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ORIGINAL ARTICLE

Improving waste management strategies in the food sector: case studies from Spain, Tunisia and Hong Kong

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Abstract

Appropriate waste generation and management is becoming increasingly important in making food systems more sustainable. It is, therefore, imperative to both reduce waste generation and sustainably manage the waste that cannot be reduced. However, this is challenging due to the heterogeneity of waste materials, the high economic costs of optimizing food systems and the low awareness of the issue in some societies. This article analyzes three case studies that explore improvements in waste management in the food sector in Europe, Africa and Asia. The case studies focus on a horticultural cooperative in Spain, a seafood company in Tunisia and municipal waste management in Hong Kong, highlighting different challenges and approaches. Key factors for horticultural waste management include a consistent regulatory framework, appropriate management systems and waste traceability. The article also highlights the potential for valorisation of waste products, such as blue crab by-products, which can be used to obtain polysaccharides, proteins, lipids, antioxidants, flavonoids, vitamins and minerals. A shift from landfill to anaerobic digestion is also recommended for a more sustainable waste management. By identifying and quantifying waste streams and problematic waste types, alternative solutions can be developed to improve the sustainability of the global food supply chain.

Keywords Food waste · Horticulture · Seafood · Municipal waste · Circular economy

Introduction

Improving the sustainability of food systems is at the heart of the European Green Deal strategies, in particular the 'farm to fork', 'circular economy' and 'biodiversity' strategies [1]. However, achieving this goal is easier said than done, as many global challenges (e.g., the rapid acceleration of climate change, the outbreak of the COVID-19 pandemic and the ongoing war in Ukraine) are affecting humanity and causing dramatic disruptions. In particular, the issue of food waste has been highlighted as a global problem and has been at the centre of many public debates in recent years. Indeed, with around one-third of food intended for human consumption never consumed, food waste is one of the main challenges contributing to the unsustainability of food systems, causing environmental, economic and social problems [2–5].

Significant amounts of greenhouse gases generated by agri-food systems are due to waste generated in the food supply chain, which increases the environmental footprint and thus hinders the achievement of climate neutrality [6–8]. From an economic perspective, better waste management is necessary to avoid loss of economic value, to generate economic benefits or savings for all actors involved in the food supply chain and to accelerate the achievement of the circular economy [9–12]. In terms of the social dimension, reducing food waste can increase social welfare, reduce food poverty and alleviate hunger [5, 13].

Food waste contains a wide range of valuable compounds that can be extracted and used in a variety of applications. For example, waste from the seafood [14], agri-food industry [15–17] and plant by-products [18] can be used in the production of food packaging materials, providing sustainable and environmentally friendly solutions to the overuse of plastics. Other applications of agricultural and seafood wastes and industrial by-products include food additives [19, 20], nutraceutical ingredients [21], and the production of renewable fuels [22], among others. However, such

Extended author information available on the last page of the article management of food waste is difficult due to its heterogeneity and the economic costs associated with the processes involved.

Digitalisation and other advanced technologies and novel strategies are being applied to reduce resource use and recover value from waste streams to achieve the goal of zero waste [7, 13, 23–25]. In this context, green technologies and novel extraction and processing strategies have been extensively investigated to improve and optimise the extraction of bioactives [26, 27]. A growing body of research shows that fourth industrial revolution (Industry 4.0) technologies have great potential to optimize the supply chain and reduce food waste [23, 28–30]. For example, the important role of big data analytics in mitigating the environmental and social impacts of food waste generation was recently demonstrated by Cicculo et al. [31].

Therefore, reducing waste in the food sector and establishing appropriate waste management strategies is essential to promote the circular economy and effectively achieve the United Nations' Sustainable Development Goals (SDGs). This article shows how this can be achieved by presenting three case studies that explore better solutions for waste management in the food sector in three different areas: a horticultural cooperative, a seafood company and a densely populated city. Thus, this article aims to show practices that can be followed to improve waste management in the food sector and consequently inspire stakeholders to identify and implement waste management optimisation procedures. These case studies were selected on the basis of the large amount of waste generated, the potential for improvement and the wide geographical scope. Each case study begins with an introduction to the sector and geographical area, followed by the case study methodology, analysis of current waste management practices, identification of waste management opportunities, and discussion and comparison with other studies and geographical areas.

