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Utilization of Eggshell as Valuable Products for Sustainable Ecosystem and Agriculture (Review)

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Abstract

Discarded as waste with the production of several tonnes per day, eggshell is a solid waste from poultry industry. Eggshell waste disposal pollutes the ecosystem by being accumulated in landfills, invites insects, which involves high management cost. Given its beneficial effects, eggshells are valuable when transformed to new values. In other words, eggshell contains a high amount of calcium component, which contributes several benefits to human beings as well as the ecosystem. In tablet form, for instance, it supplements human health by strengthening bones to treat osteoporosis and protect teeth stabilization. As a food additive, eggshell powder finds its place in cuisines and confectionaries. it also acts a catalyst in biodiesel production, acts as an absorbent in heavy metal removal in soil and water and is a stabilizer in civil industry. Eggshells are potentially utilized as a UV protectant in nylon and polystyrenes and are potentially used in cosmetic industry for several anti-aging skin care formulations. For sustainable agriculture, eggshells act as manure or soil stabilizer to enhance plant health. The current review details the utilization methods of eggshell by transforming it into new forms.

Introduction

Agricultural processes generate diverse waste materials that have severe impact on the ecosystem. To minimize the environmental issues, they should be utilized in an effective way. Globally, agricultural waste management has become crucial as it is critical for plant, livestock, and human lives (Al Seadi and Holm-Nielsen, 2004). To aid in environmental protection, the waste residues should be effectively managed by recycling, reusing and/or changing them to a valuable product. The agricultural waste could be categorized in different forms based on its state such as sludge, dried plant parts, are solid wastes. Utilization of agricultural residues is of priority for sustainable agriculture (Martin-Luengo *et al*., 2011).

Eggshells are waste materials produced in huge amount by poultry industry (Phil and Zhihong, 2009) houses, and restaurants (Amu *et al*., 2005). Globally, around 2,50,000 tons of eggshell waste is produced annually (Verma *et al*., 2012), most of which is dumped on-site that cause unpleasant odour disrupting the eco-system (Tsai *et al*., 2008a,b). Furthermore, eggshell dumps provide a habitat for insects and harmful bacteria and could cause infectious diseases and allergies to local residents(Madhavi and Chakraborty, 2016).

Eggshell

The eggshell comprises a calcified shell, and an inner and outer shell membrane. The calcified shell is entirely made of calcium carbonate crystals, a semipermeable membrane allowing air and moisture to pass through the pores. The inner and outer shell membranes are composed of proteins providing an efficient barrier against the bacterial influx. The major components of egg shell are calcium carbonate (98.2%), magnesium (0.9%), and phosphorus (0.9%) (Romanoff *et al*., 1949), whereas the major components of egg shell membrane are protein (69.2%), fat (2.7%), moisture (1.5%), and ash (27.2%) with collagen as chief protein (Froning, 1998). Eggshell and shell membrane are non-edible

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by-products of egg, but can be utilized to produce products of biological value (Nakano *et al*., 2003). The review highlights the potential utilities of egg shell and its membrane for sustainable environment and agriculture.

Egg shell as poultry feed

Poultry is the major protein source all around the world. Egg shell quality affects the profitability of poultry growers severely. Chickens lay poor quality eggs in their final laying cycles. Studies reported that 6- 10 percent of eggs have poor quality shells during production period (Hafez and Attia, 2020). Poultry eggshell/ shell membrane has multiple benefits in wide areas and utilization of eggshell as poultry feed to strengthen the eggshells and enhance fertility in chicken was reported by several researchers (Scheideler, 1998; Neuman *et al*, 2002; Prabhakar *et al*., 2014). As hen ages, egg weight increases and the quality of egg shell deters without proportionate increase in calcium deposits, thereby resulting in increased number of cracked eggs. Genetic, environment and nutrition are factors affecting egg shell mineralization and egg quality. Dietary manipulation to supplement calcium has received attention for proper calcification of egg shell (Nys, 2001). Poultry egg shell is rich in calcium and calcium is an important macro nutrient for poultry shell strength, responsible for internal shell strength (William *et al*., 2006). Feeding the eggshells back to chicken seems to be a logical outlet to effectively recycle the solid waste of eggs. The eggshells for feeding chicken should be effectively sterilized as they may be carriers of diseases like pullorum. Gongruttananun (2011) suggested eggshells as potential calcium source for improved performance in production, fertility, hatchability, quality of the emerged chicks and fine structure of egg shells. An *et al*., (2016) confirmed the appearance, strength and thickness of egg shell being increased by Ca supplementation by egg shell.

Eggshell can be used as calcium source in breeder cock diet with normal feed intake and semen quality. An experiment conducted to determine the effects of calcium source in breeder cock diets on feed intake, reveals a positive response in body weight, feed intake, sperm concentration, sperm motility, and live sperm count (Krittiya *et al*. 2016). The motility of fowl spermatozoa is enhanced by calcium supplementation in diet (Ashizawa and Wishart, 1987). The broiler breeder cockerels fed daily with 0.5 to 0.7g calcium daily portrayed better reproductive performance (NRC, 1994). Calcium and phosphorus level of poultry are negatively corelated (Norris *et al*., 1972; Bootwalla and Harms, 1989). Egg shell calcium is the best natural calcium source than limestone and it is about 90% absorbable. Therefore, converting egg shell into animal diet would transform egg shell into a valuable product benefitting the poultry industry economically (AbdulRahman *et al*, 2014). Grounded eggshell can be utilized as an efficient calcium source in breeder cock diet that improved feed intake and semen quality which is determined by body weight, feed intake, sperm concentration, motility as well as normal and abnormal sperm count. The conversion of eggshell to animal feed recommend pre-treatment at 80^{o}C to reduce microbiologic contamination (Rivera *et al*., 1999). The dietary calcium supplementation of egg shell positively influenced semen quality, gonadal development and calcium plasma (Gongruttananun, 2011).

Egg shell as human dietary supplement

Egg shell powder can be utilized as a calcium supplement which is almost equivalent to commercial tablets made from oyster egg shells (Lozano *et al*., 1994). Ground egg shell powder is an equitable alternate for increasing dietary calcium across the globe. Chicken egg shell approximately contain 380 mg calcium per gram and 2 gram of this powder is sufficient to a female's dietary requirement (Bartter *et al*., 2018). Several tribal groups in rural areas around the world utilize chicken egg shell powder as a major source to meet the calcium demands of the body as they can't afford expensive tablets (Radhika *et al*., 2020). The egg shell powder can be fortified in food products by use of novel technologies such as high intensity pulsed electric field high energy milling for efficient attraction of egg shell powder. A comparative study confirmed that egg shell calcium carbonate is more stable than commercial calcium carbonate (Murakami *et al*., 2007).

