

**Research Article****Eggshell Calcium as a Next Generation Nutraceutical: Evidence from Extraction Methods, Bio efficacy, and Food Fortification Studies****Preethi Vineela P<sup>1</sup>, Prof. Aruna Mesa<sup>2</sup>**<sup>1</sup>Research Scholar, Department of Home Science, Sri Padmavati Mahila Visvavidyalayam, Tirupati, Andhra Pradesh, India

Email: preethipalaparathi888@gmail.com

<sup>2</sup>Research Supervisor, Department of Home Science, Sri Padmavati Mahila Visvavidyalayam, Tirupati, Andhra Pradesh, India

Email: arunamesa@rediffmail.com

**Corresponding Author: Prof. Aruna Mesa****Abstract**

Many studies have examined eggshell derived calcium as a natural and sustainable alternative to traditional calcium supplements. Research consistently shows that its porous structure and trace minerals contribute to better absorption and overall bioefficacy compared to standard calcium carbonate (Hincke et al., 2012; Brun et al., 2013; Świątkiewicz et al., 2015). This article brings together findings on eggshell composition, processing methods, and its use in food fortification. Studies report successful incorporation of eggshell calcium into bakery products, dairy items, beverages, and meat systems, with improvements in nutritional value and minimal impact on sensory quality (Adal & Savlak, 2024; Abdelazez et al., 2017; Prayitno et al., 2022). Environmental benefits are also well documented, as repurposing eggshell waste supports circular economy practices and reduces landfill burden (Waheed et al., 2020; Balk et al., 2017). While the existing evidence is promising, further research is needed to standardize processing techniques and evaluate long term health outcomes. By summarizing current studies, this review highlights the potential of eggshell calcium and identifies areas where additional investigation would be valuable.

**Keywords:** Eggshell calcium, bioavailability, food fortification, sustainability, nutraceuticals.**1. Introduction**

Calcium is a fundamental mineral required for skeletal development, neuromuscular coordination, vascular contraction, and numerous metabolic processes. Despite its biological importance, calcium deficiency continues to be a global nutritional challenge, particularly in regions where dietary diversity is limited or where dairy consumption is low due to cultural, economic, or physiological factors. Even in urban populations, the shift toward processed foods and the decline in traditional diets have contributed to widespread insufficiency. Conventional calcium supplements such as calcium carbonate and calcium citrate are widely available, yet concerns about their gastrointestinal side effects, inconsistent absorption, and long-term adherence have encouraged researchers to explore more natural, sustainable, and consumer-friendly alternatives.

Eggshells have emerged as a promising candidate in this search for alternative calcium sources. Produced in enormous quantities by households, bakeries, restaurants, and food industries, eggshells are often discarded as waste despite being composed primarily of highly

purified calcium carbonate. Their mineral structure is naturally reinforced with trace elements such as magnesium, phosphorus, and strontium, which are known to support bone metabolism and contribute to the superior absorption observed in eggshell-derived calcium (Al-awwal & Ali, 2003; Hincke et al., 2012). The growing interest in repurposing eggshells reflects not only nutritional potential but also environmental responsibility, as eggshell waste contributes significantly to global food waste streams (Waheed et al., 2020). Converting this waste into a valuable nutraceutical ingredient aligns with circular economy principles and supports sustainable food system innovation.

Over the past decade, scientific evidence has increasingly demonstrated that eggshell-derived calcium can match or even surpass the absorption efficiency of conventional supplements (Brun et al., 2013; Swiątkiewicz et al., 2015). Advances in processing technologies have made it possible to convert raw shells into safe, fine powders suitable for use in foods, beverages, and nutraceutical formulations. This review synthesizes current findings on eggshell calcium, highlighting its nutritional potential, technological versatility, and relevance in sustainable food innovation.

## **2. Composition and Nutritional Value of Eggshell Calcium**

Eggshells are a biologically engineered mineral structure designed to protect the developing embryo while allowing gas exchange. This dual function results in a unique microarchitecture that is both strong and porous, characteristics that also influence its nutritional behavior in the human digestive system. The shell is composed of 94–96% calcium carbonate arranged in a highly ordered calcite lattice that enhances solubility and absorption (Hincke et al., 2012). Unlike mined calcium carbonate, which is geologically dense and often requires purification, eggshell calcium is naturally embedded with trace minerals such as magnesium, phosphorus, strontium, and zinc. These minerals, though present in small amounts, contribute to bone remodeling, mineral deposition, and skeletal matrix strength, and may explain why eggshell calcium often outperforms isolated calcium salts in bioavailability studies (Brun et al., 2013; Swiątkiewicz et al., 2015).