Horticultural cooperative in Spain: managing non-biodegradable waste

Spain, particularly the southern region of Andalusia, is one of the main producers of horticultural products [32, 33]. A major challenge in horticultural production, especially in greenhouses, is the large amount of waste generated [34]. Due to the economic costs associated with this waste management, as well as stricter regulatory frameworks and increased awareness among farmers and citizens of the importance of adopting more sustainable practices, horticultural businesses are paying increasing attention to their waste generation rates and management practices [12].

The company analyzed in this case study is a cooperative that markets horticultural products produced in Andalusia. Data were collected via interviews with company staff. The cooperative keeps an accurate record of the types and quantity of waste that they generate and their final uses and costs. The steps followed to complete this case study were:

1) Identification of the waste generated by the cooperative
2) Quantification of the yearly amount of each waste produced
3) Calculation of the cost of managing each type of waste
4) Identification of critical factors and recommendations for waste management

The cooperative has more than 600 farmers and members, 854 hectares of cultivated land and several product reception, handling and packaging centres. The cooperative has a total surface area of 20,000 m^2, divided between an 8,000 m^2 farm and a 12,000 m^2 farm, with four multi-tunnel greenhouses on each farm. The farms have a warehouse, an irrigation head and a pond. The irrigation system used in the farms is drip irrigation. The greenhouse has a metal structure, galvanised internal pipework, double doors and side and roof ventilation.

The company uses quality certification protocols for greenhouse operations, both general and specific to the agri-food sector, such as GLOBALGAP, BRC, ISO and HACCP. The waste that they generate that is difficult to manage is usually collected at the point of origin. The frequency of collection does not normally exceed six months, as the subsidiary cleaning is carried out by authorised public administration managers. The company has an agreement with an external collection service, so that when a member of the cooperative wants to dispose of their waste, they call the haulier to collect it. The member must present the certificate of membership of the collection point to receive the waste. The cooperative handles the payment. The existing consortium only manages municipal solid waste. Non-biodegradable waste is deposited in containers and bins that are taken to municipal waste treatment plants.

Table 1 shows the non-biodegradable waste generated by the cooperative in one year. The amount of waste has been determined on the basis of information gathered through regular face-to-face meetings with members of the cooperative and estimates. Calculations were made taking into account the total amount of each type of waste at the end of the greenhouse's useful life.

The total amount of waste produced is 2,386 tonnes per year, with a waste production rate of 2.79 tonnes per hectare per year. Approximately half of the waste consists of various types of plastic, while most of the rest is metal (steel). There is a small amount of other waste such as textiles, wood and cardboard. Often, these materials are mixed with plant waste, which complicates its management [34, 35]. These proportions agree with previous studies in the same region

Table 1 Non-biodegradable waste generated annually by the company

Type of waste	Quantity (t/year)	Material	Dirt	Potential use	Need for conditioning	Cost, excluding transport (euro/year)
Greenhouse structure	1,101.76	Steel	Low	Recycling	Not required	0.00
Cover film	646.06	LDPE, LLDPE, EVA	Medium	Recycling, energy recovery	Not required	Sale at 0.1 €/kg
Ventilation mesh	22.05	HDPE	Medium	Recycling, energy recovery	Not required	1322.71
Piping of irrigation systems	105.76	HDPE	Low	Recycling	Not required	6345.42
Chromotropic trap	33.07	LDPE	High	Disposal (municipal solid waste)	Not required	-
Double roof film	123.58	EVA copolymer	Medium	Recycling, energy recovery	Must be cleaned	7414.90
Thermal blankets	15.54	LDPE, LLPE, metallocene, EVA/EBA co-polymer	High	Recycling, energy recovery	Must be cleaned	932.45
Packaging of biological control products	0.25	HDPE	Low	Recycling	Not required	14.90
Plastic hives	7.94	LDPE, cardboard	Low	Recycling, energy recovery	Materials must be separated	476.65
Cardboard hives	3.67	Cardboard	Low	Recycling	Materials must be separated	0
Solarisation/disinfection film	176.26	LDPE	High	Recycling, energy recovery	Must be cleaned	10,575.70
Compost bags	13.36	LDPE	High	Energy recovery, return of deposits	Tank-return	The EPR finances the management
Returnable plastic containers	12.16	HDPE	Medium	Tank-return	Must be rinsed three times	The EPR finances the management
Plastic containers for plant protection	12.41	HDPE	Medium	Tank-return	Must be rinsed three times	The EPR finances the management
Non-returnable plastic packaging	6.01	HDPE	Medium	Recycling by the hazardous waste manager, energy recovery	Must be packed	The EPR finances the management
Other plastics found at the collection point	21.6	HDPE	Under	Recycling, energy recovery	Not required	0.00
Gloves	3.03	LDPE	Low	Recycling	Not required	0.00
Cutting tools	0.55	Wood, metal	Low	Disposal (municipal solid waste)	Not required	0.00
Plastic raffia	46.23	Polypropylene	High	Recycling, energy recovery	Plant waste must be separated	2773.51
Plastic clips used for plant formation	35.05	LDPE	High	Recycling, energy recovery	Plant waste must be separated	2103.22

