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Review on development of texture and nutrients of ice cream by utilization of eggshell or waste

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Abstract

Calcium stands as a vital macronutrient crucial for bone health and various bodily functions. Insufficient calcium levels can lead to osteoporosis, prompting the need for calcium supplements. Recent research points to the promise of eggshell-derived calcium carbonate as a viable, easily absorbed calcium source for dietary enrichment, particularly in bread. Eggshells, abundant in calcium carbonate, offer a sustainable, cost-efficient method to boost calcium intake while addressing food production waste. Eggshells are comprised of three main components: eggshells (9.5%), egg white (63%), and egg yolk (27.5%). Notably, eggshells predominantly consist of 0.8% magnesium carbonate, 0.8% tricalcium phosphate, and 98.4% calcium carbonate. This review delves into calcium's supplementation role, emphasizing eggshell calcium carbonate's effectiveness, absorption, and bone health benefits. Integrating eggshell calcium into bread not only enhances its nutritional value but also promotes sustainability by reusing waste. Furthermore, the review explores calcium solubility from eggshells, extraction methods, and eggshell powder's diverse applications in both food and non-food items. It also examines the health advantages of eggshell calcium products, from osteoporosis prevention to digestive health support. Additionally, it considers consumer attitudes toward innovative products like eggshell calcium-fortified ice cream, stressing the importance of retaining sensory aspects while delivering nutrition. Overall, this review highlights eggshell calcium carbonate's potential to boost dietary calcium, support health, and advance environmental sustainability.

Keywords: Ice cream, calcium supplementation, eggshell calcium carbonate, bone health, osteoporosis prevention, waste reduction

1. Introduction

In recent years, consumer preferences have increasingly shifted towards healthier food choices, driving a growing interest in enhancing the nutritional profile of commonly consumed items, including ice cream. As a popular and beloved frozen dessert, ice cream presents an excellent candidate for fortification with essential nutrients. One promising approach to achieving this enhancement is through the utilization of eggshells, which not only serve as a source of calcium but also have the potential to influence the texture and overall quality of ice cream.

1.1 Ice Cream

Ice cream, a dessert loved globally, plays a key role in the food industry, especially with vanilla and chocolate flavors being the most popular. However, the environmental impacts of ice cream production and consumption have not been extensively studied. An in-depth life cycle assessment (LCA) of leading vanilla and chocolate ice creams, including both regular and premium types, provides important insights into the sustainability challenges of ice cream production. This analysis highlights critical areas for improvement in the supply chain, from ingredient sourcing to manufacturing and storage practices. These findings are vital for industry stakeholders, policymakers, and consumers who want to make informed decisions about the environmental impact of their favorite ice creams (Konstantas, 2018) ^[1].

1.2 Eggshell

Eggshells, predominantly composed of calcium carbonate (CaCO₃), present an opportunity for sustainable resource utilization. The extraction of calcium from eggshells can address both the issue of waste management given the millions of tons of eggshells discarded

globally - and the need for innovative ways to fortify food products (Putkham, 2018) ^[2]. Calcium is vital for bone health and various physiological functions, and its incorporation into ice cream can significantly enhance its nutritional value. The development of ice cream texture is a crucial aspect of consumer satisfaction. The incorporation of eggshell-derived calcium introduces an intriguing dimension to this development, potentially affecting texture, mouthfeel, and overall sensory experience (Van der Hee *et al.*, 2009) ^[3].

1.3 Calcium Carbonate (CaCO₃)

Calcium carbonate, a vital mineral essential for various physiological functions in the human body, can be extracted from eggshells, offering a sustainable and cost-effective alternative source of this important nutrient (Niu *et al.*, 2022) ^[4]. Eggshell waste, generated in significant quantities by food manufacturers and households, presents an opportunity to repurpose this by-product into a valuable resource for calcium enrichment in food and other applications. This not only addresses the challenge of meeting dietary calcium requirements, especially for individuals with lactose intolerance, but also contributes to reducing environmental waste and promoting resource efficiency in the food industry.