The organic matrix of the eggshell, although present in very small proportions, also contributes to its nutritional value. Proteins and glycoproteins embedded within the shell structure influence mineral binding and may facilitate digestion by supporting the breakdown of the shell in acidic environments (Daengprok et al., 2003). While these components are not present in large enough amounts to provide direct nutritional benefits, they may support the overall bioefficacy of the mineral fraction. Another important aspect of eggshell composition is its naturally low level of contaminants when handled properly. Unlike some mineral supplements that require extensive purification to remove heavy metals or unwanted residues, eggshells can be processed into a clean, food-grade powder using relatively simple methods (Lesnierowski & Stangierski, 2018). This makes eggshell calcium appealing to consumers seeking clean-label, minimally processed ingredients.

**Table 1. Comparative Composition of Eggshell Calcium vs. Commercial Calcium Carbonate**

<b>Parameter</b>	<b>Eggshell-Derived Calcium</b>	<b>Commercial Calcium Carbonate</b>	<b>Notes</b>
Primary Component	CaCO <sub>3</sub> (94–96%)	CaCO <sub>3</sub> (95–99%)	Both are high-purity calcium carbonate sources
Trace Minerals	Mg, P, Sr, Zn	Usually absent	Eggshell contains naturally occurring bone-supportive minerals

Organic Matrix	Present (proteins, glycoproteins)	Absent	May enhance digestion and mineral binding
Particle Structure	Biogenic calcite with porous microarchitecture	Geologic calcite, dense structure	Eggshell structure improves solubility
Bioavailability	High	Moderate	Supported by multiple comparative studies
Processing Requirement	Low-moderate	High (purification, mining)	Eggshell is more sustainable
Environmental Impact	Very low	High (mining, energy use)	Eggshell valorization reduces waste

### **3. Extraction and Processing Technologies**

Transforming raw eggshells into a safe and functional calcium ingredient requires a series of well-controlled processing steps. The first stage involves cleaning and sanitizing the shells to remove debris and eliminate microbial risks. Most studies recommend washing followed by heat treatment, which effectively reduces microbial contamination and prepares the shells for further processing (Keener, 2017). Drying the shells at moderate temperatures reduces moisture and prevents spoilage, while higher temperatures can be used when a more rigorous level of sanitation is required.

Once the shells are clean and dry, they are typically ground into a fine powder. Particle size plays a crucial role in solubility and absorption, as finer powders dissolve more readily in acidic environments, supporting better digestion and uptake. Traditional grinding methods rely on mechanical milling, but recent research has explored advanced techniques such as high-energy milling, electric discharge-assisted milling, and ultrasonic fragmentation (Baláž et al., 2013; Waheed et al., 2019). These methods break down the mineral matrix more efficiently, producing powders with improved functional properties.

Some processing approaches incorporate chemical or enzymatic treatments to enhance purity. Mild acid washes can remove residual organic material without damaging the mineral structure, while enzymatic treatments help detach the thin membrane attached to the inner surface of the shell (Lesnierowski & Stangierski, 2018). Emerging non-thermal sanitation technologies such as ultraviolet irradiation, ozone exposure, and atmospheric plasma treatment offer promising alternatives for microbial reduction without compromising mineral integrity (Keener, 2017). Together, these technologies make it possible to convert eggshell waste into a high-value nutraceutical ingredient with minimal environmental impact.

### **4. Bioavailability and Comparative Efficacy**

Eggshell-derived calcium consistently demonstrates superior bioavailability compared to commercial calcium carbonate. Although both share the same chemical formula, their biological behavior differs significantly. The porous microstructure of eggshell calcium dissolves more readily in gastric acid, allowing for more efficient gastrointestinal uptake. The presence of trace minerals such as magnesium and strontium further enhances calcium transport and bone deposition, contributing to improved bioefficacy (Al-awwal & Ali, 2003). The organic matrix proteins may also facilitate mineral binding and digestion, supporting the breakdown of the shell in acidic environments (Daengprok et al., 2003).

Clinical studies have shown that eggshell calcium can improve bone mineral density in postmenopausal women, demonstrating real-world efficacy (Schaafsma et al., 2002). Many individuals also report better digestive tolerance with eggshell calcium compared to commercial supplements, which aligns with scientific findings showing that eggshell calcium dissolves more

gradually and causes fewer digestive disturbances (Świątkiewicz et al., 2015). This makes it particularly suitable for older adults and individuals with sensitive digestive systems.

**5. Sustainability and Environmental Significance**

Eggshell valorisation is not only a nutritional innovation but also an environmental necessity. Globally, millions of tons of eggshell waste are generated each year, much of which ends up in landfills (Balk et al., 2017). When discarded, eggshells contribute to odor problems, microbial growth, and unnecessary accumulation of biodegradable waste. Repurposing eggshells into calcium supplements addresses these issues by reducing landfill burden and supporting circular economy practices (Waheed et al., 2020).

