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Recent trends in application of shell waste from mariculture

Mihajlo JOVIĆ[1*], Milica MANDIĆ[2], Marija ŠLJIVIĆ-IVANOVIĆ[1] & Ivana SMIČIKLAS[1]

[1]Vinča Institute of Nuclear Sciences, University of Belgrade, P.O. Box 522, 11000 Belgrade, Serbia,
e-mail: mjovic@vin.bg.ac.rs
[2]Institute of Marine Biology, University of Montenegro, P.O. Box 69, 85330 Kotor, Montenegro

ABSTRACT

Today, commercial mollusk farming is an essential component of the global aquaculture industry with a share of 23% of the world's total production and the tendency of continual growth. Small investments and low energy consumption make this production a globally interesting source of cheap and healthy food for the growing population of people on the planet. However, since shells can account for up to 75% of total bivalve body weight, contamination of the ecosystem by bivalve shells is one of the major problems of this industry branch. Seashell waste produced in vast quantities around the globe is often dumped in landfill or the sea. This waste piles up at coastal areas and causes many environmental problems. This paper aims to draw attention to the issues and risks from seashell waste and to discuss the solutions which would potentially be a step towards mitigating the environmental burden. European Union directive has vigorously enforced the development of new technologies that exploit waste as resources and contribute to the concept of sustainable development. In this regard, recent trends in shell waste applications have been reviewed, as novel ideas for reducing the waste accumulation and valorizing of shells to achieve both ecological and economic incentives.

Keywords: mariculture, seashells waste, reuse, recycling and waste reduction, waste valorization

INTRODUCTION

Demand for bivalves is growing worldwide as they become very popular seafood. All major consuming countries reported high requests for bivalve products which led to an increase in production but still not enough to completely meet the world demand (GLOBEFISH, 2018). Small investments and low energy consumption make bivalve production a globally interesting source of cheap and healthy protein-rich food, for providing a sustainable supplement or an alternative to the marine capture fishery and also an opportunity for economic development of the area in which the farming activity is done. Bivalves are cheap, very nutritious, easy to cook, take very little time to prepare and go well with a multitude of flavors. Therefore, increased popularity is not surprising, especially among the young generation.

Bivalves do not need feed to grow and are not a burden to the environment as other cultured seafood species. However, this industry generates considerable waste co-products mainly in the form of shell material, since shells can account for up to 75% of total bivalve body weight (Yao *et al*., 2014). Contamination of the ecosystem by bivalve shells is one of the major problems with which the world's largest producers have already met, and which could endanger further sustainable development of this branch of industry. Enormous amount of waste seashells were dumped into public waters and/or landfills, and cause many environmental problems including pollution of coastal fisheries, management of public water surface, a bad smell as a consequence of the decomposition of organics attached to the shells, damage of natural landscape and health/sanitation problems (Hou *et al*., 2016). As the production and processing of bivalves have increased, efficient use of their shells has become essential, not only to maximize financial return, but also to address waste disposal problems because of their slow natural degradation rate.

The most heavily traded bivalve mollusk species are mussels, clams, scallops and oysters, mostly farmed, and world bivalve production (both wild and farmed) of selected species in 2016 were: oysters 54%, scallops 24%, mussels 18% and calms 4% (GLOBEFISH, 2018). China is the largest producer of bivalves, followed by Chile, Korea, USA, Spain, and France. Mariculture in Montenegro began to develop after the completion of initial explorations conducted in the ’60s of the last century (Mandić *et al*., 2016). From the first scientific exploring, it was obvious that environmental conditions, factors and criteria’s in the Boka Kotorska Bay are very suitable for the industrial development of the mariculture sector especially for shellfish growing (Stjepčević, 1974). Currently, there are around 20 active shell farms with annual mussel production of about 180 tons, and about 13 tons of oysters farmed only at the two of them (SY MNE, 2017). Although bivalve farming in Boka Kotorska Bay is at a relatively low level in comparison with leading countries in this sector (FAO, 2018a, b; FAOSTAT, 2018), a mild growth over the past few years and the natural potential seems to be promising for future development of the Montenegrin aquaculture.