Egg shells serve as a bio functional food ingredient for consumers with calcium requirement. The traditional polish bread spread enriched with traditional micronized egg shell is of high demand (Kobus-Cisowska *et al*., 2020). A single egg shell contains 2.07g of calcium; half an egg can supply the calcium requirement of an adult per day. Egg shell as powder can be added to bread, pizza or spaghetti, which is an excellent source to use chicken egg shell as calcium supplements (Brun *et al*., 2013).

Calcium is an important mineral to strengthen bones and modulate important physiological functions of human body. It is the chief micronutrient essential for growth maintenance of bone and teeth and contributes in other important body events such as muscle contraction, blood clotting and nerve conduction (Mann and Truswell, 2017). Abundance in calcium concentration triggers energy links and cause myofilaments to alter in shape and curtail, leading to muscle contraction; whereas drop in calcium level cause the myofilaments to drop and the muscle returns to the relaxed state (Biesiadecki, 2016). Calcium is a chief nutrient for proper functioning of heart and prevention of hypertensions (Chakraborty, 2007). .

Calcium is associated with cell signalling by conveying messages from brain to all parts of the body (Williams *et al*., 1999). Calcium is also associated with liberating hormones and enzymes related to blood movement, by which serum level is regulated (Clapham, 1995) and a constant concentration of Calcium is maintained in blood, muscles and body fluid. The surplus calcium available in the body is stored in bones to maintain a balance between resorption and deposition. Chicken egg shell is a natural source of Ca, which is readily available at home that house chickens, to supplement Ca content in the body. A study stated an enhanced bone mineral density of trochanter bone, lumbar spine and total proximal femur is reported among women with osteoporosis or osteopenia (Schaafsma and Pakan, 1999). Egg shell proteins enhances Ca absorption; the total Ca transport witnessed a 64 per-cent increase when egg shell is supplemented (Daengprok *et al*., 2003).

Egg shell powder

In order to prepare eggshell powder the cleaned and decontaminated eggshells being oven dried at 80ºC for 2 hours, grinded to powder form and sieved through fine net of 50 µm size forms the eggshell powder (Islam *et al*., 2019).The egg shell powder is an excellent source of Ca reported by several literatures (Pak and Walsdorf, 1989; Schaafsma *et al*., 2000; Rovenský *et al*, 2003). An increase in calcium concentration in bones was observed in women with osteoporosis issues when they consumed eggshell powder along with vitamin D and magnesium supplementation (Czernichow *et al*., 2010). The nutrients present in white eggshell powder is higher in concentration than brown egg shell powder (Table 1)

Table 1. Chemical composition of white and brown egg shell powders (Ray *et al*., 2017)

S.No.	Parameters	White Egg Shell Powder	Brown Egg Shell Powder
1	Moisture (%)	0.46	0.20
2	Protein (%)	3.92	5.04
3	Ash (%)	94.61	94.28
4	Fat (%)	0.3	0.08
5	Calcium (%)	34.12	33.13
6	Magnesium (%)	0.29	0.36
7	Phosphorus (%)	0.04	0.07
8	Potassium (%)	0.03	0.03
9	Sodium (%)	0.05	0.04
10	Copper (ppm)	< 1	< 1
11	Iron (ppm)	22	< 1
12	Manganese (ppm)	< 1	< 1
13	Zinc (ppm)	< 1	< 1

Egg shell in medical industry as a calcium supplement

The calcium deficiency all around the globe is met by intake of dairy products; however, required calcium amount is not consumed by the majority of people. To meet the body's Ca requirement, people intake supplementary tablets which are quite expensive (Bartter *et al*., 2018). Egg shells as a chief source of calcium, can contribute to health sector as calcium supplement tablets. As calcium is vital for normal functioning of cells, muscle, teeth and bone, a right quantity of calcium is essential for general health of a human being (van Mierlo *et al*., 2006). Calcium supplementary tablets are made from powdered egg shells to treat low blood calcium levels (Fleming & Heimbach, 1994). These supplements are used to treat conditions like osteoporosis or bone loss, osteomalacia or rickets signs of weak bones, minimized activity of parathyroid gland or hypoparathyroidism, and certain muscle disease such as tetany (Waheed *et al*., 2019). Several trials showed that calcium supplementation during pregnancy reduced the risk of preeclampsia, a complication characterized by high blood pressure and damages liver and kidney, reduced prenatal death, and increased birth weight (Hofmeyr *et al*., 2014). Daily calcium supplement reduces the risks of high pressure among pregnant woman (Villar *et al*., 2006). The lumbar bone density, femur fracture length and femur calcium content were higher in groups fed with egg shell calcium than normal calcium carbonate tablets, thereby prevent osteoporosis. The easier digestion/absorption is due to the highly porous texture of eggshell (Kikuchi *et al*, 1994). An increase in bone mass was reported among post-menopausal women in Vietnam (Sakai *et al*., 2016). Both the groups were injected with 300mg/day of calcium, and the bone mass was measured at the beginning and after 6 months, where eggshell calcium consumed group was significantly higher than the other group in all measured parameters (Table 2). The egg shell powder capsules (Figure 1) were equivalent to CIPCAL_500 calcium supplement tablets for females (Gaonkar and Chakraborthy, 2016).