[12], which holds the highest concentration of greenhouses in Europe [33]. The European Union has 43% of the greenhouse area in the world, with Spain as the leading country, followed by Italy, France, and the Netherlands [36].

The largest amount of non-biodegradable waste comes from the metal structures that support the greenhouses (steel wire and profiles), which amounts to 1,101.76 tonnes per year, or a waste production rate of 1.29 tonnes per hectare per year. This represents almost half of the total non-biodegradable waste generated. The cost of managing this steel waste is negligible as it is recycled and has a high market price. The remaining 1,284.57 tonnes of waste per year give a waste generation rate of 1.50 tonnes per hectare per year. This consists of plastic waste (excluding packaging) amounting to 1,151.11 tonnes per year, plastic containers for plant products (12.41 tonnes per year) and other types of waste such as substrates, bags and fabrics of 121.05 tonnes per year.

The total cost of waste management, excluding transport costs, is ~ 32,000 € per year. Waste management costs represent approximately 0.021% of the company's annual turnover of ~ 150 million € and approximately 0.3% of current production costs. Transport costs are estimated at 120 € per hectare, based on two removals per year. Therefore, the annual cost of waste transport can be estimated at 102,480 €. The total cost of the integral management of the non-biodegradable waste produced is, therefore, estimated at 134,000 € per year, or 157.42 € per hectare per year. Considering the optimal management of the cover film and estimating the sale of the 646.06 tonnes produced by the members per year at a unit price of 100 euros per tonne, an annual income of 64,606.09 € could be obtained from the sale of materials, which would significantly reduce the total cost of waste management.

Following the analysis of the current non-biodegradable waste management practices in the cooperative, the critical factors identified are:

- Inconsistent regulatory framework.
- Partial management to meet the documentation needs of managers, producers, shippers, traders and agents.
- Lack of individual or collective management systems that can take responsibility for proper management.
- Incomplete registration of the specific waste produced and lack of a traceability system.

Some of the aspects mentioned above have been improved in recent years, particularly regarding regulatory frameworks, but there is still room for improvement. On the other hand, the structure and size of the cooperative make it possible to take advantage of economies of scale, optimising waste management and minimising costs. Furthermore, the region where the cooperative is located, Andalusia, is at the forefront of bioeconomy and waste management in the agricultural sector, due to its ambitious policies and the importance of the sector in its economy. For example, Andalusia published the Andalusian Strategy for Circular Bioeconomy in 2018 and approved the Bill for Circular Economy in Andalusia in 2023 [37]. This encourages companies in the region to adopt appropriate waste management practices. Consequently, other researchers have also investigated waste management in greenhouses and proposed better practices, following a similar approach as described in this article [12, 38–40].

Seafood company in Tunisia: valorising co-products from blue crab processing

With almost 2,300 km of coastline and 41 fishing ports, the fisheries sector occupies an important socio-economic position in Tunisia [41]. Recently, fisheries management has been developed to preserve fishery resources and support the sustainable development of the sector. In addition, the sustainable exploitation of Tunisian fishery products is guaranteed by the implementation of rigorous traceability strategies, especially for products destined for export to the European market.

The blue crab (BC; Portunus segnis) is a species of crab native to Indo-Pacific waters that arrived in the Mediterranean shortly after the opening of the Suez Canal. Until the 2010s it was mainly found in the eastern Mediterranean, where the waters are warmer. Since then, as a result of climate change, its spread has intensified due to the warming of surface waters. It has also been found in the east American coast [42, 43], and the Baltic, North, and Black Seas [44]. In Tunisia, BC was first identified at the end of 2014 in the towns of Skhira (Sfax governorate) and Ghannouch (Gabes governorate), and was later found in the Kerkennah islands before reaching Djerba. Since then, it has been considered an invasive predator that has spread rapidly, causing ecological, economic and social problems. To overcome this situation, the Tunisian Ministry of Agriculture has continued to promote its exploitation by encouraging the development of BC recovery projects, in an attempt to turn this threat into an opportunity for the country's economy, creating value, jobs and new markets.

