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Research Article

Extraction and Characterization of Calcium Chloride from Waste

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Abstract

This study investigated the extraction of calcium chloride ($CaCl_2$) from chicken eggshell waste. The objective of the study was to extract calcium as calcium chloride from waste of eggshell and characterize the physio-chemical properties of extracted calcium chloride. Calcium chloride was obtained using 4% and 5% hydrochloric acid (HCl) solutions, and the drying time was optimized to maximize yield. Analysis of a 2g sample of the extracted $CaCl_2$ revealed an ash content of 1.71g (85%) and a moisture content of 3.4%. The resulting calcium chloride exhibited high solubility in water. The optimal extraction conditions were achieved using a 5% HCl solution with a drying time of 3hours, yielding 7.2g of $CaCl_2$ per 10g of eggshell powder, corresponding to 72% anhydrous calcium chloride. Chicken eggshells, typically considered waste and discarded into the environment, contribute to pollution despite their high calcium content. Extraction of calcium in the form of calcium chloride offers a sustainable approach to waste valorization. Calcium is an essential nutrient involved in numerous biological processes, including nerve and muscle function, cell division, blood coagulation, and the prevention of chronic diseases such as osteoporosis. This study aimed to extract calcium from eggshell waste and characterize the physicochemical properties of the obtained calcium chloride, providing a potential solution for eggshell waste management and contributing to human health through calcium supplementation.

Keywords

Chicken Eggshell, Calcium Extraction, Calcium Chloride

1. Background of the Study

In recent years, large quantities of eggshells have been generated as byproducts in households, hotels, and food-processing industries. Eggshells, the hard outer covering of eggs, are typically discarded despite their high calcium content, contributing to environmental pollution. Due to their substantial calcium content, eggshells represent a valuable resource for nutritional supplementation. Studies have shown that eggshell-derived calcium can effectively improve bone mineral density (BMD) and alleviate osteoporosis-related discomfort in elderly populations. On average, an egg weighing 55-60g consists of approximately 10% shell and membrane.

Calcium is an essential nutrient involved in numerous biological processes, including nerve and muscle function, cell division, blood coagulation, and the prevention of chronic diseases [1]. Food fortification, which involves the addition of essential micronutrients such as vitamins and minerals to food, has been practiced globally for over

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eight decades to prevent nutrient deficiencies [2-4]. Similarly, calcium fortification in food products offers an economical strategy to meet daily calcium requirements and improve overall public health [5, 6].

Eggshells are primarily composed of calcium carbonate ($CaCO_3$) crystals, with each gram containing approximately 380mg of calcium [7-9]. While dairy products such as milk, yogurt, and cheese are traditional sources of dietary calcium, eggshell-derived calcium provides a cost-effective alternative. Utilizing eggshells not only addresses nutritional needs but also mitigates waste management challenges associated with poultry byproducts. In addition to human food applications, eggshells have potential uses in animal feed, medicinal formulations, building materials, and the production of hydroxyapatite, a naturally occurring calcium mineral.

The extraction of calcium in the form of calcium chloride ($CaCl_2$) from eggshells presents an opportunity to convert waste into value-added products. Calcium chloride is widely used in food fortification to enhance nutritional content, particularly in infant foods, and can improve the firmness of fruits during processing. Extracted calcium must meet safety standards, including minimal heavy metal content, to be suitable for consumption [10-12]. By processing eggshells into calcium supplements, it is possible to reduce environmental pollution, lower disposal costs, and provide an affordable source of dietary calcium, thereby addressing deficiencies and reducing the risk of osteoporosis.

The current study focuses on the extraction and characterization of calcium from eggshell waste, with the subsequent fortification of model food products such as yogurt and biscuits. This approach not only valorizes eggshell waste but also provides a sustainable solution for improving calcium intake in the population.

2. Methodology

2.1. Sampling and Study Area

This study was conducted in Bule Hora University. Bule Hora is located southern part of the capital city of Ethiopia on the distance of 467km from Addis Ababa. Bule Hora University found in Oromia regional state of West Gujii zone. The altitude of the study area range from 500 m to 2500 m. The climate condition of area study highlands 34%, middle land 55% and lowland 11%. The annual temperature range is 15℃ land rainfall range from 500 mm to1250. The study samples were collected from located at Bule Hora. Then the samples were transported into laboratory of Department of Chemistry, College of Natural Sciences, Bule Hora University This study was done in different laboratories based on the available resources.