Table 2. Comparative health statistics of egg shell and calcium carbonate supplements (Sakai *et al*., 2016)

Characteristics	Egg Shell capsules	Calcium Carbonate Capsules
Weight (Kg)		
Baseline	50.9±8.6	50.1±5.1
After 6 months	51.9±8.1	50.6±5.0
Height (cm)		
Baseline	150.5±5.2	151.6±4.5
After 6 months	150.3±5.3	151.5±4.7
Systolic Blood pressure (mmHg)		
Baseline	135.1±20.6	131.4±23.3
After 6 months	131.8±21.7	116.9±13.2
Diastolic Blood pressure (mmHg)		
Baseline	85.2 ±9.2	83.3 ±10.0
After 6 months	77.9 ±8.4	71.4 ±6.5
Calcium intake from diet (mm/d)		
Baseline	294±74	293±61
After 6 months	445±103	469±63

Figure 1. Eggshell tablets
(Gaonkar and Chakraborthy, 2016)

Egg shell as a bone strengthener

Egg shell residues has the potential to produce hydroxyapatite, a chief component of teeth and bone. Hydroxyapatite is an excellent source used in bone repair and tissue regeneration (Abdulrahman *et al*., 2014). Calcium is an essential nutrient for strong bones, 99 percent of body calcium is stored in bones and teeth, and 1 percent in human blood. Blood calcium is very much essential for controlling blood pressure and maintaining heartbeat. The calcium present in the bones make up the human bone bank and the calcium from the food consumed is deposited and withdrawn from the bone bank according to the body's needs (Dawson-Hughes, 1998). If more calcium is utilized for body's need and enough calcium is not supplemented in food or as tablets, will lead to thin, weak bones, that may dismantle quickly. Human body requires calcium for its growth in all stages (Table 3)

Table 3. Daily calcium requirement of human

Age (years old)	Daily calcium requirement
Birth-1	Supplied by formula or breast milk
1-3	700 mg
4-8	1000 mg
9-18	1300 mg
male 19 – 70	1000 mg
female 19 – 50	1000 mg
female 51-70	1200mg

(Gaonkar and Chakraborthy, 2016)

Bone development of any organism is genetical, yet nutrition plays a major role for bone health. Egg shells naturally constitute abundant quantity of calcium carbonate along with other minerals such as fluorine and strontium that are much essential for bone metabolism. Eggshells can enhance the growth of new, strong bones substantiated by several researches (Compston, 1995; Dawson-Hughes, 1998). Incorporation of eggshell with hydrogel mixture harden bone and teeth cells with faster healing if impaired (Xinchen *et al*., 2019).

Egg shells have shown antirachitic effects in rats and humans in several experimental and clinical studies. A decline in pain, and osteoresorption with increased mobility and bone increased bone density, chondrocyte differentiation and cartilage growth were observed in postmenopausal women with osteoporosis. The clinical experimental studies revealed a positive response on bones and cartilage and is suggested for treatment of osteoporosis (Rovenský *et al*, 2003). The healthy late post-menopausal women supplemented with chicken eggshell powder as a source of dietary Ca in combination with minerals and vitamins such as Magnesium, cholecalciferol and phylloquinone, increased the calcium level after 12 months of intake (Schaafsma *et al*., 2002).

Egg shell as a tooth stabilizer (Toothpaste)

Tooth paste is a dentifrice, a smooth semisolid and homogenous mass comprising abrasives/polishing agents, surface active agents, binding agents, humectants and other apposite constituents for maintaining oral health (Gaurav and Navin, 2017). The fluoridated toothpastes when persistently used upsurges dental fluorosis issues; therefore, safe alternatives are needed to arrest dental caries (Arifa *et al*., 2019). Calcium plays an active role in remineralization of enamel and eggshell powder has a very high percentage of calcium. Eggshell is a rich source of minerals, serving as a therapeutic excipient, base source for several dental preparations. Egg shell powder is used as an abrasive in toothpaste as calcium plays a major role in tooth hypersensitivity of enamel (Gaurav and Navin, 2017). As eggshells are abundant in calcium carbonate, they are utilized as bone substitute by supplementing calcium (Dupoirieux *et al*. 1995). The high pH and rich bioavailable calcium content of eggshell favoured remineralisation (Mony *et al*., 2015). In a study by Onwubu *et al*., (2019), five internationally available toothpastes were added with eggshell powder and agitated at 800 rpm for eight hours, filtered and oven dried to create an enamel model. The Scanning Electron Microscopy (SEM) analysis characterised the surface morphology and revealed the formation of enamel-like hydroxyapatite layer in all the tested brands. The eggshell powder is suggested as an alternative for hydroxyapatite due to its rich calcium and phosphorus content as well as other minerals (Lombardini *et al*., 2014; Haghgoo *et al*., 2016; Kallahalli *et al*, 2016). Energy Dispersive Spectroscopy (EDX) analysis characterised the composition after pre-and post-agitation with egg shell powder and revealed the presence of calcium phosphate ions after agitation. Calcium Phosphate is regarded as a fundamental for the formation of teeth and its presence after agitation with eggshell powder encourages its utilization as a component in tooth pastes or human tooth substitute as a remedy for erosive attack by reducing acid reactions, which will contribute in prevention of tooth decay (Onwubu *et al*., 2017; Table 4).

Table 4. Energy Dispersive Spectroscopy Analysis of eggshell powder (Onwubu *et al*., 2019)

S No.	Sample Group	Pre-Agitation			Post-Agitation		
		Ca (wt %)	P (wt %)	O (wt %)	Ca (wt %)	P (wt %)	O (wt %)
1	Colgate	34.04	0.02	50.03	25.38	0.09	52.47
2	Oralwise	0	0.01	45.93	31.6	0.22	41.54
3	Colgate Sensitive	0	0.53	48.94	22.12	0.37	54.05
4	Sensodyne	0	0.06	62.41	34.99	0.31	42.51
5	Aquafresh	0	0	55	9.84	0.04	49.2

Moreover, eggshell powder reduces the surface roughness providing a protective effect against erosive enamel loss (Sandleen *et al*., 2017). A significant remineralization potential of demineralized enamel lesions is noticed in an in vitro study with higher calcium level, Carbon/Phosphorus (C/P) modulations and pH levels after eggshell powder treatment (Elshik *et al*., 2020).

Egg shell as a biomaterial (Hydroxyapatite)

Hydroxyapatite is an excellent source utilized in bone repair and tissue generation, present abundantly in eggshells; a cost-effective, renewable and sustainable source (Ghomi *et al*., 2011). Hydroxyapatite produced from egg shells reduces the treatment cost in bone impairment with less environmental impact (Ducheyne *et al*, 1986). Hydroxyapatite is a calcium phosphate ceramic, a very important biomaterial for incorporation in bone tissues due to its osteophilic nature. It is the chief inorganic constituent of bone and teeth tissue and is the base necessity for bone graft development. Human natural bones are made up of organic and inorganic composites, chiefly

hydroxyapatite and collagen fibres (Mulijani and Sulistyso, 2012). A fresh egg shell comprises a foamy cuticle outer layer of ceramic, a middle spongy and an inner lamellar layer, representing 11 percent of the total egg weight (Wu *et al*., 2013). Calcium carbonate constitutes calcite as a major component, which is the most stable form of calcium carbonate present in needle form is the base in hydroxyapatite production (Li-Chan and Kim, 2008). Calcification of eggshell is a quick process for biomineralization of hydroxyapatite where calcite contributed for mechanical tensile of the produced hydroxyapatite (Liu *et al*., 1997).