Today, BC's economic potential is attracting an increasing number of investors. In the face of weak domestic demand, BC's export orientation stands out as a relevant alternative to explore. According to the interprofessional grouping of fishery products [45], Tunisia's BC exports reached 7600 tonnes in 2021, representing a revenue of 75.6 million dinars (US$24 million), twice as much as in 2020 [46].

Recognized in the Tunisian seafood sector, the company analyzed in this case study is Novogel, an agri-food company based in the new fishing port of Sfax (southern Tunisia), specializing in the preparation, freezing and export of seafood products. Data from the company's activities to reduce food waste levels were collected by company staff. Following an analysis of the characteristics and quantity of waste generated, possibilities for waste valorisation were identified and discussed.

Novogel uses international certification protocols such as the European Export Agreement (No. 482). The company's main export markets are Spain, Italy, Australia and Asia, including Japan, Korea, Thailand and Malaysia. In addition to shrimps, cuttlefish and octopus, BC is one of the company's most important export products.

This has stimulated the company's interest in optimising the production of BC products, not only to increase its income but also to strengthen the national economy. However, to avoid overexploitation and to limit the environmental impact that can result from such an increase in production capacity, some practices need to be made more sustainable.

The valorisation of co-products from BC processing is a valuable solution to one of the company's challenges: turning waste into profit. In this context, Novogel follows the "Zero Waste" approach, which leads it to define a sustainable, viable and efficient post-treatment strategy to add value to the co-products of BC processing.

Based on the raw frozen crab production process defined by the company and shown in Fig. 1, the whole crab, cut crab and crab meat are the main finished products from this processing plant according to customer requirements.

The processing of BC generates co-products at various levels, which are highlighted in Fig. 2. The most relevant are the non-conforming products resulting from the qualitative sorting of the raw material at reception (small crabs with a bad smell and/or a greyish abdomen) (co-product 1). These co-products represent approximately 30% of the quantity received. Other co-products are shells and abdomens (co-product 2), eggs, gills, viscera and wastewater (co-product 3), and body skeleton and clamps (co-product 4), which are often disposed of as industrial waste, causing significant environmental problems due to the production of foul odours through microbial promotion.

The amount of main raw material received in 2022 was estimated at 1,085,463 t, while the amount of BC sold was 748,595 kg. The production of co-products was estimated at 439,283 kg per year, mainly wastewater and shells.

However, these natural co-products still contain a non-negligible amount of bioactive compounds with relevant chemical and nutritional values, such as polysaccharides, proteins, lipids, antioxidants, flavonoids, vitamins and minerals beneficial to human health. Interestingly, these co-products of BC processing can serve as valuable raw materials that can be recovered and transformed into high value-added products.

Shells and clamps co-products, which account for more than 50% of the weight of the BC raw material, are slowly biodegradable and therefore pose major pollution problems when disposed of in the environment [47]. However, research is currently underway to develop high value-added components such as chitin, chitosan, chitooligosaccharides and carotenoids. The BC exoskeleton has been successfully exploited by Hamdi et al. [48] and Kaya et al. [49] for the production of blue crab chitosan (BCC) after chitin extraction and deacetylation. The resulting BCC exhibited interesting functional properties, including high solubility and binding to water and fat, as well as promising antioxidant, antimicrobial and anti-adhesive potentials. Due to these properties, BCC could have promising applications in the food and pharmaceutical industries. Furthermore, the extraction of carotenoproteins from BCC shells using successive extractions by enzyme-assisted hydrolysis and maceration confirmed the viability of such residual biomass as an important economic source of carotenoids, particularly astaxanthin and its esters, showing a health-promoting potential for use as natural antioxidants and antimicrobial agents in the food or biomedical industries [50].

The recovery of digestive enzymes, such as proteases, chitinases and amylases, from BC viscera (co-product 3) can be considered as a very interesting and promising alternative. Indeed, considerable attention has been paid to the search for low-cost sources of new marine enzymes with interesting properties. Fish viscera have been identified as a good source of digestive enzymes with novel/improved biochemical properties that are highly valued in a wide range of industrial applications compared to their terrestrial counterparts. Recently, BC visceral co-product was used to extract highly stable alkaline proteases, which were interestingly effective in deproteinising crab and shrimp waste for chitin production [51]. Affes et al. [52] prepared a chitosanase from BC viscera and demonstrated its efficacy in producing biologically active chito-oligosaccharides from shrimp shell chitosan that were then incorporated into chitosan-based films to produce novel biodegradable, swellable, pH-sensitive biofilms suitable as drug delivery systems [53]. In the same context, Maalej et al. [54] obtained a digestive α-amylase from BC viscera that was successfully used to enhance the antioxidant potential of oat flour.