Based on the research conducted from 2016 to 2018 within the bilateral scientific project between Republic of Serbia and Republic of Montenegro “Potential applications of the mussels and oysters shells as biosorbents for heavy metal removal”, it was estimated that about 100 tons of seashell waste are generated annually in the area of Boka Kotorska Bay. For now, this amount does not represent an environmental problem, but the inevitable and expected growth of bivalve production in the near future entails issues related to the waste generation by this industry branch. A possible problem must be considered to prevent potential environmental damage and also to avoid additional costs associated with the rehabilitation and treatment of such waste. Finding solutions to the accumulation of seashell waste would reduce ecological and financial problems.

This study aimed to draw attention to the issues and risks from seashell waste and to discuss and propose the solutions which would potentially be a step towards mitigating the environmental burden. Also, this study highlights some potential waste applications that can bring both economic and ecological benefits.

APPLICABILITY OF SEASHELL WASTE

Alternative materials, such as seashell waste, are increasingly considered to reduce the exploitation of the reserves of natural limestone - one of the most exploited resources on the planet. In that sense, the utilization of seashell waste is a useful strategy for both sustainable resource management and reduced waste storage.

Seashells contribute to more than 7 million tons of "nuisance waste" discarded every year by the seafood industry that mostly winds up thrown into landfills or dumped into the ocean. Reusing and recycling of such waste can be an excellent alternative to disposal. The seashell material attracts attention due to high calcium-carbonate content, low-cost and availability provided by the fast developing seafood industry (Barros *et al.*, 2009). Over the past decades, numerous articles have been published on the subject of shell valorization, citing a variety of potential applications that could alleviate the burden of waste shells on aquaculture and food producers, and in some cases present economic as well as environmental incentives to do so (Morris *et al.*, 2019). Fig. 1 shows some of the possible application of waste seashells.

Several large-scale shell valorization strategies are currently exploited, and most of them are established in areas that generate large amounts of shell waste, i.e., where mutually beneficial partnerships have been established between shell producers and other industries (Morris *et al.*, 2019).

Further, some products from sea shells are already commercially available for a variety of applications, Table 1.

Galicia (Spain) is the leading region in Europe that currently utilize seashell waste as a liming agent, because of the proximity of agricultural land to large shellfish aquaculture sites and the seashell processing facility (Barros *et al.*, 2009; Morris *et al.*, 2019). Until now, the uses of seashells have been limited to several established and sustainable applications (soil conditioners, low-cost adsorbents, calcium supplements, construction materials, etc.).

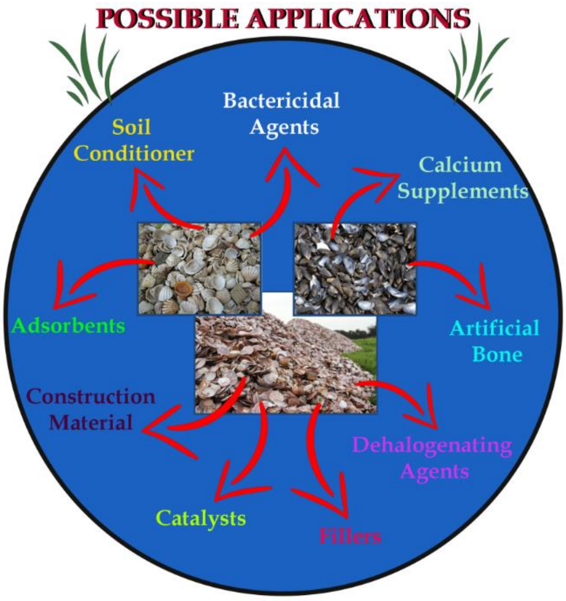

Figure 1. Possible applications of seashell waste

Table 1. Examples of the seashell market for different purposes (Morris *et al.*, 2019)

Type of application	**Processing required**	**Selling price in 2017 (€/kg)**
Poultry feed	Heat treated, crushed	0.4–3
Pet bird nutrition	Heat treated, crushed	0.6–7
Bio-filter medium	Heat treated, crushed	0.4–0.5
Aquarium/pond pH buffer	Heat treated, crushed, chlorine washed	4
Soil liming	Heat treated, powdered	0.4–0.6
Shell aggregates	Whole shell, dried	0.3–0.9
Shell aggregates	Dried, crushed	0.3–3