1.4 Health Benefits

Calcium is essential for supporting overall health and wellness. It is essential for bone health, muscle function, nerve signaling, and blood clotting. Adequate calcium intake helps prevent conditions such as osteoporosis and supports various physiological processes. Calcium has also been linked to benefits such as regulating blood pressure, aiding in weight management, and potentially preventing colorectal adenomas (Baron *et al.*, 1999) ^[5].

1.5 Nutritional Composition of Eggshell Powder

Chicken eggshell powder (ESP) is a promising source of essential nutrients. It is rich in calcium and strontium, and contains trace minerals like magnesium, zinc, and iron. ESP is highly bioavailable, facilitating efficient calcium absorption, and is low in calories, making it suitable for dietary supplementation without adding excessive calories. The neutral taste of ESP allows it to be easily incorporated into various food products without affecting flavor (Schaafsma *et al.*, 2000) ^[6].

1.6 Calcium Intake

The recommended calcium intake varies by age and gender. For adults aged 19-50 years, the Population Reference Intake (PRI) is 1,000 mg/day. For adults aged 51-70 years, the PRI ranges from 800-1,300 mg/day for men and 800-1,200 mg/day for women. The Average Requirement (AR) for calcium for adults is estimated to be 750 mg/day, with a Predicted Population Intake (PRI) of 950 mg/day when considering dermal losses (EFSA, 2015) ^[7].

2. Literature review

2.1 Role of Calcium as Supplements

Bradauskiene, Montrimaite, & Moscenkova *et al.*, (2017) ^[8] ^[15]. The normal functioning of the human body relies significantly on calcium, a crucial macronutrient known for its role in bone health and various physiological functions. Osteoporosis, a condition characterized by bone loss, often

stems from calcium deficiency in the diet. To counteract this deficiency and enhance calcium absorption in smaller amounts, calcium supplements have been recommended as a viable solution.

The incorporation of calcium carbonate from eggshell powder into bread serves as a means of fortifying the product with essential calcium, which is crucial for bone health and overall well-being. This enrichment strategy can potentially address dietary deficiencies and contribute to improved nutrient intake. Bone Health Support, calcium carbonate derived from eggshells has been identified as a valuable source of calcium that can promote bone strength and growth. By enhancing the calcium content of bread through eggshell powder, this study suggests a practical approach to supporting skeletal health and potentially preventing bone-related issues like osteoporosis. Waste Reduction and Sustainability, utilizing eggshells as a calcium carbonate source for bread enrichment not only enhances the nutritional value of the product but also aligns with sustainable practices by repurposing a byproduct that would otherwise be discarded. This approach underscores the potential for waste reduction and environmental conservation in food production. Bioavailability and Absorption, the bioavailability of calcium carbonate from eggshells is highlighted as an effective source of calcium for dietary supplementation and fortification. The study indicates that enriched products like bread can offer higher calcium absorption rates compared to traditional sources, emphasizing the importance of bioavailable calcium for optimal nutrient intake.

Kato *et al.*, (2002) ^[9] Eggshell calcium carbonate has emerged as a potential supplementary source of calcium due to its natural abundance and nutritional composition. Comprised primarily of calcium carbonate, eggshells offer bioavailable calcium that can be effectively absorbed by the body. Research suggests that calcium from eggshell sources is comparable in bioavailability to commercial calcium supplements, making it a viable option for meeting daily calcium requirements. In addition to supporting bone health, eggshell calcium carbonate may provide other health benefits, such as improving bone mineral density and potentially reducing the risk of osteoporosis. The presence of bioactive compounds in eggshells could also contribute to antioxidant and anti-inflammatory effects, promoting overall well-being. Incorporating eggshell calcium carbonate into the diet can offer a cost-effective and sustainable means of increasing calcium intake, particularly for individuals with dietary restrictions. Preparation of eggshell powder at home by grinding cleaned and dried eggshells provides a convenient method for consumption. However, ensuring the quality and safety of eggshells used for supplementation is crucial to avoid potential contamination or adverse effects. While current research supports the efficacy and potential benefits of eggshell calcium carbonate, further studies are needed to explore its long-term effects on bone health, mineral metabolism, and overall nutritional status. Comparative research with traditional calcium sources and clinical trials in diverse populations could provide valuable insights into the efficacy and safety of eggshell calcium carbonate supplementation, highlighting its promising role in promoting calcium intake and supporting overall health.

