Circular Economy Approaches in Horticultural Waste Utilization: From Postharvest Losses to Value-Added Products

Nisha R. Thorat[1]*, Ph.D. Scholar, Department of Vegetable Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, 444104.

Vaibhav U. Bansod[2], Ph.D. Scholar, Department of Vegetable Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, 444104

Hariom P. Janorkar[3], M.Sc. Vegetable Science, College of Agriculture, Nagpur, Maharashtra, 440001.

(*Corresponding Author Email: nisharthorat5298@gmail.com)

Abstract

Crops cultivated horticulturally are essential to ensuring food and nutrition security in the society. However, due to the perishability associated with these horticultural crops, considerable wastage and losses are experienced after harvest. As an alternative, circular economy practices have been proven to be a sustainable approach of making the horticultural wastes productive and minimizing their negative impacts on the environment. This study examines different sources of horticultural waste such as field waste, post-harvest losses, market waste, and processing wastes including peels, seeds, and pomace. In addition, it discusses several waste valorization methods through CE that include composting, vermicomposting, biogas production through anaerobic digestion, production of biochar, phytochemical extraction, functional food production, bioplastic manufacturing, bio-fertilizers production, and use of these products as animal feed. The roles of innovations such as cold chain logistics, smart packaging, artificial intelligence, Internet of things (IoT), green extraction methods, and biorefineries in facilitating effective horticultural waste valorization through circular economy principles are explored as well. Adoption of CE practices not only has environmental but also social and economic implications.

Keywords: Circular Economy, Biofertilizers, Horticultural Waste, Phytochemical Extraction, Biochar

Introduction

Horticulture is among the most dynamic and nutritionally significant segments of the world's agriculture industry. The horticulture sector makes a huge contribution towards food and nutrition security by growing fruits, vegetables, spices, medicinal and ornamental crops. Fruits, vegetables and other horticulture products serve as vital sources of essential micronutrients, dietary fiber, antioxidants and various phytochemicals (FAO, 2021; Slavin & Lloyd, 2012). On the other hand, horticultural produce is very perishable because of its high-water content, fast metabolism and physical/physiological degradation (Kader, 2005).

The problem of postharvest loss is a key concern for many horticultural industries around the world. Postharvest losses of horticultural produce may account for 20–50% of total fruits and vegetables available from production (Gustavsson *et al*., 2011; Hodges *et al*., 2011). Postharvest loss in developing nations is especially high because of the lack of adequate cold storage, poor postharvest handling techniques, lack of processing and logistics systems. Losses of agricultural produce leads to high economic and resource costs. Land, water, energy and labour are wasted during losses of horticulture produce (Su *et al*., 2013). In addition, environmental pollution occurs because of conventional postharvest waste disposal technologies, such as dumping in landfills (Hoornweg & Bhada-Tata, 2012).

As a solution to these problems, the concept of the circular economy (CE) has been developed as an innovative paradigm for achieving sustainability through increased resource efficiency via reduction, reuse, recycling and recovery within a closed-loop system (Kirchher *et al*., 2017; Geissdoerfer *et al*., 2017). In the agro-food sector, CE refers to the process whereby agricultural and horticultural byproducts are transformed into valuable resources, which helps to reduce waste production.

Among other things, it is now widely acknowledged that horticultural byproducts such as peels, pomace, seeds, leaves, stalks and off-grade crops contain high amounts of valuable compounds including polyphenols, carotenoids, flavonoids, dietary fibers, essential oils and organic acids, which are in wide use in various food fortifications, nutraceuticals, pharmaceuticals, cosmeceuticals and biodegradable packaging (Sagar *et al*., 2018; Schieber *et al*., 2001). The development of new biorefining and extraction techniques such as enzymatic hydrolysis, solid-state fermentation, anaerobic digestion, membrane separation and green solvent extraction technology has also contributed significantly to the process (Mirabella *et al*., 2014).

However, apart from environmental impacts, the adoption of the circular economy principle in horticultural practices is also expected to enhance farm-level profitability, foster linkages between agriculture and industries, decrease the reliance on chemical-based inputs and generate rural employment (Mayer *et al*., 2019). Circular economy principles can also be used to help meet some Sustainable Development Goals (SDGs), namely goal 2 (zero hunger), goal 12 (responsible consumption and production) and goal 13 (climate action). However, despite great strides made in terms of technology, implementation on a larger scale has been hampered by factors such as poor infrastructure, lack of policy support, poor awareness among stakeholders and disconnection between production and processing phases.