Also, numerous utilization possibilities were either discussed in the literature or have already been tested under realistic conditions but without commercialization (catalysts for biodiesel, bactericidal agents, artificial bones, dehalogenating agents, etc.). Today, the idea of seashell returning to the marine environment for conservation reasons became more and more popular and accepted among different organizations and research groups. A long-term effort is needed to seek possible recycling methods for shell waste and eliminate the environmental problems it can cause (Yao *et al*., 2014).

HISTORICAL USE OF SHELL

Historically, shells have been an important part of human culture. There is a variety of examples of mollusk shell use across the globe throughout human history, even 100,000 years ago. In prehistoric Stone Age sites in China and throughout Africa, seashells were used as a form of currency. Also, in many coastal settlements around the globe, shells (most often and traditionally oyster shells) have been used in construction and many such buildings today represent popular tourist attractions. Powdered shells have been used for medicinal purposes and have been historically attributed with a myriad of health benefits and healing powers. In African countries, wearing a shell amulet was thought to help maintain health, fertility, and luck. Shell amulets coated in gold and silver found in Egypt, and worn in recent history, was also intended to promote good health. The oldest identified piece of jewelry in the world was discovered in Israel and was made from the shells of the sea snail. There are many records on the use of seashells as tools for a variety of purposes including hammering, chipping, chopping, cutting, bevelling, etc. Furthermore, the shells of sea snail were used by native Australians as devices for expelling water from the canoes and as cooking pots (Morris, 2017).

MODERN SHELL USE

Seashells can be exploited in numerous ways as presented in Fig. 1. Valorization is the principle of assigning value or giving greater value to something, where value can be seen from an economic, social and/or environmental perspective (Morris, 2017). Such concept is particularly relevant with the recent drive towards recycling, zero waste industries, and a circular economic system (European Commision, 2015).

I. Soil conditioner

The most common management practice to ameliorate acid soils is the surface application of lime or other calcareous materials (Bolan *et al*., 2003; Yao *et al*., 2014). As the main aim of soil liming is to neutralize acidic inputs, shell waste can be considered as an adequate substitute for this process. Seashell has been used as a liming agent alone (Lee *et al*., 2008), combined with other amendments to improve soil fertility (Kwon *et al*., 2009; Paz-Ferreiro *et al*., 2012), or used to remediate heavy metals pollution in soils (Ok *et al*., 2011). Teixeira *et al*. (1997) used mussel shells (*Mytilus galloprovincialis*) as a liming agent in soils in Galicia (Spain) and found that 9 t/ha of mussel shell had a comparable short-term positive effect on soil acidity as conventionally used magnesium limestone, but in the longer term, they proved to be less effective than mined liming agents in terms of soil fertility. Application of seashells to acidic soil resulted in the increased pH, soil organic matter, available P, exchangeable cations concentrations, and improved soil chemical and biological properties and increased plant productivity (Lee *et al*., 2008). Álvarez *et al*. (2012) reported that application of mussel shells to acidic soil increased the soil pH and content of exchangeable Ca, decreased the saturation of Al in the exchange complex, and had a positive effect on dry matter yield and Ca-concentration in the plants. Addition of seashell waste was found effective in reducing Cu concentrations available to plants in Cu-polluted vineyard soil (Fernández-Calviño *et al*., 2017), decreasing bioavailability of Pb in an army firing range soil (Ahmad *et al*., 2014), and increasing Cu, Cd, Ni and Zn retention in copper mine soil (Ramírez-Pérez *et al*., 2013). Ramírez-Pérez *et al*. (2013) demonstrated that the addition of the 24 g/kg mussel shells could retain Cu, Cd, Ni and Zn within the first few centimeters of the soil column length, indicating the usefulness of ground mussel shells to decrease the mobility and availability of these pollutants drastically. The results obtained in this study showed that mussel shells facilitate remediation efforts and further restoration of contaminated acidic soils. Shen *et al*. (2018) demonstrated that oyster shell powder application was more effective at reducing the incidence of tobacco bacterial wilt and improving the soil pH than lime and biochar. These authors recommend oyster shell powder as a soil amendment in order to improve soil pH and increase the bacterial richness and diversity of acidic tobacco-growing soils and thus contribute to the suppression of tobacco bacterial wilt. Paz-Ferreiro *et al*. (2012) demonstrated that mussel shell added to Cambisol significantly improved soil pH, lowered the amount of Al held in the cation exchange complex, increased soil microbial activity and enhanced soil fertility. However, some previous studies have shown certain limitations to the use of seashell as a liming amendment, such as a possible increase of Na content held in the cation exchange complex (Lee *et al*., 2008).