Ray, S., Kumar Barman, *et al.*, (2017) ^[10] Eggshell calcium carbonate has emerged as a promising dietary supplement

due to its high absorbability and rich calcium content. With calcium being essential for various physiological functions, including bone health and metabolic processes, the use of chicken eggshell powder as a calcium source presents a cost-effective and easily accessible alternative to traditional supplements. Studies have shown that eggshell powder, with a calcium content of about 38%, can potentially enhance bone density and alleviate symptoms in individuals with conditions like osteoporosis. Furthermore, the utilization of eggshell powder in food products, such as chocolate cakes, not only enhances the nutritional value but also offers functional benefits. The incorporation of eggshell powder in varying concentrations, such as 3%, 6%, and 9%, has demonstrated a significant increase in calcium content in the fortified cakes. This natural source of calcium, derived from eggshell waste, not only addresses environmental concerns but also provides a practical solution to calcium deficiency. Overall, the research on eggshell calcium carbonate highlights its potential as a valuable supplementary source of calcium with diverse applications in the food industry, promoting both health and sustainability alternative sources of calcium, with chicken eggshell powder (CESP) emerging as a promising option.

Silva & Nabavi, *et al.*, (2019) ^[11] The cost of calcium supplements further adds to the complexity, making it a challenge for economically disadvantaged individuals to access these supplements for disease treatment or meeting dietary requirements.

2.2 Enrichment with calcium by using eggshell

Flammini *et al.*, (2016) ^[12] Several have explored several sources for fortifying food to meet daily calcium intake requirements, including calcium phosphate, cattle bone powder, milk calcium, and calcium carbonate. The use of calcium carbonate derived from eggshell powder as a supplementary source of calcium in bread production is particularly promising. Calcium carbonate, a common form of calcium salt, is recognized for its various beneficial uses and applications in the food industry. Eggshells, rich in bioavailable calcium carbonate, offer an effective source of calcium. Research indicates that calcium is crucial for bone health, hormone regulation, muscle function, and neuronal conduction. Effective calcium absorption is essential for maintaining bone density and preventing conditions like osteoporosis. In bread production, calcium carbonate from eggshell powder can enhance the quality of the final product. It reacts with acids during baking, releasing CO₂ gas, which increases the porosity and specific volume of bread. This reaction results in bread with improved texture, appearance, and overall acceptability. Additionally, calcium ions in calcium carbonate can influence the permeability of cell membranes, enhance yeast fermentation, and improve the structural and mechanical properties of bread crumb. However, it is important to note that an overdose of calcium can inhibit the fermentation process.

Eggshells, typically considered non-edible by-products, generate massive amounts of waste globally, particularly in food manufacturing, egg-based product companies, poultry farms, hatcheries, restaurants, and homes (Amu *et al.*, 2005) ^[13]. Despite being categorized as waste, eggshells have been recognized as a potential source of bioactive compounds, including calcium. The food processing industry alone produces around 250,000 tons of eggshell waste annually worldwide, with the USA contributing a significant portion of 150,000 tons (Abdullah *et al.*, 2018) ^[14].

2.2.3 Solubility of Calcium Extracted from Eggshells

Calcium lactate and citrate derived from eggshells exhibit water solubility similar to that of milk, unlike calcium carbonate, which is insoluble in water. The solubility of calcium from eggshells surpasses that of commercial supplements like Calcivit, Calcigran, and Coral Calcium.