In view of the above, this review critically analyses approaches for the utilization of circular economy in relation to horticultural waste management, focusing mainly on the transformation of agricultural losses into value-added goods.

2. Circular Economy Concept in Horticulture

Circular economy (CE) concept refers to a sustainable regenerative model which aims at minimizing the generation of waste through efficient use of resources. Instead of the conventional linear system of 'take-make-dispose', CE entails a closed-loop process whereby biological and technological materials are continually reused, recycled and recovered in order to generate more value (Stahel, 2016; Morseletto, 2020).



Fig.1: Circular economy model for horticultural

It is particularly pertinent in the horticultural industry since it is characterized by a high amount of biodegradable waste during the production, post-production and processing phases. There are four major strategies involved in applying the CE concept in this sector, namely waste minimization at the source, reuse of organic residues, recycling to productive inputs and recovering energy and nutrients. These strategies make it possible to convert horticultural waste to valuable resources rather than just waste products (Zaman, 2015; Ghisellini *et al*., 2016). At the farm level, the circularity concept entails recycling crop wastes, pruning biomass and rejected produce in compost or soil amendment. At the postharvest and market level, wasted produce can be repurposed into animal feed, bio-fertilizers and composting facilities.

Within the food-processing industry, the utilization of horticultural wastes, including peels, seeds and pomaces, is being increasingly exploited as a source for bioactive substances, dietary fibers and natural antioxidants. Such residues can also be used as inputs for producing bioenergy, making the circular economy in horticulture an approach that promotes resource efficiency, minimizes environmental contamination and enhances value in the value chain (European Commission, 2018; van Ree, 2010).

3. Sources of Horticulture Waste

There are several sources of horticultural waste in the value chain, ranging from production through consumption and post-production. Each source of waste has varying impacts on waste levels, nature of the waste and possible valorization. The identification of the sources of waste is necessary when implementing efficient circular economy models for waste reduction and valorisation.

3.1 Field-Level Waste

During the production phase, waste is created from variations in growth, pest attacks and diseases, as well as inefficient harvesting processes. Some of the major wastes during the production phase include under-harvesting and wastage as a result of disease or pests, pruning waste and waste that occurs during field grading. Such wastes tend to remain in the field, where they decompose or serve as organic material inputs to the fields (Mayer *et al*., 2018).

3.2 Postharvest Handling Waste

The phase after harvesting and during packaging, storage and grading causes a lot of waste. Poor systems of packaging and insufficient storage facilities create waste during such processes (Everett, 2022; Kumar *et al.,* 2017).

3.3 Waste Associated with Markets and Consumers

In the market and consumer phases, more waste is created as a result of beauty criteria, surplus buying behavior and rotting. The amount of wasted fruit that is actually edible is considerable, as it has no nutritional deficiency for consumption (El-Hagger, 2014; Homrich *et al*., 2018).

3.4 Waste Associated with Food Processing

Food processing produces various forms of waste in the form of peels, seeds, pomace, pulp waste and press cakes. This waste is rich in dietary fibers, proteins, sugars and other bioactive ingredients and can be very useful as ingredients for functional food products, nutraceuticals and bioenergy (Ghazanfari, 2023). Overall, there is potential to extract significant value from waste streams coming out of horticulture.



Fig.2: Horticultural waste volarization paths. In order to promote resource efficiency and the circular bioeconomy, horticultural byproducts can be transformed into compost, biogas, bioactive chemicals, animal feed, biofertilizers, and bioenergy.

4. Circular Economy Solutions to Address Waste Utilization

There is a lot of interest in using circular economy approaches for the conversion of organic waste streams into value-added product forms.

4.1 Composting and Vermicomposting

Composting and vermicomposting represent the most commonly applied biological techniques of horticultural waste conversion to stable organic manure. Through microbial decomposition and earthworm activity, biodegradable components are converted into the humus-like substance containing a substantial quantity of nutrients and microorganisms that will contribute

to improving soil properties and increase the level of its microbial diversity (Lim *et al*., 2016; Rynk, 2014).