Hydroxyapatite is produced from egg shells by several methods, of which hydrothermal and microwave irradiation are widely used. The convenient and a novel method to produce biomedical HAp by hydrothermal method employs a phosphate solution in high temperature with calcium hydroxide and calcium hydro phosphate as starting materials (Rivera *et al*, 1999). The effect of hydrothermal temperature on the composition and morphology of HAp particles was studied using X-ray diffraction (XRD), Fourier transform infrared spectrometry (FTIR) (Liu *et al*., 2003). The particle size and morphology could be determined by Scanning electron microscopy (SEM) and Transmission electron microscopy (TEM). The hydrothermal method of crystal production has excellent homogeneity, high crystallinity and high temperature favours HAp formation in main phase (Dasgupta *et al*., 2004). This methodology provides all the characteristic band of HAp and very efficient, but the process is tedious, laborious and time consuming.

The alternative method exploits a simple swift microwave irradiation technique with the aid of ethylene diamine tetra acetic acid (EDTA) as a chelating agent (Kumar *et al*., 2012). Eggshell along with EDTA solution, produces flower like HAp nanostructures in this methodology (Fig 2). This indirect process involves calcium precursor formation from egg shells, which are subjected to XRD for phase characterisation of the produced HAp (Balázsi *et al.*, 2013). It is a simple, non-toxic and cost-effective method to treat bone infections. Egg shell derived hydroxyapatite is biocompatible with mechanical strength and durability (Abdulrahman *et al*., 2014; Rhee, 2002).

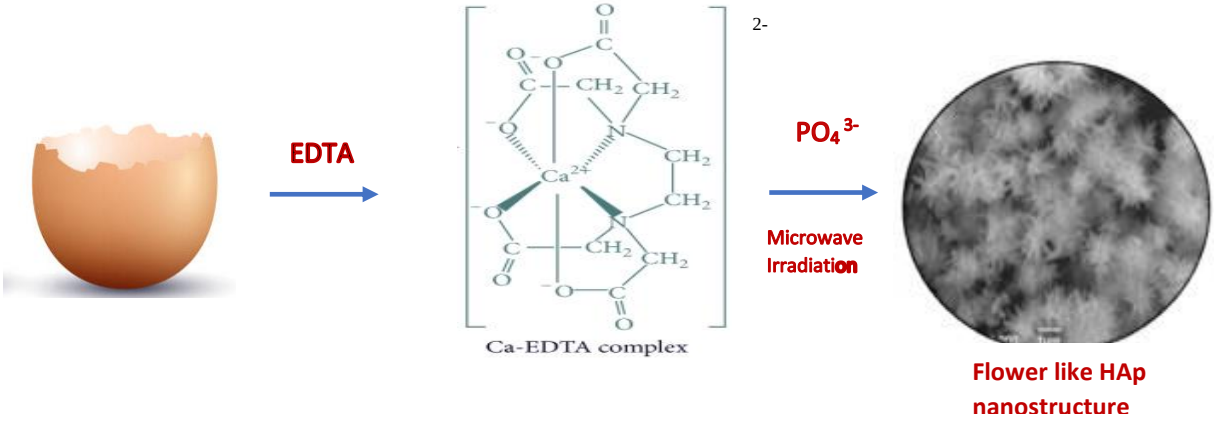

Figure 2. Formation of flower-like hydroxyapatite nanostructure through microwave (Kumar *et al*., 2012)

Eggshell as a catalyst for biodiesel production

The global energy demand is generally met by oil imported from diverse oil producing GCC countries, that causes a critical problem of energy dependence on other countries. Moreover, the increased use of petroleum products leads to global climate change that harms the environment, human health, development of harmful gases such as CO_2, SO_2, and NO_2. In view of alternates, biodiesel is of bloom as it is human-oriented, renewable, feasible, easily available and produced from local resources for a cleaner environment. In transesterification process of biodiesel production, catalysts are the most important parameter that decides the production efficiency (Yaser, 2019). Catalysts used in biodiesel production can be homogenous or heterogenous; although the yield due to homogenous catalysts are high, saponification rate, additional reagent consumption and excess cost for separation causes negative impacts. Therefore, heterogenous catalysts that prevent saponification, are utilized in biodiesel production. Calcium oxide is the chief catalyst for biodiesel production, which is an alkaline earth metal oxide produced by egg shell calcination (Bal *et al*. 2001; Nakatani *et al*. 2009; Rezaei *et al*. 2013; Syazwani *et al*. 2015). Transesterification reaction of homogenous strong bases or acids as catalysts from renewable sources such as soybean yield biodiesel in commercial firms (Morin *et al*., 2007). Egg shell is an abundant source of calcium carbonate and its pore structure in the shell surface pave way for utilization as porous solid catalyst by calcination (Witoon, 2011).

Utilization of eggshell for biodiesel production aids in waste recycling, minimize pollutant and biodiesel production cost and an eco-friendly approach (Dawodu *et al*., 2014). The eggshells are utilized for transesterification of used cooking oils with a biodiesel yield of 100 percent with 4 %weight of catalyst for 5 hours (Navajas *et al*. 2013), while eggshells undergo calcination hydration and dehydration treatments to obtain a CaO catalyst (Niju *et al*., 2014). Egg shell as catalyst obtained by calcination-hydration and dehydration at 5 percent weight, 12:1 methanol to oil ratio at 65^{o}C reaction temperature for an hour used in transesterification of waste frying oil yields 94.5 per cent biodiesel (Fig 3), while commercial CaO yielded only 67.57 per-cent biodiesel (Chen *et al*., 2014). Another researcher reported a maximum biodiesel yield of 92.7 per-cent, obtained from transesterification of palm oil under methanol to oil ratio of 9:1, for 60 minutes and ultrasonic power of 60% amplitude. In addition, the catalyst can be reused for 8 times without loss of activity (Tan *et al*., 2015). Duck egg shell, being catalyst in biodiesel production from soybean oil deodorizer distillate (SODD) resulted in 80 per-cent biodiesel yield with 5 times usage of catalyst and yielded 60 per-cent in 8 times usage (Yin *et al*. 2016). The process of calcination, hydration and dehydration is a promising method to enhance the egg shell catalytic activity (Niju *et al*., 2014). The catalytic activity was highest with high surface area when calcinated at 900^{o}C, in transesterification of *Jathropha* and Karanja oil with eggshell wastes (Joshi *et al*., 2015). Microwave assisted transesterification of palmoil with methanol, utilizing chicken egg shell as catalysts yielded 97.7 percent biodiesel, in a reaction time of 4 minutes with 900W microwave power, with higher content of CaO (Khemthong, 2012). The performance of eggshell catalysts was found to be highest compared to oyster, mollusk and other eggshells in biodiesel production by transesterification of palmoil with methanol (Viriya-Empikul *et al*., 2012). Egg shell as catalyst not only increased the yield potential of biodiesel, but adds value to the green eco-friendly biodiesel produced in low cost (Alba-Rubio *et al*., 2010). Therefore, the heterogenous base catalyst, Cao obtained from eggshells is promising in transesterification process of biodiesel production.

