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Applications of waste egg shell and egg shell membrane: a review

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Abstract. As poultry egg is a rich source of protein, World Health Organisation and all other health experts recommend human beings eat an egg daily. Therefore, there is a very high consumption of eggs throughout the world. The edible part of the egg is covered by a protective hard covering egg shell. With increasing egg consumption, egg shell waste is generated in huge amounts around the globe. Therefore, egg shell waste management became necessary to protect the environment as this can be hazardous. To overcome this problem, researchers and waste management experts are working on the development of techniques by which the egg shell waste can be used efficiently. As egg shell comprises mainly calcium carbonate and phosphate, it can be used for various industrial applications as a rich source of calcium, carbonates, CaO, etc. Because of the advantages of egg shell waste, it can be used for various industrial and household applications such as adsorbent, matrix, or reinforcement materials for making biocomposites, biotemplate, biocoating, glass foams, catalysts, etc. The present work discusses the egg shell and egg shell membrane applications in detail.
Keywords: applications of egg shell waste, egg, egg shell, egg shell membrane, waste management

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1. Introduction

Poultry eggs are a very good source of protein and have been eaten by humans for thousands of years [1]. Egg white (albumen), vitellus (egg yolk), and egg shell are significant components of a poultry egg [2]. The egg shell is the protective covering that prevents the egg white and yolk from the external environment. The structure of the egg is shown in Fig. 1.

The egg shell is made up primarily (94%) of the ceramic material calcium carbonate ($CaCO_3$); its other constituents are organic matter, calcium phosphate, and magnesium carbonate [3,4]. At the same time, the major constituents of the egg shell membrane are protein (60%), glucosamine (10%), chondroitin (9%), and hyaluronic acid (5%). The physical properties of egg shell are significantly dependent on the housing system of laying hens. Lewko et al. studied the effect of the housing system of laying hens on the physical properties of egg contents [5].

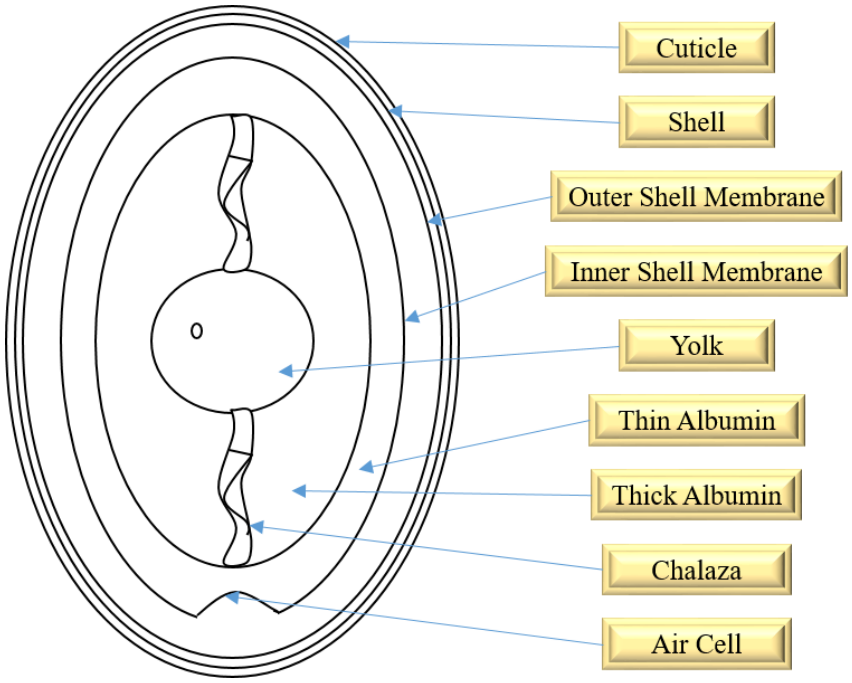

Fig. 1. Egg structure

The physical properties of egg shell are given in

Table *1*. It can be observed that the shell thickness, percentage shell content, and shell weight were highest for free-range laying hens. On the other hand, the cage has an adverse effect on the shell thickness and strength.