4.2 Anaerobic Digestion and Bioenergy Generation

Due to their moisture and biodegradability content, fruit and vegetable waste represent good sources of biogas generation via anaerobic digestion, which results in producing biogas (methane and carbon dioxide) and digestate, which is a source of biofertilizer. This method will also help to reduce dependence on artificial fertilizer and develop decentralized energy systems in rural areas (Scarlat *et al*., 2015; De Vries *et al*., 2012; Holm-Nielsen *et al*., 2009).

4.3 Phytochemicals Isolation

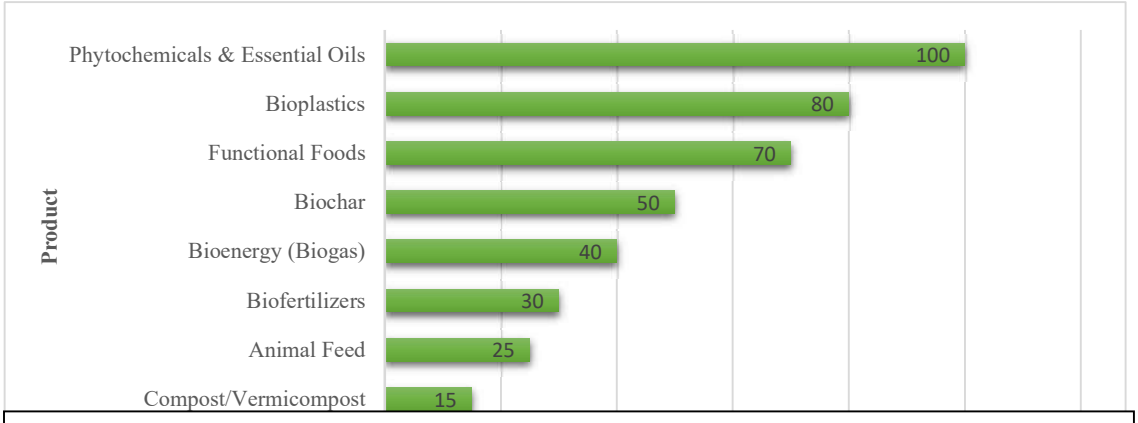
Wastes of fruits and vegetables contain numerous valuable natural substances such as polyphenols, flavonoids, carotenoids, pectin and essential oils, which are now extracted using the latest environmentally friendly techniques like ultrasound-assisted isolation, supercritical CO_2 extraction and enzymatic extractions. The phytochemicals obtained can find practical application in food production, medicine and the cosmetics industry (Galanakis, 2013; Chemat *et al*., 2012).

4.4 Formulation of Functional Foods

Bioactive components and fiber contents recovered from horticulture wastes are employed in formulating functional foods that include high-fiber bakery items, antioxidant drinks and probiotic-based foods. This value-added process improves nutrition while at the same time helping reduce food waste creation (Elleuch *et al*., 2011; Ajila *et al*., 2010).

4.5 Bioplastics and Biopolymers

Biodegradable packaging items made from horticulture waste biopolymers like pectin, cellulose and starch offer an environmentally friendly option compared to conventional oil-based plastics and help in addressing the problem of plastic pollution. Citrus peels, banana peels and potatoes have been extensively used as sources of biopolymers (Avérous & Pollet, 2012; Siracusa *et al*., 2008).



Notes - "Values are conceptual and have been drawn from literature reports to represent the relative addition value capacity of the valorization processes of horticultural waste Sagar *et al.* (2018), Galanakis (2013),

Fig.3: Value Added Products from Horticultural Waste

4.6 Livestock Feed and Insect Bioconversion Technology

Rejected horticulture produce may be converted into animal feed through proper processing and dehydration. Moreover, conversion of organic wastes using insects is another promising way of converting horticulture waste products into animal feed, mainly by employing black soldier fly larvae (Van Huis *et al*., 2013; Makkar *et al*., 2014).

4.7 Biochar and Soil Amendments

The thermochemical transformation of horticultural wastes through pyrolysis yields biochar that helps boost the fertility of soils, their nutrients and carbon sequestration capability. Using biochar increases the health of soils and it also helps mitigate climate change by ensuring that carbon remains locked in soils (Lehmann & Joseph, 2015; Woolf *et al*., 2010).