Today, there is an opportunity to valorise the co-products of blue crab processing as potential resources for the recovery of high value-added bioactive molecules. However, to promote the environmental and economic sustainability of marine resources, these strategies need to be scaled up to an industrial level, which will open the door to the expansion of circular business models beyond the conventional value chain.

Municipal waste management in Hong Kong: recovery of organic resources

In Hong Kong, with a population of over 7.5 million and a geographical area of approximately 1104 km^2, food waste has become a critical issue. In 2019, the city generated approximately 3600 tonnes of food waste per day, which corresponds to 0.48 kg per person and day. This is in the same order of magnitude as other developed cities, such as London (0.61 kg/person per day) [55], Singapore (0.37 kg/person per day) [56], US cities like Nashville (1.07 kg/person per day), Denver (1.32 kg/person per day) and New York City (1.01 kg/person per day) [57], or Chinese cities like Xiamen (0.21 kg/person per day) [58], Suzhou (0.18 kg/person per day) [59], although results for Singapore and the Chinese cities only consider household food waste. Average household food waste in high-income countries is 0.22 kg/person per day, and 0.32 kg/person per day when food service and retail are included [60].

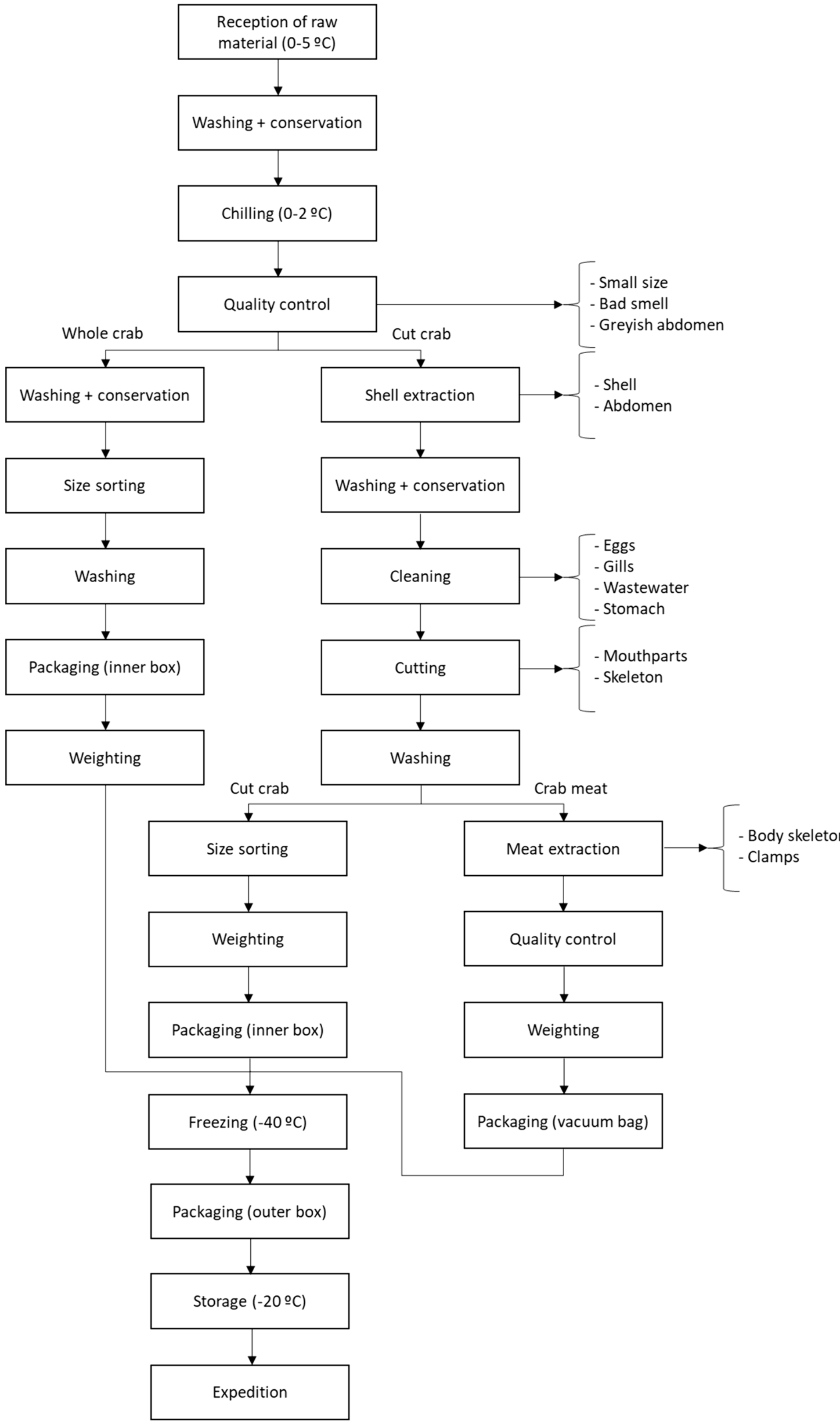

Fig. 1 Flowchart of the frozen blue crab process

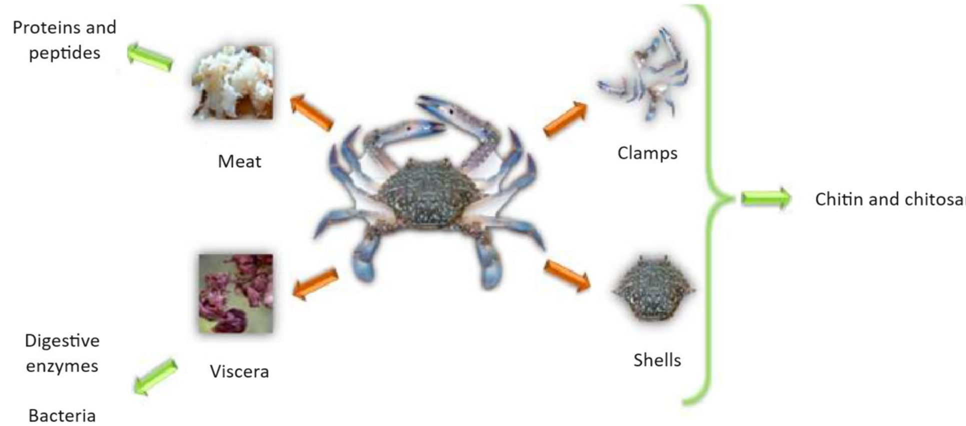

Fig. 2 Possible end uses of co-products from blue crab processing

The recycling rate of food waste in Hong Kong is still only 13% [61], mainly due to a lack of recycling facilities and insufficient public awareness and participation. As a result, a large proportion ends up in landfills [62]. Hong Kong struggles in this regard due to a lack of suitable land. Given that food waste accounts for approximately 