Table 1. Physical properties of egg shell [5]

Characteristic	Housing System		
	Cage	Litter	Free Range
Shell content (%)	8.77	9.03	9.93
Shell weight (g)	4.93	5.50	5.76
Shell Thickness (μm)	317.7	333.7	360.1
Density (mg/cm^2)	70.77	74.88	81.01

Due to the very large consumption of eggs, a high volume of waste materials egg shell and the egg shell membrane is generated [6]. It has become a challenge for food industries to dispose of these waste materials. To overcome this problem, researchers around the globe are working to find the application of these waste materials to generate valuable materials. Quina et al. suggested various possible applications of egg shell to reduce the environmental impact [7]. Fig. ***2*** shows the year-wise increasing applications of egg shell and egg shell membrane (captured on 5 October 2022 from sciencedirect.com). Date represents the number of publications year-wise on the use of egg shell and egg shell membrane [2,7]. It can be seen that the number of research on the use of egg shell and egg shell membranes during the year 1999-2002 was relatively very less (1294). From 1999 to 2022, research on egg shell and egg shell membranes have been increased by more than 477%. Still, there is a need for further research to enhance the utilization of waste egg shell and egg shell membranes.

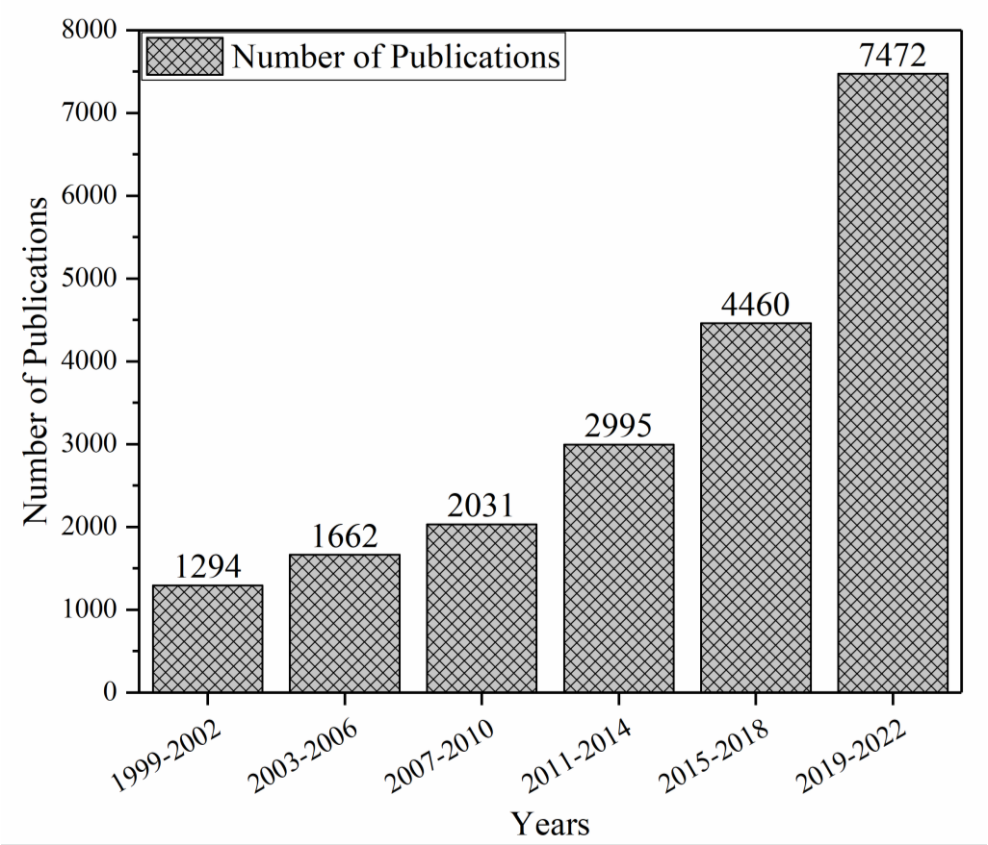

Fig. 2. Increasing applications of egg shell and egg shell membrane

Today egg shell and egg shell membranes are used for various industrial applications [8]. Industrial applications of egg shell and egg shell membranes can be divided into two categories i.e., as raw material and for operating supply. Applications of egg shell such as matrix or reinforcement materials for biocomposites, biotemplate, biocoating, glass foams, etc. belong to the raw material category [9,10]. On the other hand, applications of egg shell such as adsorbent or catalyst belong to the operating supply category.