5. Technological Innovations Facilitating CE Models

Modern technological inventions are playing a crucial role in the move towards circular economic (CE) approaches within the horticulture sector as a way of mitigating postharvest losses, improving supply chains and high-value utilization of waste biomass resources. Modern innovations involving digital technologies, materials and green processing technologies are facilitating the transition from linear systems of horticulture to smart systems that optimize and improve horticultural processes. The incorporation of digitization technologies, biotechnologies and green processing technologies makes it easy to deal with inefficiencies at different stages of production, post-harvest processes, distribution and processing stages. This has led to a situation where horticultural waste is increasingly becoming a resource (Wolfert *et al*., 2017; Baryannis *et al*., 2019).

5.1 Advancement in Cold Chain Logistics

The improvement in cold chain logistics technology is among the most important methods that can reduce horticultural waste. Through efficient cold chains, the temperature, humidity and atmospheric environment are maintained throughout from production till consumption, which will ensure reduced rates of respiration, enzyme actions and microbial spoilage of the perishables.

Pre-cooling, refrigeration, modified atmosphere packaging (MAP) and controlled atmosphere storage are among some technologies used in improving the shelf life and quality retention of fruit and vegetables. Unfortunately, in developing areas, there are still challenges associated with the lack of infrastructure and energy needed in implementing this technology (James & James, 2010).

Through the use of sensors in cold chains, the product condition and temperatures can be monitored, minimizing chances of spoilage through proper tracking. This technology is important in minimizing waste and supporting circular economy goals (Jedermann *et al*., 2009; Ruiz-Garcia & Lunadei, 2011).

5.2 Smart Packaging and Edible Coatings

There are several approaches that can minimize postharvest loss through the direct interaction of packaging technology with both the product itself and the environment surrounding it. Active packaging involves oxygen scavengers, ethylene absorbers and antimicrobial compounds which delay spoilage mechanisms. Conversely, intelligent packaging is equipped with sensors and indicators which give immediate feedback about the condition of products regarding their freshness and safety (Yam *et al*., 2005). Edible coatings composed of natural polymers such as polysaccharides, proteins and lipids create a thin coating film on the surface of fruits and vegetables. Such coatings prevent moisture evaporation, respiration and microbial spoilage while preserving product quality. What is more important, these coatings are biodegradable and edible and thus they are very convenient in use in circular food systems (Falguera *et al*., 2011; Bourtoom, 2008). It is worth mentioning that new developments in edible coatings have been introduced, such as nano-coatings and active films (Rhim *et al*., 2013).

5.3 AI-Based Forecasting Models for Waste Reduction



Fig.4: Technological advancements that promote horticulture's circular economy. Digital tools, smart packaging, green extraction and biorefinery concepts promote monitoring, reduce waste and improve sustainable value chains.

The application of artificial intelligence (AI) and machine learning techniques in horticulture is rapidly growing to ensure effective optimization of the supply chain and mitigate the problem of food waste. Such prediction models employ massive amounts of data concerning production rates, climatic conditions, consumer demand trends and market performance to anticipate the emergence of surplus products.

The use of AI allows decision-makers to choose more strategically the period of harvesting, appropriate pricing policy, and delivery logistics so as to avoid overproduction and waste. The forecasting is most beneficial in perishable products, when timely action is vital (Baryannis *et al*., 2019). Contemporary research has proven that AI could contribute greatly to efficient resource use in the field by preventing waste beforehand (Zhong *et al*., 2016; Wamba *et al*., 2020).

5.4 Supply Chain Monitoring Using the IoT

IoT has transformed horticultural supply chains by enabling real-time monitoring of environmental and logistical parameters. The use of IoT devices like temperature sensors, humidity monitors, GPS trackers and RFID tags has been instrumental in real-time monitoring of the produce through the supply chain from the farms to the final consumers (Verdouw *et al*., 2016). These technologies enhance traceability, limit information asymmetry and improve quality assurance within the supply chains. In addition, the technologies provide early warning against spoilage, which allows for

preventive measures to be taken before losses are incurred (Tzounis *et al*., 2017). The IoT is further enhanced through clou computing and blockchain technology to increase transparency and accountability, which are key factors within circular economies.