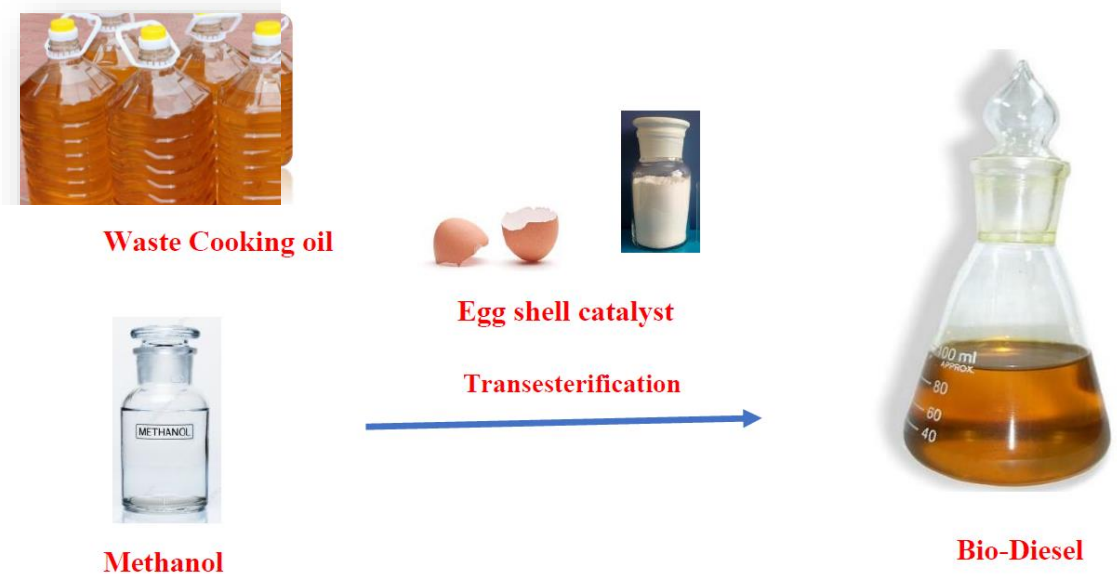

Figure 3. Eggshell as a catalyst for bio-diesel production

Egg shell as an absorbent

Inorganic pollutants such as heavy metals present in aquatic ecosystem is a serious concern due to its toxicity and non-biodegradability and their ability to accumulate in human body overtime having serious health complexities. Consequently, removal of these pollutants from aquatic ecosystem has received serious attention in recent years. Heavy meals and other metal ions in water pose a severe environmental issue to the environment and human health. The removal ability of toxic heavy metals by eggshells were studied and the influence of eggshell in improving the adsorption competences of hydrogen sulphide like heavy metal ions from waste water favours eggshell as a low-cost adsorbent. Calcium carbonate, magnesium carbonate and calcium phosphide are the chief elements of eggshell powder having excellent adsorption ability (Park *et al*., 2007). Chicken egg shell is a green and economic absorbent with the highest adsorption capacity for hydrogen sulphide (Habeeb *et al*., 2014). The calcium solution extracted from eggshell waste has been used as a low-cost adsorbent to adsorb

Cadmium, Nickel and Zinc ions (Alejandro *et al*., 2011). Ziad *et al*., (2016) reported a maximum adsorption of 8.4 and 7.01 mg/g, of copper and cadmium respectively. A maximum removal of cadmium of 89.7 per-cent was observed at 5g dose of eggshell and pH 6.0 favoured at high temperature and endothermic condition. Eggshells are considered as an economic method for cadmium removal from aqueous solutions (Lahieb *et al*., 2018). The egg shell membrane (ESM) (0.8 g) has reported the highest nickel adsorption (100 mg/L) of 90.91 per-cent at 25ºC p5.76 and 24 hrs and 100 per-cent of silver ions (25mg/L) were eliminated at 25ºC, p 5.2 and 24 h (Jou-Hsuan *et al*., 2014). Baláž *et al*., (2016) studied the ball milling effect on the structure and adsorption ability of eggshell (ES) and its membrane and concluded that milling is beneficial only to eggshell and the adsorption falls in the order Silver, Cadmium, and Zinc. The calcination of eggshell performed in a furnace at 800ºC for 2 hours after crushing the dried waste eggshells and its application in treating real electroplating waste water exhibited its capability in heavy metal ion exclusion with its high nullification ability in treating strong acidic waste water (Park *et al*., 2007). A study imposed the exclusion of Cu and Fe in diverse quantity of waste water in 85 to 95 per-cent with the fact that the adsorption efficiency depends on the amount of adsorbent; the more the metals in a solution, less is the adsorption efficiency (Agarwal and Gupta, 2014) (Table 5).

Table 5. Adsorption efficiency of eggshell powder for Cu and Fe (Agarwal and Gupta, 2014)

SI. No	Quantity of eggshell powder (g)	Adsorption efficiency (%)									
		Initial Concentration of Cu (mg/L)					Initial Concentration of Fe (mg/L)				
		5	10	20	40	100	5	10	20	40	100
1	0.5	91	90	86	70	65	82	82	80	73	62
2	1.0	93	92	90	90	80	86	85	80	76.5	70.5
3	1.5	99	98	98	97.5	95	93	90	80	80	74

Egg shell in Civil Industry

Egg shell waste comprises several organic and inorganic materials that can be composted with new materials for elevating the present assistances. Cement is the fundamental base material for construction in civil sector**,** a backbone for infrastructure development. It is the oldest traditional and unique cementing material and never replaceable in civil industry. It is a blend of several elements such as limestone, clay and shale. Concrete for buildings were made by mixing cement along with water, sand and gravel to form a hard solid mass (Jhatial et al., 2019).