II. Catalysts

Oils and fats not suitable for human consumption can be used for biodiesel production. Unfortunately, such materials usually cannot be used directly as fuel due to their high viscosity, unsuitable combustion, poor atomization and can cause severe functional problems in an engine (Hou *et al*., 2016). The molecular weight of the oil needs to be reduced, and for this purpose, trans-esterification is the most wildly used and investigated method. During the esterification process, the presence of a catalyst is mandatory for the production of biodiesel which can be used as a clean fuel in diesel engines (Hou *et al*., 2016). Among the catalysts, CaO shows promise, and many studies have been conducted using CaO-catalyzed trans-esterification (Kawashima *et al*., 2009; Kouzu *et al*., 2006; Liu *et al*., 2008). Seashell consist mainly of $CaCO_3$ (95-99.9%) with a small amount of organic matrix, and represent material that could be decomposed to CaO under high temperatures (700-1000°C) and used as catalysts for the production of biodiesel (Boey *et al*., 2011; Marinković *et al*., 2016; Salvi & Panwar, 2012; Yao *et al*., 2014). Perea *et al*. (2016) utilized waste mussel, clam and oyster shells as heterogeneous catalysts for the transesterification of *Camelina sativa* oil as a feedstock, into biodiesel, Fig. 2.

Figure 2. Utilization of waste seashells and *Camelina sativa* plant for biodiesel production

Biodiesel has gained considerable attention because of the potential depletion of fossil fuel resources and migrating pollutant emissions. Hence, the utilization of calcium sources from seashell waste as an economic catalyst has become a new global trend.

III. Separation of pollutants from wastewater and air

The prospect of using seashell waste to sequester toxic metal species, radionuclides, phosphate and dye from aqueous solutions was investigated in the range of experimental conditions (Egerić *et al*., 2018a,b; Hou *et al*., 2016; Yao *et al*., 2014).

The use of seashell material in waste management can contribute to preserving marine ecosystems and assist with waste discharge problems (Hou *et al*., 2016) Fig. 3. The possibility of using seashell waste to remove dyes (El Haddad *et al*., 2014a, b; Papadimitriou *et al*., 2017), numerous toxic metals and radionuclides (Bozbaş & Boz, 2016; Du *etal*., 2011; Egerić *et al*., 2018; Papadimitriou *et al*., 2017; Peña-Rodríguez *et al*., 2010; Wu *et al*., 2014), phosphorus and phosphates (Kwon *et al*., 2004; Park & Polprasert, 2008; Yuangsawad & Ranong, 2011) from wastewater was investigated by a number of researchers. Also, Masukume *et al*. (2014) showed a great potential of seashell in the treatment of complex wastewater, i.e. acid mine drainage, Kwon *et al*. (2004) used oyster shell waste to solve problems of water eutrophication, Tsai *et al*. (2011) used shells to remove boron from concentrated wastewater, while Onoda & Nakanishi (2012) evaluated oyster shell for the production of calcium phosphate with the objective of recovering lanthanum cations from wastewater.