5.5 Green Extraction Technologies

The application of green extraction technologies plays a vital role in extracting valuable bioactive components from horticultural waste. Traditional methods of extraction have been replaced by eco-friendly methods like ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction and supercritical fluid extraction. The new methods enhance extraction efficiency and lower solvent usage, energy consumption and environmental pollution. Such green technologies are especially effective in extracting polyphenols, flavonoids, carotenoids and essential oils from plant residues (Azmir *et al*., 2013).

Supercritical fluid CO_2 extraction has gained popularity as an ecofriendly method of obtaining pure compounds with no residual solvent, which is especially applicable to food, pharmaceutical and cosmetic industries (Chemat *et al*., 2017). This innovation helps realize circular economy objectives through efficient resource management.

5.6 Biorefinery for Integrated Waste Processing

Biorefineries constitute a cornerstone for realizing circular bioeconomy within the horticulture sector. They are characterized by the production of a diverse portfolio of products, including bioenergy, biochemicals, biomaterials and animal feed.

6. Environmental, Economic and Social Benefits of Circular Economy in Horticulture

Implementing circular economy (CE) approaches to horticulture ensures multiple benefits by converting wastage into useful materials. These benefits relate to environmental protection, economic growth, and social welfare, and hence make CE one of the best ways towards sustainable agrifood systems.

6.1 Environmental Benefits

Implementation of circular economy approaches to horticulture provides numerous benefits including environmental conservation through GHG emissions reduction. For example, CE helps reduce GHG emissions by avoiding waste disposal through open spaces such as landfills where the decomposition process generates methane emissions. This helps to mitigate climate change through CE strategies (Salemdeeb *et al*., 2017).

In addition, CE strategies help reduce reliance on the use of landfills and dumping of wastes openly which otherwise may lead to pollution of soils and waters due to contamination through leachate and decomposed products (Iqbal *et al*., 2020). CE systems ensure soil enhancement as a result of improved soil organic carbon contents as well as better nutrient cycling in the soil. In addition, CE systems aid in conserving natural resources through the provision of efficient nutrient and water recycling (Sadhukhan *et al*., 2019).

6.2 Economic Opportunities

The adoption of circular economy principles in horticulture opens up substantial economic prospects since waste is converted into valuable commodities. Residues of horticultural plants can be utilized to produce compost, biofertilizers, aromas, nutraceuticals and bioenergy, thereby providing additional income sources for farmers, processing industries and rural businesses (Aramyan *et al*., 2018). Moreover, CE helps reduce costs in agricultural enterprises through a decrease in the use of chemical fertilizers, artificial inputs and non-renewable energy. It leads to increased profitability and more efficient use of resources in farming. Besides, the emergence of bio-economies contributes to the economic development of rural areas by providing job opportunities associated with waste collection, processing, bio-conversion and selling products (Sarkar *et al*., 2020).

6.3 Social Benefits

The implementation of circular economy strategies within the horticulture sector makes immense contributions towards the development of society through enhanced efficiencies within the food supply chain and reduced post-harvest losses. Effective use of products from horticulture leads to increased food security within such societies due to improved efficiencies in the provision of foods (FAO, 2019).

Further, the implementation of such circular economy strategies creates job opportunities in the rural sectors via processes such as composting, establishment of biogas plants, insect production and bioproducts creation. This assists in promoting rural development as well as decreasing migration pressure from the rural to urban areas (Murray *et al*., 2017). Additionally, the implementation of such circular economy practices helps promote sustainability among the parties involved through increased awareness of sustainable consumption and environmental preservation.

In contrast to the production of just one product, biorefinery uses cascade utilization, whereby valuable products are produced first and then any remaining biomass is converted into energy. This process ensures optimum value and minimum wastage of resources (Cherubini, 2010). For instance, waste produced from citrus fruits could be broken down to produce essential oils, pectins, fibers and energy. Such a system is very important in ensuring zero-waste in horticultural industries (Kamm *et al*., 2010; van Ree, 2010).

