Snail Shell Waste in Food Industries

Subjects: Others

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Effective waste management has become an urgent societal challenge. Food waste is made up of items meant for human consumption that are lost, polluted, disposed of, or deteriorated; the reutilization of shells from mollusk waste is a severe problem in terms of environmental protection and the development of the circular economy. The properties of waste shells are presented and discussed, including their biological–natural origin and high calcium carbonate content. This could add social and innovation focus on shell waste management, getting a non-toxic, eco-sustainable, low-cost, biodegradable supplement to invest in. Furthermore, it has the potential to support the circular economy approach by creating a closed system that minimizes the use of natural resources and environmental contamination.

Keywords: shell waste ; food ; ecology ; circular economy ; waste valorization

1. Introduction

Effective waste management has emerged as a critical social issue, particularly with regard to waste reuse. Its utilization, especially in the case of biomass wastes [1] and challenging-to-handle waste, can advance cost-effectiveness and sustainability in the fields of food innovation and the green economy. More specifically, there is a need to research and develop agro-food waste treatment systems to minimize the impact on the environment [2]. One of the primary challenges is lowering the amount of waste produced by recycling and reusing it to create products with additional value to respect the circular economy and bioeconomy principles [3][4][5]. Using food waste as animal feed is a solution that addresses challenges related to food waste management and food safety but also reduces the need to develop conventional feeds, which is a resource and environmentally intensive effort [6]. Managing food waste is an achievable social, political, and environmental solution that promotes a circular economy. In the next years, there will be a significant rise in the need for food production due to the growing global population.

In these conditions, substantial amounts of food industry waste are gaining more and more attention from the scientific, political, and economical spheres. A third of the food produced for human use is lost or wasted worldwide, according to the Food and Agriculture Organization. Except for the retail and domestic phases of the global food supply chain, the FAO's most current data from 2019 shows that 13.8% of food produced in 2016 was lost from farm to table, highlighting the need for improved waste management systems considering the depletion of natural resources. According to national and international regulatory frameworks, minimizing waste release and maximizing its value (while maintaining standards for food and feed safety and quality) are essential tactics for an efficient management system to generate a real food industry's sustainability [7]. Reducing pollution and the quantity of scarce resources consumed are made possible by solid waste management, which also lowers costs and strengthens the green economy. Not only will the economy expand when this happens, but people will also live better, healthier lives.

2. Snail Shell Composition

In mollusks, shells are composed of more than 95% inorganic minerals such as phosphorus, manganese, iron, copper, zinc, sodium, potassium, and a tiny quantity of organic matrix [8][9]. In adults, calcium carbonate ($CaCO_3$) is typically found as calcite and aragonite; in juvenile animals, it is frequently found as amorphous calcium carbonate (ACC) [10][11]. Unlike the restricted forms of inorganic substances, there is much diversity in the organic matrix, which includes proteins, lipids, and polysaccharides involved in regulating shell formation; the regulation of $CaCO_3$ precipitation, encompassing nucleation, polymorph selection, and morphology modification via self-assembly and binding to the polysaccharide scaffold is largely dependent on shell proteins [8][12]. Active chemical substances found in snail shells include chitin $(C_8H_{13}NO_5)_n$, the primary organic material used to make chitosan. $(C_6H_{11}NO_4)_n$ [13]. The membrane-shaped tissue of the mantle is divided into compartments by mineralizing cells that line its exterior and secrete both inorganic constituents and organic matrix. Therefore, the characterization of freshwater snail shell wastes is a prerequisite for promoting their diverse uses as biological materials. These substances have potential applications as biomaterials in the medical field. However, the habitat, environment, mineral content, and microorganisms of snails all have an impact on the bioactive component profile of their shells [14].