One of the important industrial applications of waste egg shell is as a purifier. Egg shell is a very good adsorbent. Egg shell is used for the purification of water and other solvents [2]. Because of the high absorbance of egg shells, Xavier et al. used waste egg shells to remove arsenic from liquid industrial waste [11]. The use of waste egg shells as an adsorbent is discussed in detail in the next section.

Another important industrial application of waste egg shell is in the synthesis of carbon dots. Carbon dots are prepared using either a bottom-up approach or a top-down approach. In the bottom-up approach, pyrolysis of waste egg shells is done using microwave heating to produce carbon [12]. Waste egg shells are also used for the fabrication of various metal oxides. Ramya et al. effectively fabricated TiO_2 using waste egg shells [13].

Apart from industrial applications, egg shells can be used for household purposes. As egg shells are rich in calcium and mineral, these can be used to feed wild birds and chickens. The bitterness of coffee can also be reduced by adding crushed egg shells to ground coffee. Crushed egg shells can also be used as a rich source of minerals for houseplants. Also, egg shells to soil increase porosity and make soil aerated. Crushed egg shells can also be used as a natural abrasive for cleaning cooking utensils and other pots because these are hard and brittle. Heat-treated egg shells (at around 350°C for 8-10 minutes) after grinding to fine powder can be added to juice as a calcium supplement. Egg shells, after fine crushing, can be

added to paint for decorative wall texture. Therefore, there is no need to through used egg shells. Egg shells and egg shell membranes can be reused.

Considering various advantages of egg shells and egg shell membranes, the present work mentioned industrial applications of egg shell and egg shell membranes such as adsorbent, matrix or reinforcement materials for making biocomposites, biotemplate, biocoating, glass foams, and catalyst, are discussed in detail.

2. Applications of egg shell and egg shell membrane

Various industrial applications of egg shell and egg shell membranes are shown in Fig. 3. These applications are discussed in detail in the following sub-sections.

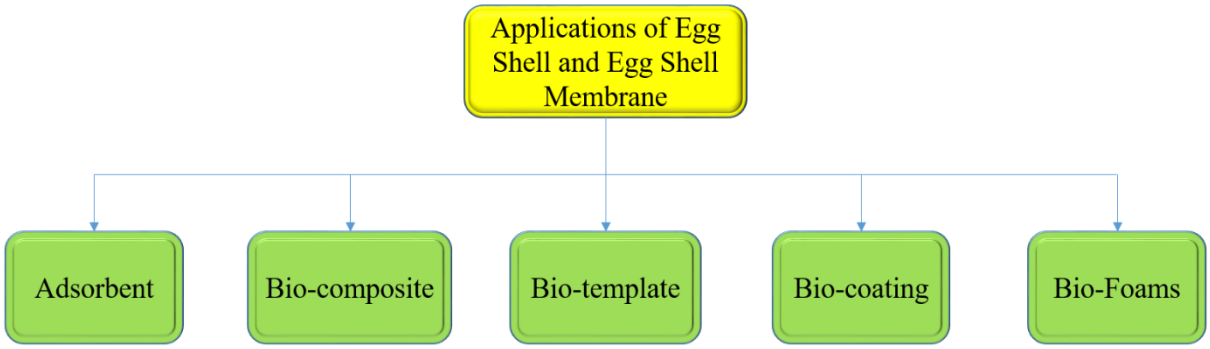

Fig. 3. Applications of egg shell and egg shell membrane

As an adsorbent. Egg shell and egg shell membranes have been purifying wastewater for ten years [2,14]. Hazardous chemicals (organic or inorganic) from water can be removed by adsorbing them on egg shell and egg shell membranes because of the inherent properties of an adsorbent [15,16]. Egg shell membrane is a better adsorbent than the egg shell due to the presence of various basic functional groups on its surface such as (-OH), (-COOH), (-SH), (-NH_2), (-$CONH_2$), etc. [17]. Egg shell membrane can be crushed and milled to nanoparticle size and can be used for removing very harmful lead and cadmium ions from water.