7. Issues Encountered during Circular Economy Implementation in Horticulture

- Though CE principles show great promise in horticulture applications, there are various issues that make their implementation difficult. For example, one of the biggest obstacles faced is inadequate infrastructure for proper collection, segregation, storage and processing of waste produced during horticulture activities. In addition, inefficient logistics and fragmented supply chains in most developing countries worsen post-harvest losses in such crops, making waste utilization schemes less feasible (Kumar & Bhattacharya, 2019).
- One more issue is the need for high initial investments required to establish biorefineries, anaerobic digestion plants and other facilities needed for waste

processing. Most often, resource-poor farmers and small-scale horticulture producers have little financial and credit support to invest in the necessary technologies (Vermunt *et al*., 2019).

- Furthermore, there is low awareness among stakeholders concerning the benefits of adopting CE practices in their businesses. In many instances, lack of training and extension services leads to ignorance of economic and environmental gains from waste utilization by farmers, traders and end users of agricultural produce (Upadhayay, 2024).
- Inefficiencies in terms of policies and institutions also significantly contribute to the delays associated with implementing circular economy strategies. There is usually poor enforcement or non-integration of regulations concerning waste management, bioeconomy and recycling in most places (Korhonen *et al*., 2018). These inefficiencies lead to poor coordination between the agriculture, industrial and environmental sectors.
- Limited access to technologies in rural settings such as advanced processing technologies, digitization and energy sources constrains the implementation of CE strategies. Moreover, the irregularity of production processes due to the seasonality of horticulture products limits a constant stream of raw material (Lieder & Rashid, 2016).

All these challenges suggest that there is need for comprehensive policy support, financial incentives, capacity development and innovations in order to facilitate the shift to circular economy practices.

Conclusions:

Circular economy models offer a sustainable and realistic way forward in dealing with waste from horticulture since they convert post-harvest losses and wastes arising from processing to usable products. There is an abundance of nutrients and active ingredients in peels, seeds, pomace, leaves, and rejects that could be harnessed for various uses like composting, biofertilizer manufacture, energy production, biofortified foods, phytochemical extraction, animal feeds, bioplastics, and biochar manufacture. This helps to protect the environment, conserve natural resources, and ensure effective resource utilization.

Technological interventions like better cold chain storage solutions, smart packaging, the Internet of Things (IoT), artificial intelligence (AI), environmentally friendly chemical-free extraction processes, and biorefinery operations make for even more efficient waste management and ensure fewer losses in the value chain. Circular economy principles yield environmental benefits by lowering greenhouse gas emissions and waste at landfills, as well as offering economic gains through value creation and increased farm incomes, which leads to job creation in rural areas. There are also social benefits in terms of food security and livelihood sustenance.

Although these benefits make the approach very attractive, problems such as lack of adequate infrastructure, limited financing ability, lack of supportive policies, lack of stakeholder awareness, and lack of access to advanced technologies impede wider adoption of the concept. Thus, the need for strong policies, financial motivators, capacity building, and technology is critical in speeding up the process. Circular economy approaches can be very useful in ensuring sustainable production in the horticulture sector.

References:

Ajila, C. M., Brar, S. K., Verma, M., Tyagi, R. D., & Godbout, S. (2010). Flavour and antioxidant properties of fruit by-products. Food Chemistry, 121(4), 1001–1008. https://doi.org/10.1016/j.foodchem.2010.01.033

Aramyan, L. H., Lansink, A. O., & Van Der Vorst, J. G. A. J. (2018). Performance measurement in agrifood supply chains. Food Policy, 80, 1–13.

Avérous, L., & Pollet, E. (2012). Biodegradable polymers. Springer.

Azmir, J., Zaidul, I. S. M., Rahman, M. M., et al. (2013). Techniques for extraction of bioactive compounds. Journal of Food Engineering, 117(4), 426–436.

Baryannis, G., Dani, S., & Antoniou, G. (2019). Predictive analytics in supply chain management. International Journal of Production Research, 57(15–16), 5195–5212.

Bourtoom, T. (2008). Edible films and coatings: Characteristics and properties. International Food Research Journal, 15(3), 237–248.

Chemat, F., Rombaut, N., Sicaire, A. G., et al. (2017). Green extraction technologies. International Journal of Molecular Sciences, 18(4), 708.

Chemat, F., Vian, M. A., & Cravotto, G. (2012). Green extraction of natural products. International Journal of Molecular Sciences, 13(7), 8615–8627. https://doi.org/10.3390/ijms13078615

Cherubini, F. (2010). The biorefinery concept. Energy Conversion and Management, 51(7), 1412–1421.