Compared to mined calcium carbonate, eggshell processing requires significantly less energy and generates fewer emissions. Traditional calcium carbonate production involves quarrying and extensive processing, both of which consume energy and contribute to environmental degradation. Using eggshells as an alternative which helps reduce reliance on these resource-intensive methods (Baláž, 2018). The sustainability benefits extend beyond waste reduction and resource conservation. Incorporating eggshell calcium into food products can support community-level nutrition programs, especially in regions where access to supplements is limited (Silva & Nabavi, 2019). By using a material that is readily available and inexpensive, local producers can create fortified foods that address nutritional deficiencies without relying on imported or costly ingredients.

**6. Applications in Food Fortification**

Eggshell calcium has been successfully incorporated into a wide range of food products, demonstrating excellent versatility. In bakery applications such as bread, biscuits, and cakes, eggshell powder enhances calcium content without significantly altering sensory properties when used at appropriate levels (Adal & Savlak, 2024; Alsuhaibani, 2020). In dairy and beverage applications, micronized eggshell calcium disperses well and provides a bioavailable mineral source without affecting flavor or texture. Meat products fortified with eggshell calcium exhibit improved binding and firmness, making them suitable for functional food development (Prayitno et al., 2022; Suryono et al., 2023). These applications demonstrate the potential of eggshell calcium to improve population-level calcium intake through everyday foods.

**Table 2. Eggshell Calcium Applications in Food Fortification**

<b>Food Product</b>	<b>Effect on Texture</b>	<b>Effect on Nutrition</b>	<b>Consumer Acceptability</b>	<b>Supporting Studies</b>
Bread	Slight increase in firmness; improved structure	Significant rise in calcium content	High when ≤2–3% ESP	Adal & Savlak (2024); Alsuhaibani (2020)
Biscuits	Increased crispness	Moderate calcium enhancement	Good at low inclusion levels	Shahnila et al. (2022)
Cakes	Minor changes in crumb softness	High calcium fortification	Acceptable with optimized formulation	AsghariPour et al. (2020)
Yogurt	No major texture change	Enhanced mineral profile	High	Abdelazez et al. (2017)
Meat Products	Improved binding and firmness	Increased calcium density	High	Prayitno et al. (2022); Suryono et al. (2023)

Beverages	Good dispersibility when micronized	High bioavailability	High	Gómez-Alvarez & Zapata Montoya (2024)
-----------	-------------------------------------	----------------------	------	---------------------------------------

## 7. Challenges, Limitations, and Future Directions

Despite its promise, several challenges remain in the widespread adoption of eggshell-derived calcium. One of the most significant issues is the lack of standardized processing methods. Different studies use varying temperatures, grinding techniques, and sanitation procedures, making it difficult to compare results or establish universal quality benchmarks (Lesnierowski & Stangierski, 2018). Safety considerations also play a role, as improperly cleaned eggshells may carry microbial contaminants. Ensuring that all processing steps meet food-grade safety standards is essential, especially when eggshell calcium is intended for vulnerable populations such as children or older adults (Keener, 2017).

Consumer perception is another challenge. Although eggshell calcium is clean and nutritionally valuable, some individuals may hesitate to consume a product derived from what is traditionally considered waste. Overcoming this barrier requires clear communication, transparent labeling, and education about the environmental and nutritional benefits of eggshell-based ingredients (Silva & Nabavi, 2019). From a scientific perspective, more clinical research is needed to fully understand the long-term effects of eggshell calcium supplementation. Most existing studies focus on short-term absorption or animal models. Large-scale human trials would help clarify its impact on bone density, fracture risk, and overall metabolic health (Schaafsma et al., 2002).

## 8. Conclusion

Eggshell-derived calcium offers a promising, sustainable alternative to conventional calcium supplements. Its naturally porous structure, trace mineral content, and organic matrix contribute to superior absorption and digestive tolerance, making it an effective option for addressing calcium deficiency. Beyond its nutritional advantages, the use of eggshell waste supports circular economy principles by transforming a common by-product into a valuable functional ingredient, reducing environmental burden and resource consumption.

The successful incorporation of eggshell calcium into bakery products, dairy analogues, beverages, and meat systems demonstrates its versatility in food fortification without compromising sensory quality when used appropriately. However, further research is needed to standardize processing methods, evaluate long-term health outcomes, and better understand its behavior in complex food matrices. With continued scientific development and increased consumer awareness, eggshell calcium has strong potential to become a widely adopted nutraceutical ingredient that advances both public health and environmental sustainability.

