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Mini Review

GGSHELLS: Are they a Waste or a Continuously Produced Natural Resource?

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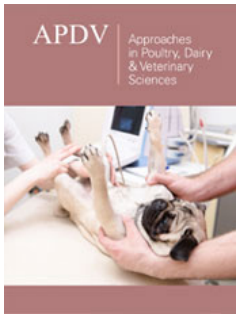

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Abstract

The primary purpose of avian eggs is for the reproduction of the species. They are integrated seamless ellipsoidal chambers that are essentially an external uterus who in the case of the domestic hen (*Gallus galllus sp.*) have a volume that ranges between 44.0 and 63.2cm^3, surface area from 64.2 to 86.1cm^2 [1]. However, humans have highjacked the hen's egg as an inexpensive source of highly nutritious food [2]. As a result, billions of eggs are produced to meet the consumer's demand; China, United States of America, India, Indonesia, and Brazil account for 66.7% of the annual global production [3]. In terms of eggshell waste, the global production was estimated in 2006 to be about 50,000 tonnes annually [4].

Keywords: Eggshells; Waste; Natural resource; Construction materials; Foodstuffs; Medical applications; Cosmetics; Catalysis; Water treatment

Abbreviations: $CaCO_3$: Calcium Carbonate; CaO: Calcium Oxide; ESM: Eggshell Membrane; FTIR: Fourier-Transform Infra-red; SEM: Scanning Electron Microscopy; TEM: Transitional Electron Microscopy; WCES: Waste Chicken Eggshells; XRD: X-ray Diffraction

Introduction

Eggs are composed of the yolk, albumen which is commonly called the white, and the shell. They weight in the range 47-67g of which 8-11% is the shell [1]. The shell is about 95% Calcium Carbonate ($CaCO_3$) and 3.5% of an organic matrix of proteins, glycoproteins, and proteoglycans [5]. In addition, there are small quantities (<1%) of Magnesium Carbonate, Magnesium Phosphate, Calcium Phosphate and Silicon Dioxide [6]. Calcium Carbonate contains 40.1% Calcium or in terms of Calcium Oxide, 71.5%.

Although the shell of an egg appears to be solid, electron photomicrographs of a cross section show it consists of five distinct layers. These are, from the interior out, inner, and outer membranes, mammillary, palisade, phosphate-rich layer, and finally the cuticle, a layer organic material. A very thin membrane that surround the egg's content lies against the inner membrane layer, whereas the outer membrane is the "foundation" on which shell formation begins by the deposition of amorphous $CaCO_3$ at specific site on it. As continuous deposition occurs these depositions enlarge and immerge with each other to form the palisade layer. The $CaCO_3$ in this layer form calcite crystals in which an organic matrix of proteins can be found; this layer is the thickest, however, it contains thousands of pores that are formed as the calcite crystals merge. These allow gaseous exchange between the embryonic chick and the exterior and allow transfer of gases (carbon dioxide out ↑ and oxygen ↓ in). About 2 hours before the egg is to be laid, a layer phosphate-rich crystal deposited followed a thin coating of organic material over the egg's surface. This layer, known as the cuticle, covers the pores and prevents the entry of microbes into the interior but resolves after incubation begins [7]. The addition of the components of the egg (thick and thin albumen and the shell) as it passes down the fallopian tube is tightly orchestrated while at the same time more than 900 matrix proteins, many of which have antibacterial or antibiotic properties [8].

Since it is the yolk and albumen that are used by humans, the shell becomes a residue, a waste. Basically, eggs are used either 1) In the home, 2) The production of liquid egg products, or 3) For the hatching of chicks; these later two uses generate large quantities of shell wastes. The shell waste from home use is to a limited extent included in food wases that are generally composited otherwise they become part of the garbage in land fill sites. However, very large volumes of shell residues are generated by both the liquid egg trade and hatching egg industry.