De Vries, J. W., Vinken, T. M. W. J., Hamelin, L., & De Boer, I. J. M. (2012). Comparing environmental impacts of biogas systems. Renewable and Sustainable Energy Reviews, 16(6), 3660–3669.

El-Haggar, S. M. (2007). Sustainable industrial design and waste management: Cradle-to-cradle for sustainable development. Academic Press.

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fiber and bioactive compounds in food waste. Food Chemistry, 124(2), 411–421.

European Commission. (2018). A sustainable bioeconomy for Europe: Strengthening the connection between economy, society and the environment. Publications Office of the European Union.

Everett, E. (2022). Combining the circular economy, doughnut economy, and permaculture to create a holistic economic model for future generations. *Environmental Sciences Proceedings*, *15*(1), 19.

Falguera, V., Quintero, J. P., Jiménez, A., et al. (2011). Edible films and coatings. Trends in Food Science & Technology, 22(6), 292–303.

FAO. (2019). The state of food and agriculture: Moving forward on food loss and waste reduction. Food and Agriculture Organization of the United Nations.

FAO. (2021). The state of food and agriculture 2021. Food and Agriculture Organization of the United Nations.

Galanakis, C. M. (2013). Emerging technologies for recovery of bioactive compounds. Trends in Food Science & Technology, 31(2), 113–126.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The circular economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757–768.

Ghazanfari, A. (2023). An analysis of circular economy literature at the macro level, with a particular focus on energy markets. *Energies*, *16*(4), 1779.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste. FAO.

Hodges, R. J., Buzby, J. C., & Bennett, B. (2011). Postharvest losses and waste in developed and developing countries. Journal of Agricultural Science, 149(S1), 37–45.

Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. (2009). Biogas plant technologies. Bioresource Technology, 100(22), 5478–5487.

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of cleaner production*, *175*, 525-543.

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: A global review of solid waste management. World Bank.

Iqbal, M. F., et al. (2020). Circular economy and sustainable agriculture. Science of the Total Environment, 712, 136–141.

James, S. J., & James, C. (2010). Cold chain logistics. Trends in Food Science & Technology, 21(3), 125–132.

Jedermann, R., Ruiz-Garcia, L., & Lang, W. (2009). Intelligent transport systems in cold chain. Computers and Electronics in Agriculture, 65(1), 16–25.

Kader, A. A. (2005). Increasing food availability by reducing postharvest losses. Acta Horticulturae, 682, 2169–2175.

Kamm, B., Gruber, P. R., & Kamm, M. (2010). Biorefineries: Industrial processes and products. Wiley-VCH.

Kirchherr, J., Reike, D., & Hekkert, M. P. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. Ecological Economics, 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy limitations and challenges. Ecological Economics, 143, 37–46.

Kumar, N., & Bhattacharya, S. (2019). Waste management challenges in agro-food systems. Waste Management, 87, 1–12.

Lehmann, J., & Joseph, S. (2015). Biochar for environmental management. Routledge.

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review. Journal of Cleaner Production, 115, 36–51.

Lim, S. L., Lee, L. H., & Wu, T. Y. (2016). Sustainability of using composting and vermicomposting. Environmental Technology & Innovation, 5, 66–78.

Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on insect feed. Animal Feed Science and Technology, 197, 1–33.

Mayer, A., et al. (2019). Circular economy in agriculture: Opportunities and challenges. Sustainability, 11(5), 1–18.

Mayer, A., Rachuri, S., & Rios, J. (2018). Circular economy strategies in agri-food systems. Sustainability, 10(10), 3456.

Mirabella, N., Castellani, V., & Sala, S. (2014). Current options for the valorization of food waste. Journal of Cleaner Production, 65, 28–41.

Morseletto, P. (2020). Targets for a circular economy. Resources, Conservation and Recycling, 153, 104553. https://doi.org/10.1016/j.resconrec.2019.104553

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration. Journal of Business Ethics, 140(3), 369–380.

Rhim, J. W., Park, H. M., & Ha, C. S. (2013). Bio-nanocomposites for food packaging. Progress in Polymer Science, 38(10–11), 1629–1652.