Bradauskiene *et al.*, (2017) ^[15] underscored the importance of calcium in human health, highlighting its role in critical physiological functions like bone formation, muscle contraction, and nerve signaling. Despite its significance, many individuals fall short of consuming sufficient calcium, leading to potential health issues such as bone loss and osteoporosis. To combat this deficiency, researchers have explored diverse calcium sources for fortification, including eggshells, renowned for their high calcium carbonate content. Eggshells have emerged as a promising natural calcium source owing to this characteristic. Studies have demonstrated that eggshell powder could serve as an economical calcium supplement with readily absorbable calcium. The solubility of calcium derived from eggshells is a pivotal factor in determining its efficacy as a fortification source. Various research efforts have delved into methods to enhance the solubility of calcium from eggshells. For instance, investigations into dissolving eggshell powder in acidic solutions like lemon juice or vinegar have been undertaken. These endeavors aim to ensure the effective absorption and utilization of calcium from eggshells when incorporated into food products like bread. In the realm of bread fortification with calcium using eggshell powder, the solubility of the extracted calcium is crucial to prevent unfavorable texture alterations in the end product. Through experimentation with different incorporation techniques and assessment of sensory characteristics, researchers can ascertain the optimal conditions for maximizing calcium solubility while upholding bread quality and appeal. Future research endeavors could concentrate on further refining the solubility of calcium obtained from eggshells for various food applications, including bread fortification. A comprehensive understanding of the factors influencing calcium solubility from eggshells will enable the development of effective strategies to enrich the nutritional content of food items and address calcium deficiencies in populations.

2.2.4 Eggshell Composition

Eggshells are comprised of three main components: eggshells (9.5%), egg white (63%), and egg yolk (27.5%). Notably, eggshells predominantly consist of 0.8% magnesium carbonate, 0.8% tricalcium phosphate, and 98.4% calcium carbonate. These minerals, along with trace elements like boron, copper, iron, magnesium, molybdenum, sulfur, silicon, and zinc, contribute to the nutritional richness of eggshells.

Schaafsma *et al.* (2000) ^[17] revealed that chicken eggshell powder is abundant in essential minerals crucial for bone health, particularly calcium (Ca) and strontium (Sr). The average calcium content was measured at 401 mg/g, surpassing recommended daily intakes for adults, while strontium, with a mean content of 372 µg/g, also contributes significantly to bone health. Additionally, the powder contains trace amounts of zinc (Zn), iron (Fe), copper (Cu), selenium (Se), and other essential minerals vital for overall well-being. Although the absolute concentrations of amino acids in eggshell powder are relatively modest per gram,

their presence enhances the powder's nutritional profile. Amino acids play various roles in bodily functions, though their impact on bone metabolism from eggshell powder may be limited due to their low concentrations. Moreover, the study identified hormone-like activity in eggshell powder, including calcitonin and transforming growth factor- β 1 (TGF- β 1), which are known to influence bone metabolism and may contribute to the potential benefits of eggshell powder on bone mineral density and pain reduction. Furthermore, eggshell powder was found to contain low levels of potentially harmful elements such as lead (Pb), aluminum (Al), cadmium (Cd), and mercury (Hg). These controlled low levels of toxic elements establish eggshell powder as a safe mineral source for human consumption, particularly when compared to other calcium supplements that may contain elevated levels of hazardous contaminants.

2.2.5 Microbial Parameters of Eggshell

Eggshells, membranes, and yolks are susceptible to contamination by various microorganisms, including pathogens like *Listeria monocytogenes*, *Escherichia coli*, *Yersinia enterocolitica*, *Salmonella*, and *Campylobacter jejuni*. Surface conditions, storage environments, dirty shells, and cracked eggs play a role in microbial contamination, highlighting the importance of proper handling and storage practices (Ricke *et al.*, 2001^[18]).

2.2.6 Calcium Extraction Methods

Several methods have been employed for calcium extraction from eggshells, ranging from simple processes involving hydrochloric acid to more advanced techniques like pulse electric field treatment (PEF) and ultrasound-assisted extraction. These methods aim to efficiently extract calcium from eggshells for various applications (Garnjanagoonchorn and Changpuak, 2007)^[19].