30% of total municipal solid waste, there is an urgent need to identify alternative waste management options [63]. This section discusses current waste management practices and a waste reduction and recycling strategy. The data presented in this case study were taken from published, mostly governmental, information.

There are three strategically located landfills in the city: the West New Territories (WENT), South East New Territories (SENT) and North East New Territories (NENT) landfills, which are approaching capacity and may eventually fill up [64]. In Tuen Mun, in the western region of Hong Kong, the WENT landfill covers 180 hectares. It has been the main landfill site since it was officially opened in 1982. It is expected to reach capacity in 2024. The 200 hectare SENT landfill, located in Tseung Kwan O, has a capacity of 62 million cubic metres and was first used in 1993. It is expected to reach capacity in 2026. NENT's 200-hectare landfill site at Ta Kwu Ling has a capacity of 61 million cubic metres and was first used in 1994. It is expected to reach capacity in 2027 [64].

Although the city's waste is well managed in these landfills, this approach is not a sustainable option in the long term. Landfills use significant land resources, emit greenhouse gases and generally pose a threat to the environment and human health. The government and the waste management industry are seeking solutions that focus on recycling and waste reduction techniques, the creation of state-of-the-art waste treatment technology and the promotion of a more circular and sustainable economy. To address these issues, the Hong Kong government has launched a number of waste reduction and recycling initiatives. These initiatives include the promotion of waste separation and recycling, the establishment of waste-to-energy facilities and the construction of organic waste treatment facilities such as O·PARK1, described below.