Abdi et al. used egg shells to bleach soybean oil [18]. It was observed that the 2wt.% egg shell powder decreased carotenoids amount by nearly 83%, and at the same time, chlorophyll content decreased by nearly 47%. Therefore, egg shells can be recommended as a very good adsorbent and bleaching agent for edible oils as it efficiently removes unwanted contents from oils.

As a matrix or reinforcement for fabricating bio-composites. As egg shell is composed mainly of ceramic material calcium carbonate, it found applications |as a reinforcement material for making low-cost biocomposites [19]. Egg shell is also being utilised as a matrix material to fabricate novel bio-composites. Agarwal et al. fabricated coconut jute fibre reinforced egg shell ceramic biocomposites by powder processing technology [1]. Gelatin gel was used as a binder. It was observed that the coconut jute fibre formed interfacial bonds with egg shell particulate in the gelatin gel matrix. The highest hardness was obtained for egg shell biocomposites reinforced with one wt.% coconut jute fibre.

Lertcumfu et al. also fabricated ceramic biocomposites [3]. Hydroxyapatite/beta-tricalcium phosphate composites with different compositions were fabricated by solid-state technique. Calcium carbonate used for making composites was obtained from cockle and egg shell. Calcium carbonate was then reacted with diammonium phosphate to produce hydroxyapatite and beta-tricalcium phosphate. Obtained hydroxyapatite and beta-tricalcium phosphate were then mixed in ethanol by mechanical mixing. After mixing, powders were compacted and heat-treated to form the bio-composites.

Okoye et al. fabricated egg shell reinforced aluminium matrix composites [6]. Composites with 15 wt.% carbonised egg shells were fabricated by stir casting technique. Bose et al. also fabricated aluminium matrix composites by reinforcing carbonised egg shell and snail shells and SiC by stir casting [20]. It was observed that the addition of egg shells in the aluminium matrix enhanced the mechanical strength and corrosion resistance. At the same time, the cost of the composite decreased.

Reddy et al. used egg shells as a cement replacement in concrete structures as the cost of cement increases due to its high demand and consumption. It was observed that the compressive strength increased with the addition of 10wt.% of concrete in cement [21].

Viswanath et al. studied the effect of egg shells on the mechanical properties of polyester composites [22]. It was observed the mechanical properties improved significantly with the addition of 12wt.% egg shell. Channabasavanna et al. also observed a similar effect of egg shell on the mechanical properties of polymer composites [23].

Asha et al. fabricated polymer matrix composites by reinforcing egg shell powder [24]. Composites were fabricated by an injection molding technique. It was observed that the mechanical properties enhanced significantly with the addition of egg shell powder.

As a bio-template. Egg shell and egg shell membranes are also used as a bio-template to produce bio-morphic materials. The natural structure of egg shell and egg shell membranes is replicated by various techniques to produce functional materials. Sabu et al. fabricated bio-morphic alumina using an egg shell membrane as a template [9]. Fibrous alumina was prepared by replicating the fibrous structure of the egg shell membrane. Egg shell membrane was shocked in a hydrated aluminium nitrate solution and calcinated over a temperature range (400°C-1200°C).

As a bio-coating material. Bio-coating is done on the implants to increase their life. Currently, hydroxyapatite is used for coating implant material, but its cost is very high [25,26,27,28]. So, researchers are working on developing low-cost bio-coating material for bio-implants [29,30,31]. Venkatesh et al. used egg shell, alumina, and seashell powders to form bio-coating on polyvinyl chloride, Teflon, and polyurethane [10]. Venkatesh et al. also alumina, egg shell, and sea shell bio-coated stainless steel 316L and Ti-6Al-4V bio-implant materials [32]. It was observed that the coating of egg shell on the implant materials was more uniform and free from defects than the coating of alumina and sea shell due to its high cohesiveness.