Ruiz-Garcia, L., & Lunadei, L. (2011). The role of RFID in agriculture. Computers and Electronics in Agriculture, 78(1), 174–184.

Rynk, R. (2014). On-farm composting handbook. Natural Resource, Agriculture, and Engineering Service.

Sadhukhan, J., Ng, K. S., & Hernandez, E. M. (2019). Biorefinery and circular economy integration. Renewable and Sustainable Energy Reviews, 113, 109–124.

Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G. (2018). Fruit and vegetable waste: Bioactive compounds and valorization. Food Chemistry, 248, 1–14.

Salemdeeb, R., zu Ermgassen, E. K. H. J., Kim, M. H., Balmford, A., & Al-Tabbaa, A. (2017). Environmental impacts of food waste management. Resources, Conservation and Recycling, 127, 31–45.

Sarkar, S., Poon, J., & Kundu, A. (2020). Circular economy business models in agriculture. Journal of Cleaner Production, 277, 123–134.

Scarlat, N., Dallemand, J. F., & Fahl, F. (2015). Biogas: Developments and perspectives in Europe. Renewable Energy, 129, 457–472. https://doi.org/10.1016/j.renene.2018.03.006

Schieber, A., Stintzing, F. C., & Carle, R. (2001). By-products of plant food processing. Trends in Food Science & Technology, 12(11), 401–413.

Singh, J., Laurenti, R., Sinha, R., & Frostell, B. (2020). Progress and barriers in circular economy adoption. Journal of Cleaner Production, 229, 413–425.

Siracusa, V., Rocculi, P., Romani, S., & Dalla Rosa, M. (2008). Biodegradable polymers for food packaging. Trends in Food Science & Technology, 19(12), 634–643.

Slavin, J. L., & Lloyd, B. (2012). Health benefits of fruits and vegetables. Advances in Nutrition, 3(4), 506–516.

Stahel, W. R. (2016). The circular economy. Nature, 531(7595), 435–438. https://doi.org/10.1038/531435a

Su, B., Heshmati, A., Geng, Y., & Yu, X. (2013). A review of the circular economy in China: moving from rhetoric to implementation. *Journal of cleaner production*, *42*, 215-227.

Tzounis, A., Katsoulas, N., Bartzanas, T., & Kittas, C. (2017). IoT in agriculture. Biosystems Engineering, 148, 104–118.

Upadhayay, S., Alqassimi, O., Khashadourian, E., Sherm, A., & Prajapati, D. (2024). Development in the circular economy concept: systematic review in context of an umbrella framework. *Sustainability*, *16*(4), 1500.

Urbinati, A., Chiaroni, D., & Chiesa, V. (2017). Towards a new taxonomy of circular economy business models. Journal of Cleaner Production, 168, 487–498.

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible insects: Future prospects for food and feed security. FAO.

van Ree, R. (2010). Biorefineries and biomass utilization. Biomass and Bioenergy, 34(3), 301–306.

van Ree, R. (2010). Biorefineries: Adding value to the sustainable utilization of biomass. Biomass and Bioenergy, 34(3), 301–306. https://doi.org/10.1016/j.biombioe.2009.10.007

Verdouw, C. N., Wolfert, J., Beulens, A. J. M., & Rialland, A. (2016). Virtualization of food supply chains. Computers and Electronics in Agriculture, 117, 189–204.

Vermunt, D. A., Negro, S. O., Verweij, P. A., Kuppens, D. V., & Hekkert, M. P. (2019). Exploring barriers to circular economy adoption. Journal of Cleaner Production, 212, 1203–1213.

Wamba, S. F., Gunasekaran, A., Akter, S., et al. (2020). Big data analytics in supply chains. International Journal of Production Economics, 229, 107758.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming. Agricultural Systems, 153, 69–80.

Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). Sustainable biochar to mitigate climate change. Nature Communications, 1, 56.

Yam, K. L., Takhistov, P. T., & Miltz, J. (2005). Intelligent packaging. Journal of Food Science, 70(1), R1–R10.

Zaman, A. U. (2015). A comprehensive review of the development of zero waste management: Lessons learned and guidelines. Journal of Cleaner Production, 91, 12–25. https://doi.org/10.1016/j.jclepro.2014.12.013

Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2016). Intelligent manufacturing in industry 4.0. Engineering, 3(5), 616–630.