quality of the product. As reported by Nemeth et al. (2015), eggshells that were initially heavily contaminated with fecal matter and had high levels of *Enterobacteriaceae* (nearly 10^5 CFU/g) showed a drastic reduction to below 10 CFU/g within the first hour of drying. Samples subjected to heat treatment were determined to be devoid of harmful bacteria. The *Enterobacteriaceae* concentrations were below 10 CFU/g, and the overall count of mesophilic aerobic spores did not exceed 10^2 CFU/g in all examined samples (Nemeth et al. 2015). Alternatively, eggshells can be sterilized using an autoclave at 134°C for 15 minutes to ensure thorough elimination of microorganisms (Brun et al. 2013; Hassan et al. 2015).

A summary of microbial reduction methods for eggshell powder is presented in **Table 2.** This table outlines various decontamination techniques such as washing with chlorinated water, acid soaking, drying at specific temperatures, autoclaving, and chlorine dioxide gas treatment, highlighting their effectiveness in reducing microbial loads, particularly *Salmonella* spp., *Enterobacteriaceae*, and *Staphylococcus* spp.

3.3. *Safety of eggshell powder*

Potential hazards associated with eggshells include chemical hazards such as antibiotic and pesticide residues, as well as microbiological hazards, particularly the presence of *Salmonella* (Food Safety and Inspection Service USA 2020). A study by Milbradt et al. (2015) investigated the risk of toxic metal contamination in eggshells, focusing on elements such as lead (Pb), cadmium (Cd), and mercury (Hg). The results of the study indicated that no significant amounts of Fe, Cr, Mn, Mo, Ni, Se, Al, Cd, or Pb were detected in the samples. These findings provide assurance regarding the chemical safety of eggshells for consumption.

Table 2. Microbial reduction methods for eggshell powder.

Methods	Microorganisms	Effectiveness (log reduction)	References
Boiling in deionized water for 30 minutes followed by dried in hot air oven at 80°C for 2 h, sterilization in an autoclave at 134°C for 15 minutes and in a microwave for 5 minutes	Total bacterial counts	200 x 10^3 cfu/g before treatments to 90x10^5 cfu/g after treatments	Hassan et al. (2015)
Cabinet drying at 125°C for 4 hours	Mesophilic aerobic total spore count *Enterobacteriaceae* *Salmonella enteritidis* *Salmonella typhimurium* *Listeria monocytogenes*	Below 10^3 cfu/g Below 10 cfu/g Negative/25 g Negative/25 g Negative/25 g	Nemeth et al. (2015)
Soaking in 1% sodium hypochlorite solution for 5 min followed by 10 min in boiling water and drying at 50°C for 24 hours	*Salmonella* *Coliform* *Staphylococcus*	Negative	Milbradt et al. (2015)
ClO_2 gas-generating system using a chamber	*Salmonella enterica* subsp. *enterica* serovar Enteritidis and *Salmonella enterica* subsp. *enterica* serovar Gallinarum	More than 4 log reduction in bacterial populations after 30 min of exposure to ClO_2 each at 20 ppm, 40 ppm, and 80 ppm against *S.* Enteritidis and 40 ppm and 80 ppm against *S.* Gallinarum	Kim et al. (2016)
Sterilization by using 70% ethyl alcohol solvent in soxhlet, followed by drying using an incubator at 40°C	Total mesophilic aerobic bacteria	Negative for mold-yeast and *Salmonella* spp.	Zerek et al. (2022)
Boiling in water at 95°C for one hour or steaming at 121°C for 15 minutes	Total plate count, yeast, mold, *Escherichia coli* and *Salmonella*	Total plate count, yeast and mold below 10 CFU/g, *Escherichia coli* below 3 MPN/g, and negative/25 g for *Salmonella*	Therdthai et al. (2023)

Ensuring the safety and quality of eggshells is crucial due to the potential presence of harmful substances such as lead and pathogenic bacteria. Eggshells possess approximately 10,000 to 20,000 pores, which can adsorb various toxic compounds including chromium, lead, methyl orange, and cadmium. This high adsorption capacity highlights the importance of conducting toxicity evaluations. Toxicity testing aims to determine the harmful effects of a substance when administered in a single, large dose, providing critical information about the dose levels that may cause toxic symptoms or result in mortality (Fajriaty et al. 2024).