2.1. Proximate Composition of Snail Shell

Foods' proximate composition is made up of their protein, carbohydrate, lipid, and moisture contents. The inclusion of these food components can be of great significance to the food industry, as they present an analytical opportunity for product development and quality control, allowing for improved product formulations and more rigorous quality assurance processes (QC) or regulatory reasons. The analysis of proximate composition conducted by Jatto et al. (2010) [15] showed a higher level of carbohydrate value, calculated as nitrogen free extract (NFE), as a soluble carbohydrate. In *Achatina achatina* species (African giant snail), it could lead to the use of these ingredients in the development of new 'healthy' products. The findings of a study carried out by Nkansah et al. (2021) [16] on three different snail species, such as *Achatina marginata*, *Achatina fulica*, and *Achatina achatina,* showed and confirmed that ash, which can range from 94.8% to 96.31%, is the primary component of the snail shell in *Achatina marginata*, indicating the quantity of carbon compounds and inorganic components.

2.2. Chitin and Chitosan

Natural aminopolysaccharides, chitin, and chitosan polymers have distinct structures, multifaceted characteristics, extremely complex functions, and a variety of uses in the biomedical and other industries [17][18][19], particularly in the health sector, are useful as antibacterial agents. It is now highly sought after as a novel functional biomaterial with enormous promise across a range of industries, in addition to being an underutilized resource [20][21]. When analyzing the content of chitin and chitosan compounds in different snail shell species of the class Gastropoda, such as *Achatina achatina*, *Achatina fulica*, and *Archachatina marginata*.

The results of the chitosan test obtained from these shell species against potentially dangerous bacterial strains showed that an inhibitory power of 34.33 mm against Staphylococcus aureus was observed at an optimal concentration of 500 ppm [22]. Additional test results demonstrating a sensitive response were obtained from patients with diabetic ulcers caused by the *Staphylococcus aureus* bacteria at concentrations between 300 and 700 ppm [23]. *Achatina fulica* species-derived snail shell chitosan was tested for its positive antibacterial activity on cotton fabric by observing how different soaking times affected *Staphylococcus aureus* growth activity. According to this study, the longer the cotton cloth is submerged in chitosan acetate (*Achatina fulica*), the more effective it is at inhibiting bacterial activity [24]. The potential of chitin and chitosan to mitigate the usage of synthetic food preservatives lies in their antibacterial and antifungal attributes. Additionally, N-carboxymethylated chitosan, a water-soluble derivative, exhibits antifungal properties. In comparison to synthetic wraps, chitosan-based films surpass in terms of decreased oxygen permeability and improved moisture transfer.

2.3. Calcium Carbonate

As mentioned earlier, food waste is associated with nutrient losses. Chemical properties, together with the wide range of particle sizes, particle size distributions, and even different crystalline structures, make calcium carbonate an attractive starting material and the right carrier for various mixtures. Therefore, to increase the absorption of calcium from the diet, foods fortified with calcium are commercially available today [25]. Therefore, the calcium carbonate content of the snail shell needs to be extremely high in order for it to be considered a potential source for various industries, as Sundalian et al. (2022) have determined, finding that $CaCO_3$ is the major component of the shells. In order to support the claim, Parveen et al. 2020 [26] attempted to clarify the physical and chemical characteristics of the shells of three Indian freshwater snails, namely, *Bellamya bengalensis* (Lamarck, 1882) (Gastropoda: Viviparidae), *Pila globosa* (Swainson, 1828) (Gastropoda: Ampullaridae), and *Brotia costula* (Rafinesque, 1833) (Gastropoda: Pachychalidae), for the assessment of the calcium carbonate content through field emission scanning electron microscopes (FE-SEM) and energy-dispersive spectroscopy (EDS) microstructure observation and characterization [27].

This increasing need to carry out the mineralogical properties characterisation analysis for snail shell powder in order to further elucidate its characteristic industry potentials also with energy dispersive X-ray (SEM/EDX), X-ray fluorescent (XRF) and the X-ray diffraction (XRD) analysis [28][29].

Images from scanning electron microscopy (SEM) and the corresponding energy dispersive X-ray spectroscopy (EDS) spectra of the shells confirm the high concentrations content (mean percentage of dry weight), supporting and somewhat validating the hypothesis that 95.0–99.9% of snail shells are made of calcium carbonate [30]. Strong calcium peaks, along with carbon and oxygen peaks and the incidence of magnesium and silicium peaks, are seen in the $CaCO_3$ polymorphs.