A huge amount of thermal and electrical energy is consumed in cement manufacture, which accounts for half of its operational cost (Amu *et al*., 2005). With the less-availability of non-renewable resources, rise in number of building globally and the huge demand of construction materials, safe alternatives for cement production is of utmost need. Around half the quantity of earth's resources are required in cement production and releases equal amount of carbon dioxide in the environment. Egg shell has cementing ability and hence reusing of eggshell can be cost effective and cause decline in energy consumption. Giddings *et al*. (2002) studied the properties of concrete with eggshell powder of 5-15 percent, which indicated that ESP can be magnificently used as a replacement of cement, with strength higher than the concrete control at 5 % egg shell powder. The compressive strength of 5% egg shell powder was higher at 7 and 28 days of curing (King'Ori, 2011). In another study by Amu *et al*. (2005), a cement mortar with 1:3 proportion in which cement is partially replaced with eggshell powder at 5, 10, 15, 20, 25, and 30 percent weight disclosed a steady decrement in compressive strength beyond 5 percent egg shell powder replacement. Pongtonglor *et al*. (2011) proved that egg albumen foamed concrete mixed with 5 per cent egg shell powder increased compressive strength, split tensile strength and flexural strength and can act as partial replacement for cement. Another analogous study Poornika *et al*. (2019) stated that compressive strength, hardness and specific gravity was higher than control concrete for 10 percent egg shell powder replacement at 7 and 28 days of curing ages, with the initial and final setting time of 93 and 210 minutes. The workability of the concrete is decreased by increasing the amount of eggshell powder, indicating egg shell powder as a replacement material for cement. Amarnath (2014) studied the effect of diverse egg shell powder concretes, by replacing 5-15 percent of eggshell powder for cement and suggested that egg shell powder can positively be used as a partial replacement of cement in concrete production. The egg shell powder cement has the compressive strengths greater than control for 5% egg shell powder replacement and split tensile strength comparable to the control at 10% egg shell powder, with flyash improving the compressive and split tensile strength. Egg shell concrete has similar performance as limestone filler concrete. The maximum sorptivity, which is the measure of capacity of water to be absorbed by egg shell powder (capillary water absorption) was 0.17 mm/s. The compressive strength, split tensile strength, density, absorption percentage, permissible voids and sorption percentage increased and a maximum was observed in 45 parts of eggshell powder added with 210 parts of cement and 4 parts of flyash (Table 6).

Eggshell as a fertilizer

Continuous farming depletes the nutrients from the soil. Organic nutrients are supplied to soil in the form of fertilizers to meet the requirement of crops which are diverse for varied crops. Soil pH has a major role that affects the nutrient availability and toxicity of soil. Soil pH ranges from 6.0 to 7.5 is suitable for plants in general (Jariwala & Syed, 2016). Any plant requires 16 essential elements for their growth; plants receive the major elements carbon, oxygen and hydrogen from soil and atmosphere; the others minor elements such as nitrogen, phosphorus, calcium, magnesium, sulphur, zinc, iron, manganese, copper, boron, molybdenum and chlorine are to be supplemented in fertilizer form (Uchida, 2000). Synthetic chemical fertilizers are a remedy but pollute the soil ecosystem and decrease the immunity of soil. Natural fertilizers derived from organic sources are receiving attention in agricultural sector. Egg shell is recommended as organic fertilizer, that increases the nutritional intake of plants (Hamester *et al*., 2012). In Agriculture, egg shells act as a fertilizer enhancing plant growth and yield. A study in tomato plants using egg shell as a fertilizer help in decreasing the plant diseases, blossom end root, and minimized the cost of tomato production (Madhavi and Chakraborty, 2016). Egg shell is utilized as a stabilizing agent and it could be a substitute for lime as its composition is similar to lime (Alzaidy, 2019). Egg shell is a compound used to bio-remediate contaminated soils due to oil and petrol as the physiochemical properties of egg shell have many applications as low-absorbent of pollutants (Arunlertaree *et al*., 2007; Park *et al*., 2007; Pundir *et al*., 2009).

Eggshells are generally used in agriculture to fix pH of soil and its role as calcium source reducing the utility of limestone (Boron, 2004). Egg shells comprises 96 percent calcium carbonate approximately. Calcium carbonate has porous structure that makes eggshells semipermeable for air and moisture. Apart from calcium, eggshell contains sulphur, potassium, sodium, magnesium; residues of protein adhere with eggshells act as nitrogen source (Oliveira *et al*., 2013). Egg shells contain Al_2O_3, SiO_2, SiO_3, CaO, MnO, Fe_2O_3, ZrO_2, Cl, K_2O etc. which are essential micro and macro nutrients for plants. A study performed to find the effect of eggshells on the pH of soil found that coarse pieces do not help to decrease pH neither act as lime source, but ground fine powder change the soil pH in acidic soil as eggshells stop decomposing at this pH (Oliveira *et al*., 2013). Calcium carbonate is insoluble in water and alkaline medium, but soluble in acidic medium and act as a fertilizer in acidic soil (Biswal *et al*., 2019). The seeds of *Vigna mungo*, establishes and grows well in eggshell treated soil which is 10 mm larger than the plant grown in control. Egg shell as fertilizer in tomato plants increases the nutrient intake while it decreases Blossom End Rot (BER) and the cost of plantation (Gaonkar and Chakraborty, 2016). Radha and Karthikeyan (2019) investigated the effects of eggshell on growth of cowpea with different rations of egg shell *viz.*, 2,4,6,8, and 10 g and the growth parameters, germination percentage, shoot and root length, number of leaves ad plant weight increased consequent to eggshell application (Table 7). Mayur and Sagar (2019) utilized CHNS analysis to regulate carbon, hydrogen and oxygen (CHO) composition in eggshell for suggesting it as a fertilizer. The results revealed that 0.398, 12.601, and 0.26 percent of N, C and H exist in egg shell powder which nominate it as a fertilizer for crop plants (Table 8, Fig 4). In another investigation, eggshell powder was found to be the best organic fertilizer source for peas and potatoes (Aisha *et al*., 2018). In red pepper, provision of eggshell had a positive impact on plant yield, number of fruit-bearing branches, fruits per plant and weight gain of fruits at the dosage of 30g eggshell per plant (Kurniatuti, 2018).