Garnjanagoonchorn, *et al.*, 2012^[19]. The extraction of calcium from eggshells to produce calcium chloride involves several key processes that are essential for the successful conversion of waste material into a valuable product. The extraction process typically begins with collecting and cleaning the eggshells to remove any impurities. The cleaned eggshells are then crushed into small pieces and dried to facilitate further processing. Once the eggshells are prepared, they are mixed with a hydrochloric acid solution, initiating a chemical reaction that dissolves the calcium carbonate present in the eggshells. The mixture is stirred periodically until no gas bubbles are observed, indicating the completion of the reaction. Subsequently, the mixture is centrifuged to separate the solid residues from the liquid supernatant. The supernatant containing the dissolved calcium chloride is then heated to evaporate the liquid content, leaving behind calcium chloride crystals or powder. This drying process is crucial for obtaining the desired calcium chloride product from the eggshells. The resulting calcium chloride powder can then be further characterized for its properties, such as protein content, ash content, solubility, and pH. Additionally, the extracted calcium chloride may undergo impurity analysis to ensure compliance with safety regulations and standards. This analysis may involve testing for metal impurities and other contaminants to verify the quality and purity of the extracted calcium chloride.

2.2.7 Non-Edible Applications

The application of eggshell powder spans beyond its use in

food to encompass fertilizers, papermaking, and bone graft materials. In agriculture, eggshell powder is employed to enrich soil and combat blossom end root disease. Moreover, it has attracted attention in the paper industry for its potential to bolster paper strength while mitigating the environmental impact of conventional paper production methods. Additionally, eggshells show promise in bone grafting applications due to their biocompatibility and ability to facilitate bone regeneration (Gaonkar *et al.*, 2007; Abdullah *et al.*, 2018; Dupoirieux *et al.*, 2001; Neunzehn *et al.*, 2015)^[14].

2.2.8 Edible Applications

Researchers have explored incorporating eggshell powder into various food items to boost their calcium content. Bread, cakes, biscuits, and even methods for preserving fruits and vegetables have been examined as potential ways to deliver the nutritional benefits of calcium from eggshells. Although studies have shown positive impacts on the nutritional value of these products, there may be some effects on sensory characteristics (Das *et al.*, 2013; Ray *et al.*, 2017; Wesley & Renitta, 2018; Thakur *et al.*, 2019).

2.2.9 Eggshell calcium-based products offer several health benefits

Bone Health and Osteoporosis Prevention: Eggshell calcium, primarily composed of calcium carbonate, is essential for bone and teeth formation, aiding in preventing osteoporosis, characterized by weakened and brittle bones. **Antacid Properties and Digestive Health:** The calcium carbonate in eggshell calcium acts as an antacid, neutralizing excess stomach acid and providing relief from heartburn and indigestion. This property can alleviate symptoms of acid reflux, indigestion, and stomach upset, promoting overall digestive health. **Reduced Risk of Calcium Deficiency-Related Conditions:** Eggshell calcium provides a readily absorbed form of calcium, helping to mitigate the risk of calcium deficiency-related conditions such as rickets and osteomalacia. Additionally, it may contain trace amounts of other minerals like magnesium, zinc, and iron, contributing to overall mineral balance in the body.

2.2.10 Consumer perception towards eggshell calcium-based ice cream

Consumer perception of eggshell calcium-based ice cream is crucial for food manufacturers aiming to innovate or modify products to meet changing consumer preferences. Understanding how consumers view alternative ingredients like eggshell calcium and how ingredient swaps affect overall product quality and subjective perception is vital. Health-conscious consumers may prefer ice cream fortified with eggshell calcium due to its alignment with their desire for healthier options. Taste and texture are key factors influencing consumer perception, with the product needing to maintain the expected deliciousness and creaminess of traditional ice cream to be well-received. Additionally, consumers following the "clean label" trend seek transparency about food ingredients, while there is also a growing demand for diverse calcium products and nutrient-rich foods. This prompts food manufacturers to consider reformulating ingredient lists to cater to these evolving preferences.

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