These chemical properties, together with the wide range of particle sizes, particle size distributions, and even different crystalline structures, make calcium carbonate an attractive starting material and the right carrier for various mixtures. Therefore, commercially available foods fortified with calcium are available to increase the amount of calcium absorbed from the diet today [31]. Calcium supplementation is often used to prevent and treat osteoporosis. Several calcium salts and formulations are available on the market worldwide. Many calcium supplements contain additional ingredients such as vitamin K and magnesium. The most commonly available forms of calcium are calcium carbonate and calcium citrate.

2.4. Other Mineral Elements

Minerals serve a multitude of purposes, including forming the components of our bones, impacting the function of muscles and nerves, and controlling the body's water balance [32]. Similar to vitamins and other vital nutrients found in food, different animal species have different mineral needs [33]. The two main categories of elements found in minerals are macro (major) and micro (trace). The ultra-trace elements fall into the third category. Calcium, phosphorus, sodium, and chloride are examples of macro minerals. Iron, copper, cobalt, potassium, magnesium, iodine, zinc, manganese, molybdenum, fluoride, chromium, selenium, and sulfur are examples of microelements [34]. The requirement for macrominerals is above 100 mg/dL, and the requirement for microminerals is below 100 mg/dL [35]. The ultra-trace elements, which have been identified in animals and are thought to be vital for these creatures, include boron, silicon, arsenic, and nickel. It is impossible to overstate the significance of mineral elements for plant, animal, and human nutrition.

As nutraceuticals, they have also acquired immense importance in recent animal science in that the nutritional and health-promoting effects of their constituents are considered to have beneficial pharmacological effects, contributing, for example, to the establishment of a normal physiological state of health, to the prevention of diseases and, consequently, to the improvement of production performance, and, as dietary supplements, they can reduce the use of antibiotics [36].

The chemical composition of giant African land snail shells, Archachatina marginata, collected from six southwestern States of Nigeria, was studied by Akinnusi et al. (2018) [37]. Eighteen locations throughout the states were used to gather snails, with three locations in each state. The concentrations of magnesium, calcium, iron, sodium, potassium, chloride, and phosphorus were measured in the shells, evidencing calcium as the most abundant mineral element (1618.89 mg/100 g) and chloride was the least abundant (6.37 mg/100 g). Shells from Lagos State had the lowest concentration (745.6 mg/100 g), while those from Ondo State had the highest total mineral concentration (780.0 mg/100 g), with no discernible difference between them and those from Ekiti State. The table displays the overall mean value of the chemical composition of the snail shells from the six southwestern States of Nigeria. All the mineral elements studied were found in the shells but in different concentrations. Calcium was the highest (260.75–279.68 mg/100 g). The phosphorus content in the shells varies between 196.27 mg/100 g and 206.08 mg/100 g. The shells analyzed collected from Ekiti State had the highest concentrations of Mg^{2+}, Fe^{2+}, and K^{+} (although not significantly different from those from Ondo State), while the highest Ca^{2+} levels were found in the shells from Ondo State. Those from Lagos State had the lowest concentrations of Mg^{2+}, Fe^{2+}, and K^{+}.

3. Food Industry Applications

Communities are trying to help solve the problem of sustainable use of existing shell waste, and many projects are being launched around the world to sensitize local people to its reuse as useful items. However, these practices are just a drop in the ocean until the valorization of shells and the development of new products become the main focus of the actual food industry [38]. The content of snail shells found in nature varies depending on the diet, including the influence of protein, microorganisms, and mineral content of the living environment, along with constant research about the active chemical compound content of several gastropod-class snail shells, which can be used as a reference basis for biomaterials, food industry preparations, animal feed, and pharmaceutical suppl