An acute toxicity test was conducted to evaluate the safety profile of eggshell membrane when administered orally to mice in a single high dose. The test revealed that the median lethal dose (LD_{50}) exceeded 2000 mg/kg body weight (BW), which classifies the substance as having low acute toxicity according to OECD (Organization for Economic Co-operation and Development) guidelines. Throughout the 14-day observation period following administration, no clinical signs of toxicity were observed, such as changes in behavior, physical condition, food and water intake, or mortality. The absence of these symptoms suggests that the eggshell membrane does not pose significant short-term toxicological risks at this dosage level. These findings support its potential safety for use in food or pharmaceutical applications, although further studies on chronic toxicity and other safety parameters are still recommended (Ruff et al. 2012).

To assess the safety of eggshell powder, related research on both oral acute toxicity and sub-chhronic toxicity tests has also been conducted. Oral acute toxicity evaluation assesses toxic effects that appear shortly after administering a substance, either as a single dose or repeated doses within 24 hours, by monitoring signs of toxicity and mortality. In contrast, sub-chronic toxicity tests involve repeated dosing over a longer period, typically 28 days, to evaluate potential longer-term effects. A study by Fajriaty et al. (2024) demonstrated that eggshell powder did not induce any signs of poisoning or cause a reduction in the body weight of rats. The LD_{50} value of eggshell powder was determined to be greater than 5000 mg/kg body weight, classifying it as practically non-toxic. Additionally, eggshell powder had no significant effect on body weight gain in both male and female rats and did not alter the hematological profile. Biochemical blood parameters remained mostly within normal ranges, although female rats exhibited increases in total cholesterol and LDL levels, while male rats showed elevated creatinine levels. Some reversible histopathological changes were observed, including heart hypertrophy and necrosis as well as kidney glomerular atrophy in both sexes, but no alterations were detected in the lungs or spleen. Overall, these findings indicate that eggshell powder is likely safe for human consumption, though the noted biochemical and histological changes warrant further investigation.

4. Conclusions

This review consolidates evidence on the safety of eggshell powder as a food additive, focusing on microbiological and chemical risks, including toxicity. The findings confirm that while eggshells are a promising source of calcium for food fortification and can act as a preservative, they are susceptible to microbial contamination from pathogens such as *Salmonella* spp. and *Escherichia coli*. Numerous foodborne outbreaks have been linked to contaminated eggs, underscoring the critical need for effective decontamination. The production process of eggshell powder must incorporate validated microbial reduction strategies, such as thorough washing, heat treatment (drying at 65°C-160°C), chlorine dioxide gas, or autoclaving, which have been shown to significantly reduce pathogen loads.

Chemically, eggshells have low levels of toxic heavy metals (e.g., Pb, Cd). Acute toxicity is minimal: eggshell membrane's LD_{50} exceeded 2000 mg/kg BW in mice, and eggshell powder's LD_{50} was over 5000 mg/kg BW in rats (practically non-toxic), causing no acute poisoning signs. Sub-chronic tests on eggshell powder showed no major impact on rat body weight or hematology, but some reversible biochemical (cholesterol, creatinine) and histopathological (heart, kidney) changes occurred. Though considered likely safe, these changes require further study. In summary, eggshell powder holds considerable potential as a safe and valuable food additive. However, its use must be predicated on stringent microbiological control measures throughout processing. While acute toxicity is low, the subtle biochemical and histological changes observed in sub-chronic studies highlight the importance of ongoing research to fully delineate long-term safety parameters for its widespread use in food products, ensuring consumer health remains protected.

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