The alkaline material, such as CaO, $CaCO_3$, $Ca(OH)_2$, NaOH, Na_2CO_3, $NaHCO_3$, KOH, MgO, $Mg(OH)_2$, dolomites, and dolomite-limestone ($CaCO_3/MgCO_3$), are used to remove SO_2 and acid gases in flue gas cleaning processes (Jong-Hyeon *et al*., 2007). The utilization of shell material as alternative is economical and also important for waste recycling. Considering that hygroscopicity and production costs are critical factors, calcium-based materials obtained from seashell waste are highly promising commercial adsorbents (Jong-Hyeon *et al*., 2007; Jung *et al*., 2000). Based on the results obtained experimentally, Jong-Hyeon *et al*. (2007) concluded that waste oyster shells could be used as acid gas cleaning agents to reduce air pollution problems and that treated seashells can be applied directly to industries attempting to reduce their emissions of SO_2 and NOx.

Figure 3. Seashell waste application as a removal agent for a variety of pollutants

IV. Construction material

Seashells have been used in construction in many coastal settlements around the globe. The concrete made by heat-treated shells mixed with sand, water, ash, and broken shells is known as Tabby, Fig. 4 (Morris, 2017). Many authors explored the potential utilization of seashell waste in concrete in terms of re-using the discarded seashells as a replacement for conventional materials, such as cement, sand and coarse aggregate fraction (Lertwattanaruk *et al*., 2012; Mo *et al*., 2018; Olivia *et al*., 2015, 2017; Yoon *et al*., 2004).

The seashell characteristics suggest that, similar to limestone, this waste could be used as an inert material in concrete (Mo *et al*., 2018). Investigations have shown that seashell waste can be used as a replacement for both cement and aggregate. Heating of shells at high temperature and crushing to achieve appropriate fineness are desirable treatments that improve the quality of the products (Mo *et al*., 2018). Despite the reduction in the workability, compressive and tensile strength and elastic modulus, it is suggested that seashell waste could still be utilized as an aggregate at a partial replacement level of up to 20% for adequate workability and strength of concrete for non-structural purposes (Mo *et al*., 2018; Yang *et al*., 2005, 2010).

Figure 4. Examples of constructions built from seashells

One of the most interesting applications of seashells today involves shells returning to the marine environment by using them as a material for creating the artificial reef structure, Fig. 5. Biomimicry, i.e., imitation of design and conceptual solution that can be found in nature, was the starting point and guideline for this potential application.

Namely, in the natural systems, adult seashells provide a suitable substrate for larvae settling and fixing and thus forming reefs along the coast. Except as a suitable substrate for the mussels and oysters reproduction, these artificial reefs would provide shelter, an appropriate place for development and food source for many other marine organisms. They provide other ecosystem services as they create a habitat in coastal environments on which complex food webs are based and also are increasingly constructed for shoreline protection and erosion control (Walles *et al*., 2016). Mussels and oysters form dense three-dimensional reef structures which can alter water flow and reduce wave action while trapping and stabilizing sediment (Borsje *et al*., 2011; Walles *et al*., 2015). Walles *et al.* (2016) showed that the persistence and sustainability of artificially constructed oyster reefs are strongly dependent on the local environmental conditions. They concluded that the artificial reef structure provides a substrate which facilitates reef establishment, but that tidal emersion is an essential factor that can be used to predict where artificial oyster reefs have the potential to develop in self-sustaining reefs and to contribute to coastal protection.

Figure 5. Artificial oyster reefs for oyster and herring populations, for shoreline protection and erosion control, for reducing wave action and promoting the establishment of plant and animal life in the vulnerable area