Eggshell as a soil stabilizer

Soil stabilization, by *in situ* improvement of soil properties through addition of natural or synthetic additives is essential in modern scenario as soils with required nutritional status are not readily available. Soil stabilization studies were conducted with various type of materials such as rice husk, flyash, as soil stabilizing agent (Petry and Dallas, 2002). Egg shell powder has been used as a stabilizing agent, replacing artificially synthesized lime, as its chemical composition is same as lime, constituting calcium, magnesium carbonate and protein (Tocan, 1999). Utilization of eggshell powder as a soil stabilizer is advantageous over lime, as production of lime releases CO_2 and pollute environment as heating is done up to 750^{o}C. Therefore, eggshell powder as a soil stabilizer is comparatively cost-effective, sustainable and eco-friendly (Bonavetti *et al*., 2003).

The effect of eggshell powder on the stabilizing potential of lime on expansive clay soil was studied by Amu *et al*. (2005), where egg shell powder and quarry powder as soil stabilizing agent was reported to enhance soil binding properties (Amu *et al*., 2005). Ground eggshells are an effective lime source, as compared by soil pH change and crop yield attained of corn and soybean (Holmes and Rueber, 2007). Clay is stabilized with egg shell powder with increase in specific gravity for a low percentage of egg shell powder and decreases for a higher percentage. The liquid limit value also showed a decrease with increasing egg shell powder mixture (Poornika *et al*., 2019). The maximum dry unit weight increases at a low percentage of egg shell powder (3%) and decreases at 6 and 9 %. Consequently, it was concluded that the maximum dry unit weight of the

soil and soil shear strength parameter increased with increased percentage of egg shell powder.

Thus, utilization of ESP for soil stabilization can improve soil bearing capacity which aids in construction sector (Munirwan *et al*., 2019). Anoop *et al*., (2017) investigated egg shell powder with 0.5, 1.0, 1.5, and 2.0% of weight of soil and suggested and recommended eggshell powder as an effective replacement of limestone by 25 percent for practical utility.

Table 6. Comparative properties of normal and egg shell powder supplemented concrete (Amarnath, 2014)

Concrete (Cement+ESP+Flyash)	Compressive strength (MPa)			Split tensile strength (MPa)			Density (Kg/m^3)	Adsorption percentage		Permeable voids	Sorption mm/s
	1 day	7 day	28 day	1 day	7 day	28 day		30 min	72 hour		
300+0+0	6.8	11.1	22.3	0.4	0.8	2.4	2364	1.38	4.39	7.7	0.12
285+15+0	4.9	14.4	24.0	0	1.3	2.4	2347	1.02	2.94	7.7	0.106
270+30+0	7.7	10.7	18.9	0.2	1	2.3	2323	1.39	3.41	8.9	0.11
255+45+0	6.6	9.8	16.1	0	1.4	1.6	2305	1.67	4.38	8.3	0.16
210+45+45	4.4	11.0	19.4	0.2	1.3	2.2	2317	1.88	5.13	9.4	0.17

Table 7. Effect of eggshell in growth parameters of cowpea (Radha and Karthikeyan, 2019)

S.No	Type of seed	Soil Content (g)	Irrigation	Percent of eggshell	Germination percentage (m)	Shoot length (cm)	Root length (cm)	Number of leaves (g)	Fresh Weight (g)	Dry Weight (g)
Control	Cowpea	200	Tap water	-	50	6.0	3.4	30	0.05	0.01
A1	Cowpea	200	Tap water	2.0 g	60	8.0	6.0	45	0.06	0.03
A2	Cowpea	200	Tap water	4.0 g	80	9.5	7.0	50	0.07	0.04
A3	Cowpea	200	Tap water	6.0 g	80	9.8	8.0	69	0.08	0.05
A4	Cowpea	200	Tap water	8.0 g	85	10	9.	0 75	0.09	0.06
A5	Cowpea	200	Tap water	10.0 g	90	12	9.5	80	0.1	0.07

Table 8. NCH composition of eggshell analysed by CHNS analyser (Mayur and Sagar, 2019)

S.No.	Retention Time/min in CHNS Analysis			Percent Content (%)		
	N	C	H	N	C	H
Egg shell	0.8	1.192	3.308	0.398	12.601	0.26

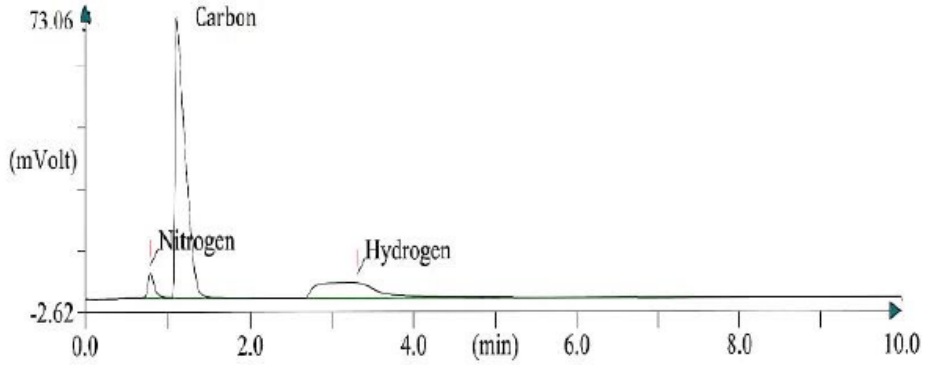

Figure 4. Proportional combination of the elements presents in egg shell powder (Mayur and Sagar, 2019)

Egg shell as a UV protection source

The unprocessed chicken egg shells provide durable and effective UV protection against synthetic polymers: polystyrene and nylon and can act as novel economically pleasing eco-friendly UV protective additives (Lippens *et al*., 2017). The unprocessed eggshells providing protection against photooxidative degradation of polymers, is a new area for recycling of waste eggshells. Placing eggshell pieces on nylon and polystyrene provides effective protection during 800 h

of high UV illumination. Generally, for protection of nylon or polystyrene against UV protection, TiO_2 are embedded on it (Dondi *et al*., 2006). The nylon and polystyrene covered with eggshells exhibited slower photooxidative rates than nylon embedded with TiO_2. The UV protection was 57.1% and 43.5% for brown eggshell and white eggshell, which was lesser for nylon embedded with TiO_2. (Ricci *et al*., 2003). A thin film of grinded eggshell particles exhibits the same efficacy as a layer of TiO_2 to resist UV radiation (Than *et al*., 2012). The multi scattering UV response of the porous structures in egg shell by Mie scattering theory by multi scattering described the pores being responsible for back scattering of UV rays (Ladouce *et al*., 2020)