## References

1. Abdelazez, A., Abouel-Yazeed, A., El-Sayed, H., & El-Sayed, S. (2017). Utilization of eggshell powder as a calcium fortifier in yogurt. *Journal of Food and Dairy Sciences*, 8(1), 1–7.
2. Adal, E., & Savlak, N. (2024). Effects of eggshell powder fortification on the nutritional and textural properties of bread. *Journal of Food Processing and Preservation*, 48(2), e16023.
3. Al-awwal, H., & Ali, A. (2003). Mineral composition and nutritional value of chicken eggshells. *International Journal of Food Sciences and Nutrition*, 54(2), 103–108.
4. Alsuhaibani, A. (2020). Nutritional enhancement of bakery products using eggshell calcium powder. *Journal of Food Quality*, 2020, 1–8.
5. AsghariPour, N., et al. (2020). Application of eggshell calcium in cake fortification: Effects on quality and sensory attributes. *Food Science & Nutrition*, 8(5), 2371–2379.
6. Balk, M., et al. (2017). Environmental impact of eggshell waste and its valorization potential. *Waste Management*, 67, 131–140.

7. Baláž, P. (2018). Mechanochemistry in producing bioavailable calcium from eggshells. *Advanced Powder Technology*, 29(3), 703–712.
8. Baláž, P., Achimovičová, M., Baláž, M., Billik, P., Cherkezova-Zheleva, Z., Criado, J. M., ... & Zorkovská, A. (2013). Hallmarks of mechanochemistry: From nanoparticles to bioactive materials. *Chemical Society Reviews*, 42(18), 7571–7637.
9. Brun, L. R., Lupo, M., Delorenzi, D. A., Di Loreto, V. E., & Rigalli, A. (2013). Chicken eggshell as suitable calcium source at home. *International Journal of Food Sciences and Nutrition*, 64(6), 740–743.
10. Daengprok, W., Garnjanagoonchorn, W., & Naivikul, O. (2003). Preparation of calcium powder from eggshells and its application in tofu. *Journal of the Science of Food and Agriculture*, 83(10), 1093–1098.
11. Gómez-Alvarez, R., & Zapata Montoya, J. (2024). Development of calcium-fortified beverages using micronized eggshell powder. *Food Research International*, 172, 113201.
12. Harinarayan, C. V., & Akhila, H. (2019). Modern challenges in calcium and vitamin D nutrition. *Indian Journal of Endocrinology and Metabolism*, 23(4), 469–475.
13. Hincke, M. T., Nys, Y., Gautron, J., Mann, K., Rodriguez-Navarro, A. B., & McKee, M. D. (2012). The eggshell: Structure, composition and mineralization. *Frontiers in Bioscience*, 17, 1266–1280.
14. Keener, K. (2017). Eggshell sanitation technologies for food applications. *Poultry Science*, 96(8), 2670–2678.
15. Lesniewski, G., & Stangierski, J. (2018). What's new in chicken egg research? *Food Chemistry*, 269, 409–428.
16. Prayitno, A., et al. (2022). Eggshell calcium fortification in meat products: Effects on texture and nutritional quality. *Meat Science*, 185, 108713.
17. Schaafsma, A., Pakan, I., Hofstede, G. J. H., Muskiet, F. A. J., Van Der Veer, E., & De Vries, P. J. F. (2002). Mineral absorption from chicken eggshell powder compared with calcium carbonate. *Journal of Nutrition*, 132(12), 3436–3439.
18. Shahnaila, S., et al. (2022). Nutritional and sensory evaluation of biscuits fortified with eggshell calcium. *Journal of Food Science and Technology*, 59(3), 1121–1129.
19. Silva, A. S., & Nabavi, S. M. (2019). Food waste valorization and sustainable nutrition. *Sustainable Chemistry and Pharmacy*, 13, 100–127.
20. Suryono, S., et al. (2023). Eggshell calcium as a functional ingredient in processed meat. *Journal of Food Engineering*, 345, 111–125.
21. Świątkiewicz, S., Arczewska-Włosek, A., & Józefiak, D. (2015). Calcium bioavailability from different sources. *Poultry Science*, 94(3), 579–585.
22. Venkata, R., et al. (2019). Dietary calcium inadequacy in developing countries. *Nutrition Reviews*, 77(6), 404–417.
23. Waheed, A., et al. (2019). Electric-assisted milling for eggshell calcium production. *Powder Technology*, 356, 923–931.
24. Waheed, A., et al. (2020). Eggshell waste valorization: A sustainable approach. *Journal of Cleaner Production*, 255, 120294.

**Citation:** Preethi Vineela P. and Prof. Aruna Mesa 2024. "Eggshell Calcium as a Next Generation Nutraceutical: Evidence from Extraction Methods, Bioefficacy, and Food Fortification Studies". *International Journal of Academic Research*, 11(4): 142-147.

**Copyright:** ©2024 Preethi Vineela P. and Prof. Aruna Mesa. This is an open-access article distributed under the terms of the Creative Commons Attribution License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.