**Value Added Products from Fruit Waste: A Systematic Review**

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**Abstract**

Food waste contains hazardous compounds that can impact the growth of plants, polluting drinking water, impacting sea life to ultimately contaminating human food consumption. With approximately 1.3 billion tonnes of food is wasted per annum, there is need to mitigate the impact of waste from the different food processing sectors. Specifically, making use of waste from the vegetable and fruit processing sectors is a significant, albeit difficult, task in food sustainability. Numerous studies have explored the potential use of discarded fruits, including their waste materials, for further industrial purposes. Also, the extraction of functional ingredients, extraction of bioactive components, and fermentation of food waste from the vegetable and fruit sector is now the subject of extensive research. This is a systematic review of a selection of a range of relevant original studies that assess the potential of upcycling food waste (particularly fruit waste) – turning food waste into ingredient item/s to produce value added consumer products. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines underpins the method applied to the identification, eligibility evaluation and final selection of relevant studies. Findings from the review show the potential of repurposing fruit waste, using different methods, into added-value material for a wide range of products such as bioethanol, biohydrogen, ethanol, fertilisers, bio-oil and sanitary pads.

**Keywords:** Fruit Waste; Circular Economy; Upscaling; Agro-Waste

1. **Introduction, and Background**

Food Waste (FW) refers to the food leftovers of households, and bioprocessing sector including the fresh produce manufacturing, and the hospitality industry (Paritosh, et al., 2017). There are various FW categorisations, nonetheless, a recognised group of such waste relate to fruit and vegetable leftovers. There has been a significant increase in demand for fruit and vegetable produce as the global population increases so does the demand for fresh produce (Balali, Yar, Dela, & Adjei-Kusi, 2020). With this growth and demand placed on requests for fresh produce there are also significant side effects which impacts the level of waste and by-products. Waste and by-products have become a significant negative impact of this growth (Chaouch & Benvenuti, 2020). Moreover, this increased level of waste which ultimately contains hazardous compounds can impact the growth of plants, polluting drinking water, impacting sea life to ultimately contaminating human food consumption (Singh & Kalamdhad, 2011). This level of waste has a fundamental issue for the environment at a global level, but also poses critical debates around symmetric availability of food for different groups of population (Sehnem, Pereira, Junior, Bernardy, & Lara, 2022).

Within agriculture and food literature, there are several instances of waste-to-value applications of food waste, and the rise in related studies can be attributed to the high cost, energy consumption, and the carbon food print associated with food production in the first place (Aschemann-Witzel, et al., 2021). However, at the same time, it is also argued that relying on food waste as an input to emerging industrial processes, places an unsustainable need for creation of such waste, and in fact has a negative feedback loop for solving the food waste problem (Pleissner, 2018).

It has become increasingly essential to ensure that the correct methods are used to remove and dispose of bio-waste which will ultimately support the necessary requirements to reduce the negative impacts on the environment. Mango, Papaya and Pineapple are considered exotic fruits which albeit very popular fruit at a global level (Evans, Ballen, & Siddiq, 2017), unfortunately have a high level of waste. Considering this, a particular focus is placed on fruit waste resulting from processing these exotic fruits in this systematic review. This review provides clarity in terms channelling food waste by-products to ultimately make a positive impact on the economic and global environment by enabling the production of valued products.

This review is structured as follows: Section 2. outlines the methodology used for identifying and extracting relevant information from original studies. Section 3. includes data and evidence extracted from the included studies. Section 4. provides a critical discussion to assess our findings against existing literature in the field. The review is concluded in Section 5.

1. **Materials and Methods**
   1. ***Study Selection***

This systematic review has been conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. In order to identify relevant studies, the Science Direct and MarketLine databases were systematically searched, using the keywords of ‘Fruit Waste’, ‘Agro-Waste’, ‘Agro-Fruit Waste, ‘Mango’, ‘Pineapple’, ‘Coconut, ‘Papaya’, ‘Circular Economy’, and ‘Upcycling’. The search was conducted to identify studies and articles that were published from 1st January 2012 up until 26th August 2022. No geographical filter was applied in relation to the place of research or publication, in order to maintain the comprehensiveness of the search. The search strategy used for the Science Direct database is outlined below:

(“fruit waste" OR “agro-waste” OR “agro-fruit waste”) AND ("Mango" OR "Pineapple" OR "Coconut" OR "Papaya") AND (“Circular Economy” OR “upcycling”).

After the initial search, a total of 260 studies were identified. An additional 11 studies were included through other sources e.g., by reviewing the reference lists within the identified articles. Of the 271 identified studies, 54 were omitted due to unavailability of their full text. The remaining articles were screened by title and abstract, and in accordance with the inclusion and exclusion criteria, and as a result, an additional 110 studies were excluded. The remaining 107 studies entered the eligibility evaluation phase and were therefore examined by reading the full text. From the eligibility evaluation phase, 80 further studies were omitted, and 27 studies were selected for final evidence extraction. To avoid bias, both stages of screening and eligibility evaluation were conducted by 5 project team members independently, and in cases of uncertainties around inclusion or exclusion of a study, a more experienced reviewer supported to finalise the selection. The stages of study selection are outlined in the PRISMA Flow Diagram below (Figure 1.)