2.2. Sample Preparation

2.2.1. Preparation of Membrane-Free Eggshells Powder

Shell membranes were separated from eggshells manually. Eggshells were washed both inside and outside to get rid of dirt and other organic materials, and then sun dried and crushed to small pieces (approximately 0.25 cm). Crushed eggshells were dried in an oven at 85℃ for 4 h, and then ground to a particle size of around 0.2 mm. The proximate analysis of dried eggshell was carried out according to AOAC. The crushed and dried eggshells were then packed in plastic bags and stored in a desiccators at room temperature and used as raw material for the entire experiment [1].

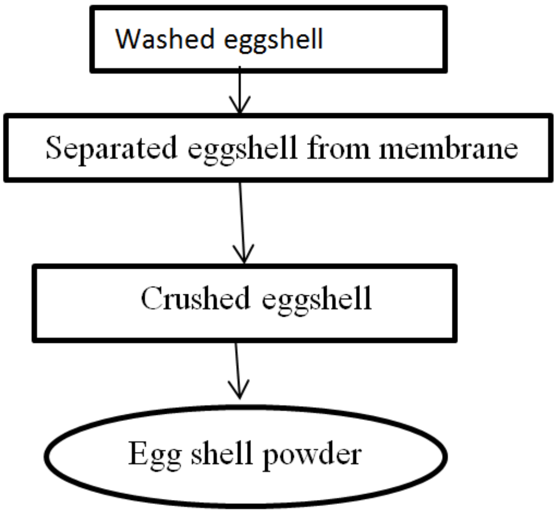

Figure 1. *General flow chart for egg shell powder preparation.*

2.2.2. Extraction of Calcium Chloride from Chicken Eggshells

Eggshell calcium chloride was prepared by reacting crushed chicken eggshells with a hydrochloric acid (HCl) solution. The mixture was stirred intermittently for 3hours, until the evolution of gas bubbles ceased. The resulting solution was then centrifuged at 1774rpm for 10minutes, and the supernatant was collected. This supernatant was subsequently heated at 110-115℃ until complete drying; yielding calcium chloride crystals (eggshell calcium chloride). Two factors were investigated for their effect on the extraction yield. First, the concentration of HCl was evaluated at two levels: 4% and 5% (w/v). Second, the ratio of eggshell to acid solution was tested at two levels: 1: 5 and 1: 15 (w/v). The percentage yield of calcium chloride was determined for each combination of these factors, and the condition producing the highest yield was selected for further analysis [13-15].

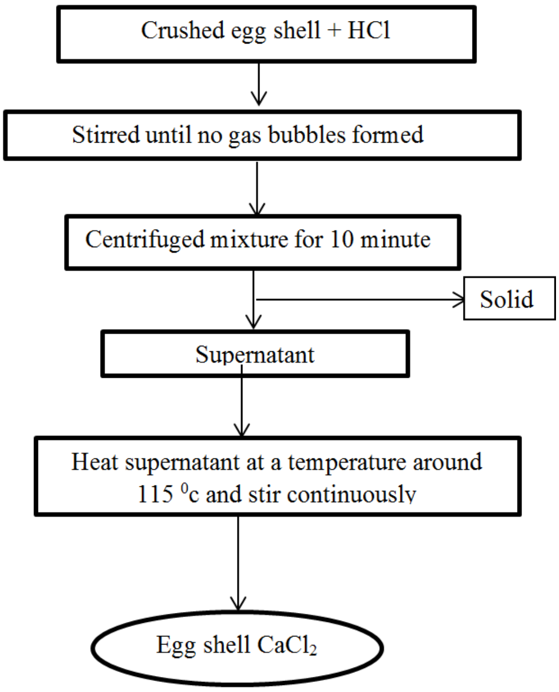

Figure 2 *Extraction process of calcium chloride from eggshell.*

$$\% \text{ Yield of } CaCl_2 = \frac{\text{Weight of CaCl2 crystals obtained after drying}}{\text{weight of crushed eggshell used}} \times 100 \quad (1)$$

2.3. Physicochemical Character of Calcium Chloride

2.3.1. Ash Content Determination

Ash refers to inorganic residue remaining after either ignition or complete oxidation of organic matter in a food sample determining the ash content of a food was part of proximate analysis for nutritional evaluation and it is an important quality attribute for some food ingredients. Also, ashing is the first step in the preparation of a sample for specific elemental analysis. This laboratory exercise uses the dry ashing technique with a muffle furnace to determine the ash content of a variety of food products. Moisture content determination is also included so ash content data can be expressed on a dry weight basis.