Equipment uses in the liquid egg trade break at least 7,200 eggs per hour and thus 57,600 eggs in an 8-hour shift, this rate produces daily about 330kg of shell residue per breaker unit. Several breaker units operated at the same time to produce liquid whole egg, liquid albumen, or liquid yolk, each of these are available in liquid, frozen or dried state. In the case of the hatchery industry, eggs from three different sources are hatched: those to produce replacement chicks for table egg stocks, to produce meat-type chickens, and to produce turkey poults. To fill an order for 25,000 "table" egg pullet chicks about 54,000 eggs should initially be placed in incubators. Over the next 21-day incubation period this number of eggs will generate about 300 kg of shell material (Note: Twice the number of eggs need to be set in the case of "table" egg chicks because only the female birds are kept, the males are discarded.) However, if 25,000 meat-type (broiler) chicks are ordered, the about 27,500 eggs need to be set which after 21 days would generate 150kg of waste. Since commercial hatcheries operate many incubators at a time, the amount of eggshell waste generated daily is several multiples of the foregoing amounts. Eggshell residues are reported to be the 15th highest source pollution and cause of major environmental deterioration [3]. In 2012, the annual global production of shell waste was reported to be about 250,000 tonnes [9].

The liquid egg trade produces an array of products that include liquid whole egg, liquid albumen, or liquid yolk, each of which are sold as liquid, frozen or dried. In the case of the hatchery industry, eggs from three different sources are hatched; those to produce chicks for replacement table egg stocks, to produce meat-type chickens; or to generate turkey poults. Eggshell residues are reported to be the 15th highest source of pollution and cause of major environmental deterioration [3]. In 2012, the annual production of eggshell waste was reported to be about 250,000 tonnes [9].

Concerns about the use of land fill sites for the disposal of these wastes and their impact on the environment motivated scientists and engineers to identify other possible avenues for their disposal. Over at least the last three decades numerous alternatives have been identified as evident by the extensive number of published scientific papers. This presentation very brief identifies a few applications that have been published but it barely scratches the surface of what has become a very active area of research.

Since the published literature on this topic is very extensive and the space allotted for this presentation is somewhat limited, emphasis is given to review papers that concisely summarize the essential details and major results obtained. Tables in the following publications summarized published results according to purpose and main findings: Awogbemi et al. [3,5,10]; from among other papers. However, to illustrate some of these applications extracts from this publication are summarized in the following are tables according to the published format (Tables 1-3).

Table 1: Applications for use of eggshell waste from Shi et al. [5].

Application	Methods	Function	Reference
Joint health	Fine ESM powder filled gelatine capsules	Promoted joint health and reduced pain and stiffness.	Keirs et al. [19]
Wound healing	Natural ESM	Providing a scaffold for the fibroblasts migration and reducing the phrase for wound healing	Guarderas et al. [14]
Gut health	Fine ESM powder	Regulating the cell proliferation and restitution, improving. energy metabolism as well as well as alleviating intestinal microbiota dysbiosis	Jia et al. [17]
Tissue engineering	ESM powder below 0.5μm size	Increasing surface area of the scaffold, allowing better cellular. infiltration and proliferation	Pillai et al. [24]
Food packing	ESM-derived gelatin-chitosan blend edible film	Improving mechanical and barrier properties of films	Reza et al. [28]

Table 2: Examples of the use of eggshell waste reported by Baláž et al. [10].

Milling Input	Experimental Techniques Results	Most Important	Final Product/Application	Reference
Eggshell + rice straw	XRD, SEM, absorption kinetics and thermos-dynamics and influence of various factors	Maximum sorption capacity of 231mg/g was evidence for balanced eggshell: rice straw	Phosphate ions absorbent/ waste-water treatments.	Liu et al. [20]
CaO from Eggshell	XRD, SEM, chemical oxygen demand, biogas and methane production	Size reduction into the nano-range resulted in palm oil mill significant improvements effluent: cow in biogas production manure mixture	Biogas production	Sari et al. 2020

Eggshell	XRD, SEM, TEM FTIR, mechanical properties, microhardness, erosion resistance	Different amounts of eggshell (1-4%) in the in the composite were beneficial for different mechanical properties	Eggshssell-epoxy composite	Panchal et al. [22]
Eggshell	Particle size, SEM, XRD, AFM, mechanical properties, chloride ion permeability	Improvement of the mechanical properties of oil well cement and accelerated hydration process	Oil well cement-eggshell composite	Salman et al. [29]

Table 3: Potential for the use of eggshell wastes in the construction and food industries adapted from Awobbemi et al. [3].