Egg shell as a food additive

The best technique to utilize eggshell powder is adding with bread, pizzas, noodles etc. This may result in no change in flavour, but a minor change in texture is noticed (Margaritha *et al*., 2007; Brun *et al*., 2013). In Japan, rice crackers and confectionaries are tinted with egg shell powder as a calcium additive (Mine, 2008; Kewpie, 2014). The eggshell chocolate cake, prepared from wheat flour accompanied with eggshell at three levels of 3, 6, and 9 percent resulted in calcium content of 504.5, 816.8, and 1364.5 mg/100g,respectively (Ray *et al*., 2017). Ali and Badawy (2017) suggested using up to 10 percent of eggshell powders to fortify bread at home . In Brazil an investigation was carried out on ten common low-cost traditional dishes fortified with eggshell powder containing 37.4 per cent calcium, along with 1 to 100 g of flour. The results exhibited abruptly high calcium concentrations ranging from 111.5 to 506.4 mg/100g, supplementing 14-32 percent calcium requirement of adults. Therefore, eggshell powder is recommended as an additive in food materials to prevent calcium and osteoporosis deficiency among adults (Naves *et al*., 2007).

Egg shell as antiaging agent

Nutrition plays an important role in hair, skin and nailhealth and appearance. Oral supplementation of 450mg/day hydrolysed eggshell membrane for 12 weeks enhances hair, shin and nail growth and appearance (Kalman and Susan, 2020). Natural egg shell concentrate powder is one of the most efficient antiaging products in cosmetic sector. Moreover, it is shown to increase cellular activity and collagen production as well as prevent skin aging (Chandramohan *et al*., 2020). Egg shell membrane primarily contains collagen (Wong *et al*., 1984; Ruff *et al*., 2009).

Eggshell membrane is a thin membrane lining the eggshell, that is water-soluble and unique with water-soluble ingredients rich in proteins, diverse type of collagens, keratin and elastin (Rittié and Fisher, 2002), glycosaminoglycans that include chondroitin, glucosamine and hyaluronic acid as well as desmosine and isodesmoine, that help in hydration, improve elasticity and has the ability to support and enhance healthy- and young-looking skin (Blanken *et al*., 1989; Kalman and Susan, 2020). Further, eggshell membrane has exposed the increased cellular activity and collagen production, thwart aging of skin and minimize injuries due to UV light and inflammation (Park *et al*., 2012; Vuong *et al*., 2017). The face creams with water-soluble egg membrane such as BiovaDerm and Biova, contain naturally occurring collagen and elastin and other compounds have been found to minimize skin wrinkles, reduce wrinkle depths, oxidative damage and inflammation, enhances skin smoothness, softness, richness and luminescence when topically applied (Guarderas *et al*., 2016). Yoo *et al*., (2014) suggested the UV protectant role of egg shell membrane with 10 KDa molecular weight possess qualities such as anti-lipopolysaccharide, anti-IFN- γ-induced inflammation, anti-collagenase and anti-elastase activities and suggested in cosmetic industries for production of anti-inflammatory, anti-wrinkle, anti-microbial and moisture protection creams. In a study by Chandramohan *et al*. (2020), the natural egg membrane concentrate (NEMCTM) is administered into Nano size powder form (50 nm) with different active ingredients to produce different formulations such as face cream, face mask, body lotion, gel and foundation powder and applied to treat wrinkles, blemishes, acnes, dry and brittle skins and for whitening the skin. The results of the four-week study applied on human skin reveals that NEMCTM is deemed to be an effective anti-aging product in cosmetic field by increasing cellular activity and collagen production.

Other applications

Egg shells act as pest deterrent especially pests belonging to the Phylum Mollusca such as slugs and snails. Coarse sharp pieces of egg shell cause abrasion to the fragile feet of snails that act as pest deterrent. Crushing the eggshells coarsely in food processor and spread them around the plants prevent slugs, snails and crawling insects (Afzal *et al*., 2016). Egg shells as a whole can be used as a seed germination pot. They can be filled with moist soil and seeds to let them grow enough until being transplanted in the soil. The egg cartons will provide a perfect container to hold the egg shell pots, until ready to plant (Purwanti and Heruwati, 2020). Grinded eggshell can be used as an abrasive to clean pots and pans at home, but care should be taken to avoid scratches (Balaz, 2016). Eggshells can also be used to make textured paint for 3D effects in artwork (Kavithambika and Palanichamy, 2021).

Risks of Eggshell Consumption

When prepared in an appropriate manner, eggshells are considered safe. Egg shells should be consumed in powder form. If swallowed as large fragments, will injure the throat of living organisms. As eggs shell are contaminated by several bactreia such as *Salomonella enteritidis*, there is risk of food poisoning. Boiling egg shells will restrict microbial contamination (Guard-Petter, 2001; Davis *et al*., 2008). In general, natural calcium supplements contain high amounts of toxic metals such as lead, aluminium, cadmium and mercury (Whiting, 1994; Ross *et al*., 2000). However, egg shell contains lower level of toxic elements (Schaafsma, 2000). For safer consumption egg shells should be ground powdered and boiled.

Conclusion

Chicken eggshell, a waste material from domestic sources such as hatcheries, poultry farms, fast food industries, egg product factories, homes and restaurant, has been a serious matter as global awareness regarding organic waste materials and pollution problems was increased. The management of agricultural wastes including eggshell is indispensable and a crucial strategy in global waste management. However, if the eggshells are treated and processed according to areas mentioned in this review, they can be channelled towards the production of value-added products. This review highlighted the results of utilization of eggshell as waste characterisation material in diverse utilities. Eggshell has multiple uses such as a source of calcium for osteoporosis patients, a bone and teeth strengthener, a starting material to prepare calcium phosphate bioceramics (e.g. HAp), a low-cost adsorbent for removal of ionic pollutants from the aqueous solution and a biodiesel catalyst, a valuable fertilizer, a soil stabilizer, a dietary supplement in poultry industry, better alternative for cement, a food additive, a pest control agent etc. Consequently, it can be concluded that chicken egg shell cannot be just considered as a waste and can be effectively used for many applications as a treasured product. This will generate employment as well as increased return from poultry industry and make products available at a reasonable cost.

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