$$\% \text{ Ash (dry base)} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100 \quad (2)$$

About 2g of calcium chloride was measured and then placed (burned) on furnace for ash content determination. Weight of crucible measured is 18.6 g. The sum of weight of sample and weight of crucible for 5% concentration of HCl solution was 20.6g. The weight of crucible for 4% HCl concentration is 22.9 and the sum of weight of crucible and weight of sample (2g) was 24.9g. The sample was burned in a furnace for 18 hours. The weight of the 5% HCl, the ash content was 20.14-18.6=1.54 gram and the weight of the 4% HCl ash content was 24.61-22.9 = 1.71 gram, 4% HCl solution 10: 150 the gram of the $CaCl_2$ is 9.99 gram.

When the HCl concentration increases the percent of $CaCl_2$ also increase.

2.3.2. Moisture Content (MC)

Moisture content refers to the amount of water present in a material or substance. Measuring water content can be challenging due to the complex intermolecular interactions within the material matrix. For practical purposes in processing and evaluation, the water content of a sample is expressed as its moisture content. This allows for standardized measurement and assessment, ensuring that moisture levels can be reliably monitored and controlled during processing.

Cleaned and dried crucible was prepared and the mass was weighed as the representative sample (22.9g) was weighed (W_1) (mass of sample with mass of crucible before drying was 24.9 g) dried at, 105 ℃ for 4hour and cooled in desiccator. The mass after cooling was measured (W2= 24.0533g). The moisture content of calcium chloride was calculated by using the following formula.

$$\% \text{ Moisture} = \frac{(W1-W2)}{W1} \times 100 \quad (3)$$

W_1 = Mass of sample and crucible before drying (g)
W_2 = Mass of sample and crucible after drying
MC = (24.9-24.0533)/(24.9)*100
MC = 0.846/24.9*100 = 3.4%

2.3.3. Solubility

The solubility of calcium chloride powder extracted using different HCl concentrations was evaluated in water. Results indicated that increasing the HCl concentration during extraction enhanced the solubility of the resulting $CaCl_2$ powder. Notably, 1g of $CaCl_2$ obtained from the 5% (w/v) HCl extraction completely dissolved in 1mL of distilled water. This observation aligns with the well-known high solubility of calcium chloride in water. The solubility was found to correlate positively with the proportion of anhydrous calcium chloride present in the sample.

3. Results and Discussions

3.1. Calcium Chloride ($CaCl_2$) Percent Yield

Calcium chloride extracted from eggshells appeared as an odorless white powder. The yield of $CaCl_2$ was strongly dependent on the concentration of hydrochloric acid used during extraction. Using 4% (w/v) HCl, the extraction produced a 36% yield, whereas 5% (w/v) HCl resulted in a significantly higher yield of 72% (Figure 3). Figure 3 (A) illustrates calcium chloride obtained with 4% HCl, while Figure 3(B) shows the product from 5% HCl.

Eggshell calcium chloride was prepared through the hydrolysis of eggshells with HCl, providing sufficient acid to react with the calcium carbonate ($CaCO_3$) present in the shells. The highest yield and purity of calcium chloride were obtained with the 5% HCl solution, achieving 72% anhydrous calcium chloride and requiring a relatively short drying time of 3hours compared to the 4% HCl treatment.

The extraction process was influenced by several factors, including HCl concentration, the ratio of eggshell to acid, and the interaction between these parameters, all of which significantly affected both the yield and purity of the product. During the reaction, carbon dioxide gas was evolved, observed as bubbles rising to the surface of the solution. Gas evolution continued for approximately 3hours, after which it ceased, leaving only a small amount of unreacted eggshell powder in the mixture.

Chemical reaction occurred during extraction of calcium chloride from eggshell is shown below in equation (4).

$$CaCO_3\,(s) + 2HCl\,(aq) \rightarrow CaCl_2\,(s) + CO_2\,(g) + H_2O\,(l) \quad (4)$$

In this experiment, the $CaCl_2$ solution was then dried by heating the solution on a hot plate at110-115 ℃, the crystals thus obtained was analyzed. The ash content of the eggshell calcium chloride determined from 2g calcium chloride sample was 1.71g as a result of 85%. And also the moisture content of calcium chloride determined from 2g sample was 3.4%.