Kathiravan et al. produced activated charcoal from egg shell to coat paper for humidity sensing [33]. It was observed that the sensor was fast responding with very less recovery time. Therefore, egg shells can be used to produce activated charcoal-based eco-friendly humidity sensors.

Fine egg shell powder can also be used to coat ferrous materials to prevent rusting. Also, cooking utensils holders can be coated with egg shell to reduce the heat transfer rate as egg shell is ceramic in nature and hence have poor thermal conductivity and high thermal stability. Egg shell powder is also used for texturing of house walls by mixing fine grinded egg shell powder with paint. The addition of egg shell in paint also enhances the anti-bacterial properties of walls. Therefore, coating of egg shell is very useful.

As a foaming agent. The egg shell is composed mainly of calcium carbonate (95%); it is also used as a foaming agent to fabricate glass foams. On heating to a temperature of around 600°C -800°C, oxidation of egg shells takes place, and CO_2 gas is released, which expands and foaming in the material takes place. Fernandes et al. used egg shell waste as a foaming agent to produce glass foams from cathode ray tube glass waste [34,35].

Egg shell waste after crushing can also be used as a space holder material to produce copper, iron, and steel foams by powder metallurgy technique [36,37,38,39,40,41]. During sintering of the green compacts of the above-mentioned materials above 800°C, carbonate

will oxidise to release CO_2. Produced CO_2 will try to escape through the pores present in the materials and as a result foaming in the material will take place.

As a raw material for bio-foams. Egg shell ceramic and other materials such as silica are also for fabricating glass-ceramic foams. Ayawanna et al. fabricated porous glass-ceramic material for orbital implant using egg shell waste, SiO_2, and $NaCO_3$ by foam replication method [42]. Glass-ceramic implants fabricated from egg shells had an open-macropore structure and more stability than the glass-ceramic implants produced from commercial $CaCO_3$.

Leszczynska et al. fabricated polyurethane foams with egg shells as a filler material [43]. It was observed that the addition of egg shells reduced the bacterial infection on the foam surface.

As a catalyst. Egg shell and egg shell-derived materials such as CaO are also used to catalyse various chemical reactions [44,45]. Zhang et al. derived CaO from egg shell and used it to catalyse the bio-diesel formation from chicken feather meal oil [46]. It was observed that the 95% conversion of chicken feather meal oil into bio-diesel just took place in 5 minutes. Therefore, egg shell-derived CaO proved to be an efficient and low-cost catalyst. Rahman et al. also used egg shells to produce Zn/CaO catalyst to produce biodiesel [47]. The Zn/CaO catalyst proved to be an efficient catalyst for the trans-esterification of waste-frying oil to biodiesel.

Le et al. studied the catalytic effect of egg shell on hydrocarbon processing [48]. It was observed that the use of egg shells significantly improved the catalysis of hydrocarbon processing.

Proenca et al. also used egg shells as a catalyst to convert macauba oil into methyl esters [49]. It was observed that the use of egg shells as a catalyst resulted in a 91% conversion of macauba oil into methyl esters.

3. Conclusions

The following conclusions are drawn after the detailed literature survey on the reuse of egg shell and egg shell membrane waste:

- Egg shell waste is mounting because of the very high consumption of eggs.
- Researchers and waste management officials are looking for the applications of egg shell waste so that it can be used efficiently without affecting the environment.
- Egg shell and egg shell membranes are very useful for industrial applications and household purposes.
- The egg shell powder can be used efficiently as an adsorbent and bleaching agent.
- Egg shell can be used to produce other necessary chemicals such as activated charcoal and CaO.
- Egg shell powder is also very useful for fabricating bio-composites and bio-foams.
- Egg shell and egg shell derived chemicals are very effective in catalysing oil conversion into biodiesel.
- Therefore, the reuse of egg shell waste is very beneficial in cost-saving and environmental protection.

4. Future scope

As discussed above, egg shell and egg shell membranes can be used for various industrial applications such as catalyst, reinforcement, raw material, adsorbent, etc. Still, there is a need for further research to enhance the percentage utilization of egg shell and egg shell membranes. As egg shell an excellent adsorbent, the use of egg shell as an environment purifier should be deeply investigated so that air pollution in cities can be controlled.

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