3.1. Functional By-Product Production

Traditional Chinese medicine (TCM) is an ancient and important ethnomedical document that still holds an important place in healthcare in China and is also embraced by the Chinese population worldwide [39]. Mollusks are an essential component of many TCM recipes that are used to treat various medical conditions, where shells are either consumed whole or ground into a powder or decocted (heated to extract essence). A number of conventional respiratory medications with Indian origins contain the ashes of burned mollusk shells or cuttlefish bones that have been processed into pills, pastes, and solutions [40]. Traditional Eastern Mediterranean healers used to treat skin conditions, rheumatism, and stomach ulcers by inhaling smoke from opercula from the Muricidae and Strombidae families [41][42]. A particular incentive for research into anti-inflammatory compounds stems from the fact that mollusks are used extensively in traditional medicine to treat symptoms of inflammation and that mollusks are the most important mollusk product used worldwide for the same purpose [42]. However, many European civilizations believed that burning opercula ash could heal split veins [43]. Shells from *Monetaria moneta* have been used in India to treat a variety of conditions, including asthma [44], and in Zimbabwe, snail shells have long been used as a treatment for topical abscesses [45]. Overall, TCM therapeutic formulations benefit from the contributions of four classes of mollusks: Poly-placophora, Cephalopoda, Bivalvia, and Gastropoda, which have 2, 3, 31, and 34 species, respectively [46].

A recent investigation by Chitprasert et al. (2023) [47] put an eye on the benefits of the use of $CaCO_3$-like nanoparticles to encapsulate and promote the gastrointestinal digestion and bioactivity of vitexin in vitro to improve the bioaccessibility for functional food application. Calcium carbonate is the most common and cheapest form of calcium. For many patients, cost plays an important role. A study that evaluated the cost of calcium from foods and supplements found that calcium carbonate was the cheapest form of calcium, accounting for about a third of the cost of the cheapest food sources, such as frozen skim milk and calcium-fortified orange juice [48].

This investigation revealed that the bioaccessibility, in vitro, was significantly enhanced by this nanoencapsulation with $CaCO_3$, guaranteeing higher antioxidant activity compared to the free vitexin. As a result, this study demonstrates that vaterite $CaCO_3$ nanoparticles are intriguing delivery systems for vitexin meant for use in functional food applications. Furthermore, the $CaCO_3$ nanoparticles are promising options for large-scale production and may raise the possibility of successful commercialization because of their established benefits and low cost [47].

Filter aids or clarifiers are currently used in industrial beer production to improve the quality and clarity of beer. These active ingredients help capture contaminants and/or suspended solids that form blockages or deposits [49]. Due to the high demand for these commercials, these raw materials are relatively expensive and not readily available; cost-effective and locally available alternative filter aids are needed. This can be achieved by finding alternatives to these commercial filter aids from some locally available sources, such as snail shell powder, which mainly consists of calcium compounds, specifically $CaCO_3$, as opposed to diatomaceous earth, which mainly contains silica from the remains of diatoms. Therefore, the use of some of these locally available products as filter aids during brewing has the potential to yield products with desirable qualities comparable to those achieved using commercially available filter aids. This study demonstrated that snail shell powder showed a moderate clarifying effect during the beer-making process, even though the clarity of beer treated with eggshells and other filter aids was excellent [50]. Nevertheless, improving the production of snail shell powder by improving its methods and cost could enhance its use as a potential filter aid in beverage clarification, especially for the large quantities of single-use snail shell waste that are practically available.

3.2. Valorization in Livestock Feed Supplement

Crushed shells are an important calcium supplement ($CaCO_3$) when included in livestock feed. Calcium supplementation is used to improve livestock health, especially bone health, as well as in laying hens as a supplement to improve eggshell quality and strength [51]. Replacing calcium in limestone with calcium in some marine shellfish increases bone development, egg production, and egg strength, weight, and thickness in chickens [52][53][54][55] and ducks [56]. It has been shown that, according to EU Regulation (EC) No. 1069/2009, shell waste can only be used as a feed additive if it does not contain meat in order to exempt it from classification as an animal by-product [57]. The allocation of standards is regulated by the respective authorities of each member state. Ultimately, the recovery of this species needs to consider the distance between shellfish production and farms, both from the perspective of environmental and economic sustainability [58].

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