3.2. Physicochemical Properties and Solubility of Extracted Calcium Chloride

The extracted calcium chloride exhibited high solubility in water, an important property for its potential application in food and flavoring formulations. Its high water solubility allows easy mixing with other ingredients, enhancing its suitability for food processing uses.

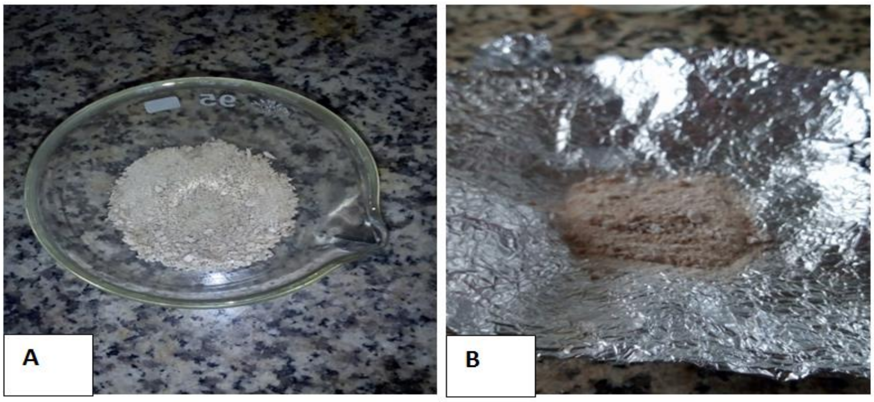

Figure 3 Extracted calcium chloride from eggshell.

Table 1. Different HCl concentration on $CaCl_2$ powder extraction from eggshell waste.

HCl concentration (%w/v)	Drying time (hr.)	Yeild of $CaCl_2$(g) per 10 g eggshell powder	Percent yeild of calcium chloride (%)
4	4	3.6	36
5	3	7.2	72

% yield of $CaCl_2$ by 4% HCl concentration extraction
% yield of $CaCl_2$ = (3.6/10)* 100% = 36%
% yield of $CaCl_2$ for 5% HCl concentration
% yield of $CaCl_2$ = (7.2/10)*100%= 72%

About 3.6g of calcium chloride was obtained by extracting 10 g mass of crushed (powdered) eggshell powder with 4% HCl concentration at the ratio of 10: 50 (mass by volume).

Calcium chloride powder extracting from different HCl concentration was tasted for its solubility. The resulted indicated that the calcium chloride has the higher solubility in water.

Table 2. *Solubility of $CaCl_2$ powder extraction from eggshell waste.*

HCl concentration (%: W/V)	An amount of $CaCl_2$ dissolving in 10ml distilled water (g)		
	1	2	3
4	√	√	√
5	√	√	√

4. Conclusions

White solid calcium chloride ($CaCl_2$) was successfully extracted from waste chicken eggshells using a solid-liquid extraction method with an aqueous hydrochloric acid solution at optimum conditions. The physicochemical properties of the extracted $CaCl_2$ were consistent with those of commercial calcium chloride.

The product contained 85% ash and 3.4% moisture per 100g, indicating the high calcium carbonate content of eggshells. During pre-treatment, the protein fraction was removed as eggshell membrane (EGM), while the eggshells contained negligible carbohydrates and fiber. Calcium chloride exhibited high water solubility, which increased with higher HCl concentrations; for example, 1g of $CaCl_2$ obtained from the 5% HCl extraction fully dissolved in 10mL of distilled water.

The extraction reaction proceeded until gas evolution ceased, due to the release of carbon dioxide. The liquid extract was separated and heated at 110-115℃ to obtain crystalline $CaCl_2$. The maximum yield (72% per 100g eggshell powder) was achieved using 5% (w/v) HCl. Both the HCl concentration and the eggshell-to-acid ratio, along with their interaction, significantly influenced the yield and purity of the calcium chloride. Finally, $CaCl_2$ was recovered by centrifugation and drying, producing high-purity crystalline calcium chloride.

Abbreviations

$CaCl_2$	Calcium Chloride
$CaCO_3$	Calcium Carbonate
HCl	Hydrochloric Acid
CO_2	Carbon Dioxide
H_2O	Water
% w/v	Percent Weight per Volume
hr	Hour
℃	Degree Celsius
ml	Milliliter
eq.	Equation

Author Contributions

Wabi Reggassa Boggale is the sole author. The author read and approved the final manuscript

Data Availability Statement

All data generated or analyzed during this study are included in this published article. Additional datasets, if required, are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflicts of interest.

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