V. Calcium supplements

Calcium supplementation is used to improve the health of livestock, particularly bone health, but also in laying birds as a supplement to enhance the quality and strength of eggshells (Suttle, 2010). $CaCO_3$ sourced from mined limestone is commonly used, however, several studies have tested and proved oyster shell-derived $CaCO_3$ as a potentially cheaper source of $CaCO_3$, compared to limestone (Morris *et al*., 2019). Generally, seashells are a vital source that can be used in the production of inorganic Ca with application in food industries. There are many literature data on using oyster and mussel shells as a supplement in the poultry industry, especially for laying hens (Gerry, 1980; Muir *et al*., 1976; Oso *et al*., 2011), and as effective Ca supplements for lactating dairy cows (Finkelstein *et al*., 1993). Poultry producers have been using the oyster shell for more than 100 years (Yao *et al*., 2014). Although calcium enriched food, such as seashell, can potentially help consumers to achieve required Ca intake, it is necessary to evaluate the adsorption of Ca from this sources in comparison with available commercial products for human consumption (Malde *et al*., 2010). Some issues need to be considered when seashells are planned to be used as a food supplement. For example, the content of the organic materials (seashell contain about 5%), the concentration of trace elements (especially toxic As, Hg, Pb, Cd, etc.) which must be lower that the safety limit recommended for human consumption, the potential parotid swelling induced by oyster shells calcium supplements, etc. (Hou *et al*., 2016). In Regulation (EC) No 1069/2009, it is outlined that seashells can be used for supplementation as long as they meet a free-from-flesh standard, with which they are then exempt from animal by-product classification. Today, there is considerable demand for calcium carbonate by the livestock industry; however, the expansion of the use of seashells may be limited by the costs associated with accumulating enough mass of shells at a single location for the continued and reliable source that large livestock producers expect. From both an environmental and economic perspective, only farms close to large shell producers are likely to be candidates for this type of seashell valorization (Morris *et al*., 2019).

VI. Other potential seashell applications

In this section, some of the potential applications of seashell waste are described. Many of them are unrealized, theoretically discussed, tested on a laboratory scale or used in real scenarios, but they that could prove viable economically and environmentally benign. Seashell is a functional biomaterial, and some studies have investigated its use as filler (Chong *et al*., 2006; Funabashi *et al*., 2010). $CaCO_3$ is the most widely used inorganic filler in polymers, so seashell is material that offers advantages of cost reduction and modulus improvement, without drastically increasing the specific gravity of the composite, in comparison with commonly used inorganic fillers, $CaCO_3$ and talc (Yao *et al*., 2014). Also, $CaCO_3$ in seashell can be converted into CaO by using heat treatment (≥ 700°C) which exhibits strong antibacterial activity (Li *et al*., 2014; Yao *et al*., 2014). The antibacterial activity of calcined seashells is mainly related to the alkaline effect caused by the hydration of CaO (Yao *et al*., 2014). Seashell waste from the aquaculture industry can be potentially used also as the calcium donor in the formation of calcium acetates as an eco-friendly de-icer substance for use on roads (Morris, 2017). Green roofs, very popular in the last decade in urban areas, are another potential use of seashell waste. Whole shells are ideal for formation a 3D structure of drainage layer which role is important in carrying away excess water from the roof, in the neutralization of acid rain and also as a bio-filtration medium for reducing heavy metal contamination in the resultant drainage water (Morris, 2017). Basic oxides (such as CaO, MgO, Fe_2O_3, etc.) play an essential role in dissociating organic halogens from halogenated compounds and represent another potential application of waste seashells (Ahmad *et al*., 2014; Yao *et al*., 2014). Seashells have also been investigated and advocated in various cosmetic applications and one of the most commonly used is as a skin exfoliator with the additional anti-bacterial properties (Green *et al*., 2015; Latire *et al*., 2014). The most widely discussed biomedical use for seashells is in bone and tissue re-engineering (Morris, 2017). The calcium carbonate component of seashells can be converted to calcium-based compounds suitable for biomedical applications (bone engineering and augmentation) (Niida *et al*., 2012; Zhang *et al*., 2017). The $CaCO_3$ powder shell has been shown to have osteogenic properties and acts as a substrate on which new osteoblasts can grow and secrete bone (Morris, 2017). Researchers have suggested that shell $CaCO_3$ could be converted to calcium phosphate (hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$) which is the primary mineral component and constituent of human bones. Seashell waste, the material of the future, has great potential use as a bone substitute (artificial bones) in orthopedic surgery (Yao *et al*., 2014).

CONCLUSIONS

Bivalve farming is an essential component of the global aquaculture industry with the tendency of continued future growth. Consequently, this industry generates considerable waste co-products mainly in the form of shell material that is currently under-utilized. As shells can account for up to 75% of total bivalve body weight, contamination of the ecosystem by bivalve shells is one of the major problems. Already today, the enormous amount of waste seashells were dumped into public waters and/or landfills, and cause many environmental problems including pollution of coastal fisheries, a bad smell, damage of natural landscape and health/sanitation problems. Marine pollution by waste seashells has become one of the severe problems in mariculture industry in China, Korea, Spain, USA, France, major producer of bivalves.