In response to the growing demand for effective waste management solutions, the Hong Kong Government launched the O·PARK1 project as part of its overall waste reduction and recycling strategy. O·PARK1 is the first Organic Resources Recovery Centre (ORRC) to convert organic waste into renewable energy. Located in Siu Ho Wan on Lantau Island, the facility became operational in 2018 and serves as a model for future waste management initiatives in the region [65]. The O·PARK1 facility uses advanced anaerobic digestion technology to convert organic waste into biogas, which can be further purified to produce biomethane [66], as described below and shown in Fig. 3:

Food waste collection

Source-separated food waste is collected from various sectors, such as commercial and industrial establishments, and transported to O·PARK1.

Pre-treatment

The collected food waste is pre-treated to remove contaminants and produce a homogenised feedstock for the anaerobic digestion process.

Anaerobic digestion

The pre-treated food waste is fed into anaerobic digesters where micro-organisms break down organic matter in the absence of oxygen to produce digestate and biogas.

Biogas upgrading

To meet energy production requirements, raw biogas (mainly methane and carbon dioxide) is upgraded and purified to

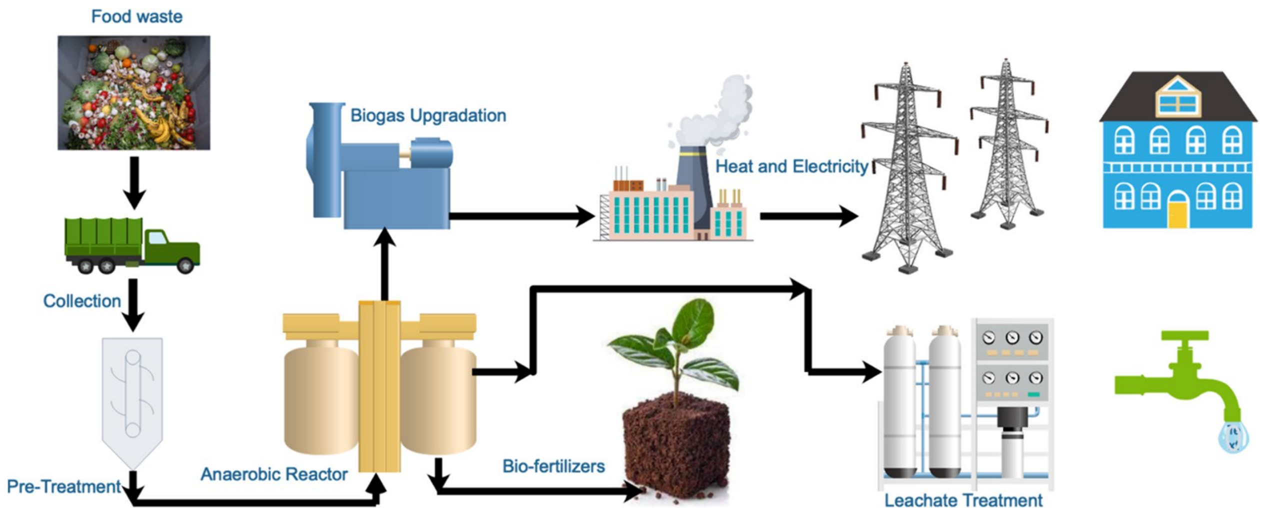

Fig. 3 Steps involved in treatment at O·PARK1

remove impurities such as moisture, carbon dioxide and hydrogen sulphide.

Renewable energy production

The upgraded biogas is used to produce electricity and heat, which can be used by the facility or fed into a nearby power grid as a renewable energy source.

Biofertiliser production

The digestate, a nutrient-rich organic material, is further processed to produce biofertiliser (compost) for use in landscaping and agriculture.

Biofertiliser distribution

The biofertiliser is distributed to farms and landscaping initiatives to promote sustainable agriculture and reduce the need for chemical fertilisers.

Leachate management

Leachate produced during the pre-treatment process is treated in a dedicated treatment facility, and the treated leachate is discharged or reused, thus avoiding environmental pollution.

The entire process serves as an example of a closed-loop resource recovery system, reducing greenhouse gas emissions, recovering valuable materials from food waste and producing renewable energy. O·PARK1 processes up to 200 tonnes of organic waste per day and produces approximately 14 million kWh of electricity and 20 tonnes of compost per year [65].

The Hong Kong Government intends to implement a comprehensive waste management policy, including the promotion of food waste reduction and recycling programmes, as well as further phases of the ORRC project to address these issues. The main phases of the overall ORRC project are described below.

ORRC Phase 1

The O·PARK1 facility was completed in 2018. It can process 200 tonnes per day, producing 14 million kWh of electricity and 20 tonnes of compost per year [65].