Area of Application	% WCES Added	% Cao in WCES	Effect of Addition on WCES on Concrete	Reference
Cement additive	0%, 5%, 10% and 15%	55.7	Improved mechanical strength	Parthasarathi et al. [23]
Cement additive	0%, 5%, 10%, 15% and 20%	ns	Improved compressive strength	Balouch et al. [12]
As asphalt binder	0%, 3%, 6%, 9% and 12%	ns	Better moisture damage and higher rut resistance properties	Huang et al. [16]
.....				
Food product	Degree of fortification	Effect on product		Reference
Bread	0-2% (w/w) of ingredients	↑Nutritional value, shelf life, and appearance ↓Acidity		Platon et al. [25]
Chocolate cakes	3-9% (w/w) of wheat flour	↑Calcium content, bulk density moisture content ↓Fat		Ray et al. [27]
Muffin	8g/500g and 16g/500g wheat flour	↑Calcium content, sensory characteristics, nutritional benefits, and acceptability		Afzal et al. [11]
Yogurt	0.1-0.5% (w/w) of ingredients	↑Calcium content, textural properties, and sensory attributes		El-Shibiny et al. [13]
Beef sausage	0 - 0.6% (w/w) of ingredients	↑Acceptability, physical appearance, flavor, chewiness, and color		Prasetyo & Prayitn [26]

The source of eggshell for these and other applications determines where eggshell wastes are used. This is because how the eggs have been handled before the shell wastes are generated. Eggs sourced for the egg breaker industry are washed (Figure 1), passed over a light table for the removal of rejects (blood or meat spots), dried before they are broken and eggs content divided to produce the liquid components and the shell. In contrast, eggs used for hatching meat-type chickens are placed in trays and set in the incubator where they remain for 21-days at 37.5 °C and initial relative humid about 60% which gradually increased to 70%. The shell material intended for human application It is fortunate that there are two different hatchery sources of eggshell waste - "table egg" hatcheries and meat-type chicken hatcheries [11-29].

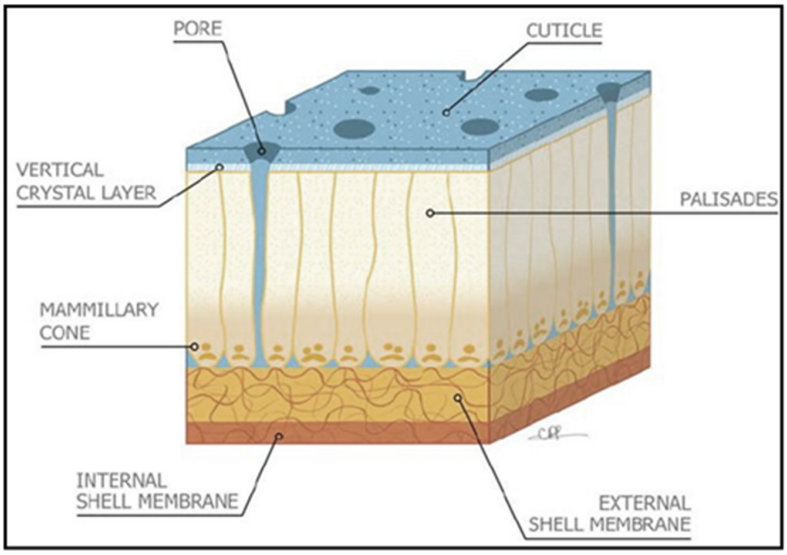

Figure 1: A schematic diagram of the cross-section hen's eggshell. This figure was originally.

There are numerous, numerous other applications where eggshell waste has been used to produce "value added" products. This presentation only scratches the "tip" of what has been developed based on eggshell wastes. It is now obvious that shell

residues are no longer wastes but rather a "natural resource" that is continuously being produced. Further, some components prepared from residual eggshells are very valuable such as purified collagen which is reported to be worth US$1,000 per gram.

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