As shell waste remains a barrier to the sustainable growth of bivalve aquaculture, this study aimed to draw attention to the problems and risks from seashell waste and to discuss the potential solutions. Recycling seashell waste offers many advantages and has potential application in various fields. Over the past decades, numerous articles have been published on the subject of seashell valorization, proposing a variety of potential applications that could alleviate the burden of waste seashells on aquaculture and food producers. Some applications represent current, well established, widely utilized, large-scale and sustainable applications. On the other hand, there are many more strategies that are not yet fully explored or commercialized. An increasing worldwide research indicates considerable potential for utilization of seashells as soil conditioner, catalysts for biodiesel production, adsorbents for removing dyes, toxic metals, radionuclides and phosphates from wastewaters, absorption of SO_2 and acid gases in flue gas cleaning processes, construction material as a replacement for cement, sand and coarse aggregate, calcium supplements, antibacterial protection, bone implants, etc.

However, certain limitations and restrictions must be taken into considerations, and the additional investigations must encompass the overall performance, economic and environmental indicators and benefits for each potential application. For example, using seashells as artificial bones is promising, but clinical applications and methods of enhancing their performance should be further investigated. Also, there is a remarkable diversity among shells species, so there are differences in their physicochemical properties that are necessary to examine and select the appropriate types of seashells for each desired application. Seashells contain a small amount of organic matrix and elements which concentrations and effects must be evaluated especially when used as a substitute material. Any seashell treatment and use as a raw material for CaO production require an evaluation of both environmental impacts and the resulting economic values. In contemporary society, ecological benefits are unfortunately underestimated with respect to financial ones. Therefore, the distance between seashell sources and processing facilities is a very important factor in the analysis of the feasibility of seashell waste utilization. The expansion of the use of bivalve shells may also be limited by the costs associated with the accumulation of enough mass of shells at a single location for the continued and reliable supply of large consumers.

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Savremeni trendovi primjene otpadnih ljuštura školjki iz marikulture

Mihajlo JOVIĆ, Milica MANDIĆ, Marija ŠLJIVIĆ-IVANOVIĆ & Ivana SMIČIKLAS

SAŽETAK

Komercijalno uzgajanje školjki danas je ključna komponenta globalne industrije akvakulture sa udjelom od 23% ukupne svjetske proizvodnje i sa tendencijom kontinualnog rasta. Mala investiciona ulaganja i niska potrošnja energije čine ovu proizvodnju globalno zanimljivom sa stanovišta obezbjeđivanja velike količine jeftine i zdrave hrane za rastuću populaciju ljudi na planeti. S obzirom da ljušture mogu činiti i do 75% ukupne tjelesne težine školjki, kontaminacija životne sredine otpadnim ljušturama školjki jedan je od glavnih problema ove grane industrije koji čak može ugroziti njen održivi razvoj. Ovaj otpad se proizvodi u ogromnim količinama širom svijeta, a najveći dio se odlaže na kopnu ili vraća u more. Ljušture školjki gomilaju se u priobalnim područjima gdje prouzrokuju mnoge ekološke probleme. Ovaj rad ima za cilj da skrene pažnju na problem i rizike koje sa sobom nosi ova vrsta otpada, da diskutuje i predloži rješenja koja bi potencijalno mogla da budu korak ka ublažavanju opterećenja životne sredine ovim otpadnim materijalom. Direktiva Evropske Unije snažno je nametnula i podržava razvoj novih tehnologija koje iskorištavaju otpad kao resurse i doprinose konceptu održivog razvoja. U tom smislu, izvršen je pregled i sumirane su sve dosadašnje potencijalne aplikacije otpadnih ljuštura školjki, koje imaju za cilj da spriječe akumulaciju otpada i valorizuju ljušture radi postizanja pozitivnih ekoloških i ekonomskih efekata.

Ključne riječi: Marikultura, otpadne ljušture školjki, ponovna upotreba, recikliranje i smanjenje količine otpada, valorizacija otpada