ORRC Phase 2

The O·PARK2 facility is currently under construction and is expected to be completed in 2024. It will produce approximately 22 million kWh of electricity and 25 tonnes of compost per year, with a processing capacity of 300 tonnes per day [67].

ORRC Phase 3

The third phase of the ORRC project is currently in the design phase and is expected to be completed in 2027. The facility will be designed to treat a variety of waste streams, including industrial waste, municipal solid waste and construction and demolition waste. It is expected to treat 300 tonnes of organic waste per day [68].

The Hong Kong ORRC project is expected to significantly improve the city's environment. The project aims to promote sustainable waste management by reducing the amount of waste sent to landfill, reducing greenhouse gas emissions, generating renewable energy and producing high quality compost.

The O·PARK1 project demonstrates the ability of cutting-edge waste management approaches to address the critical issue of waste disposal in urban areas. O·PARK1 contributes to Hong Kong's transition to a circular economy by converting organic waste into renewable energy, which benefits the environment. Continued investment in waste management infrastructure, together with public education and policy initiatives, will be critical to the long-term success and expansion of the ORRC project. Overall, the long-term objectives of the ORRC project are to establish a sustainable waste management system in Hong Kong that promotes the use of renewable energy, circular economy and environmental protection, while promoting public education and awareness of sustainable waste management practices. By implementing innovative approaches and improving public awareness, Hong Kong can move towards a more sustainable waste management model and reduce its overall environmental impact.

Despite the success of O·PARK1, there are still a number of hurdles to overcome. These include the need to encourage citizen participation in waste reduction initiatives, to increase waste sorting and separation at source, and to increase the capacity of facilities to handle the growing volume of organic waste. However, the challenges seem feasible, and the advantages largely outweigh the disadvantages. Managing municipal waste by anaerobic digestion has also been proposed in other cities, such as London [69], Malmö [70], Montreal [71] and Milan [72]. There is a broad consensus in the literature on the benefits of treating the organic fraction of municipal solid waste by anaerobic digestion [73–76].

Conclusions

This article has illustrated how waste management in the food sector can be improved by presenting three case studies: a horticultural cooperative in Spain, a seafood company in Tunisia and the case of municipal waste management in Hong Kong. The three case studies take place in different continents (Europe, Africa and Asia) and illustrate the diversity of waste management challenges and approaches across the continents. The horticultural cooperative generates large quantities of waste, half of which is various types of plastic and most of the rest is steel. Critical factors identified for the management of their waste are an inconsistent regulatory framework, partial management to meet the documentation needs of different stakeholders, lack of individual or collective management systems that can take responsibility for proper management, and incomplete recording of the specific waste generated and lack of a traceability system. The seafood company has recently started to exploit blue crab, a new product, which has brought with it the need to manage new co-products and waste. The most relevant waste is the non-conforming products resulting from the qualitative sorting of the raw material at reception (small crabs with bad smell and/or greyish abdomen). This waste contains bioactive compounds with relevant chemical and nutritional values, such as polysaccharides, proteins, lipids, antioxidants, flavonoids, vitamins and minerals, which can serve as valuable raw materials to be used in new products with high added value. Finally, the shift from landfill to anaerobic digestion has been described as a strategy for more sustainable food waste management in Hong Kong. Hong Kong is implementing policies to reduce the use of landfill, increase the use of renewable energy, minimise environmental impacts and promote public awareness of the importance of sustainable waste management practices. All three case studies highlight the need for more sustainable waste management practices in their respective sectors and regions. In addition, each case study highlights the importance of a consistent and effective regulatory framework for waste management that encourages companies to minimise waste generation and optimise waste management. The results also highlight the importance of raising public awareness of sustainable waste management practices to reduce waste generation and promote proper waste separation and disposal.

The identification of opportunities to improve waste management in such diverse sectors (horticulture, seafood, urban) and geographical areas (Europe, Africa and Asia) suggests that waste management can be improved throughout food supply chains worldwide. To do this, it is essential to first identify and then quantify the waste streams, identify the wastes that are most problematic to manage (due to their high volume or high environmental and/or socio-economic costs) and finally identify an alternative solution to improve the sustainability of the system. It is also important to create new market opportunities and business models based on circular economy attributes. Regional and national governments can support this approach by implementing stricter regulatory frameworks and providing financial subsidies. This would further encourage businesses to reduce their waste generation and optimize their waste management. Researchers also have an important role to play by proposing new ways of managing waste and calculating benefits and costs. Finally, society should be made more aware of such an important issue to reduce its waste generation and to separate and dispose of its waste properly.

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