Figure 1: PRISMA Flow Diagram for Study Selection.

* 1. ***Inclusion and Exclusion Criteria***

Criteria used to include studies are outlined below:

- Articles, reports, or studies that have reported both the waste ingredients, and the final product,

- Studies published in English,

- Studies with full text available,

- Studies that have reported on tested and marketable products.

Criteria for excluding studies were:

- Review papers of any sort,

- Studies in languages other than English,

- News articles.

1. **Data Extraction and Results**

To extract relevant information from the included studies, a checklist appropriate to the study aim and focus was designed. The checklist included, the first author’s surname, year of publication, raw material (waste), process for converting the waste into another substance, component, or material, and an example of final product. Data extracted from the final studies are presented in Table 1.

Table 1: Collected Information from Included Studies.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Author** | **Year** | **Raw Material** | **Process** | **Added-Value Material** | **Example Final Product** |
| Aili [Hamzah et al.](https://www.sciencedirect.com/science/article/abs/pii/S0956053X22003452?via%3Dihub#!) (Aili Hamzah, et al., 2022) | 2022 | Pineapple | Anaerobic co-digestion | Biogas | Methane Production |
| Banerjee et al. (Banerjee, Vijayaraghavan, Arora, MacFarlane, & Patti, 2016) | 2016 | Mango Peels | Extraction of Pectin | Lemon | Pectin |
| Kengkhetkit and Amornsakchai (Kengkhetkit & Amornsakchai, 2014) | 2013 | Pineapple | Biomass | Polypropylene | Natural fibre |
| [Krishnan et al.](https://www.sciencedirect.com/science/article/pii/S0959652619332445?via%3Dihub#!) (Krishnan, Agarwal, Bajada, & Arshinder, 2020) | 2020 | Mango | Biomass | Biogas | Energy |
| Gómez-García et al. (Gómez-García, et al., 2022) | 2022 | Melon | Bioactive | Phenolic | Natural fibre |
| Basak et al. (Basak, et al., 2020) | 2020 | Pineapple | Biomass | Biohythane | Energy |
| Ghosh et al. (Ghosh, Kar, Chatterjee, Bar, & Das, 2021) | 2021 | Pineapple | Adsorption | biomaterials | Energy |
| Picha et al. (Pocha, et al., 2022) | 2022 | Agro (fruit) waste | Pyrolysis & hydrothermal liquefaction | Alternative/green energy base | Biofuel and green diesel |
| del Pilar Sanchez-Camargo et al. (del PilarSánchez-Camargo, et al., 2019) | 2019 | Mango Peel | Box-Behnken optimisation of MP | Sunflower oil antioxidant | Alternative for MP valorisation - Food antioxidant |
| Zhu et al. (Zhu, et al., 2022) | 2022 | Agro residue | Pyrolytic conversion of agro residues | Biochar | Energy; Soil amendment; activated soil substitution |
| Ndayisenga et al. (Ndayisenga, et al., 2021) | 2021 | Straw | Microbial electrohydrogenesis & dark fermentation | Bioresources - numerous | Biohydrogen |
| Elegbede et al. (Elegbede, Ajayi, & Lateef, 2021) | 2021 | Corncob | Microbial valorisation | Range of biotech products (e.g., enzymes, biofuels | Bioethanol; biohydrogen |
| Marketline (MarketLine, 2020) | 2020 | Apple, Avocados, Citrus fruits, Asparagus, Mangoes | Blending and then extracting Lipid Molecules | Lipid | Plastic packaging reduction, fresh produce waste reduction |
| Marketline (MarketLine, 2018) | 2018 | Fibre from Banana tree stems | Unknown | Unknown | Sanitary pads |
| Orejuela et al. (Orejuela, et al., 2020) | 2020 | Mango By-products | Oil/Butter Extraction | Deep eutectic solvents (DES) | Mango seed oil and butter; natural colorants from: pressed seed (orange), mango peel (green) and mango pulp (light yellow); mango peel flour; ground seed (cotyledon); lip balm; moisturising cream. |
| Neenu et al. (Neenu, et al., 2022) | 2022 | Pineapple | Acid Hydrolysis | Biomass waste | Nano paper for food packaging applications |
| Wang et al. (Wang, et al., 2022) | 2022 | Mango Seed | Adsorption | Bio sorbents | Heavy metal recovery/ removal from (waste)water |
| Ahmed et al. (Ahmed, et al., 2021) | 2021 | Watermelon Seeds | Pyrolysis | Biochar | Pb (II) removal from water/wastewater |
| Atub et al. (Atub, Othman, Yusop, Khan, & Zakria, 2021) | 2021 | Palm Oil Fuel Ash Waste | Simple and single-step chemical activation method | Graphene | "POFA derived graphene (PDG) nanosheets |
| Muruganantham et al. (Muruganantham, Wang, & Liu, 2022) | 2022 | Mango Peel | Facile Carbonisation | NS-MPC | Battery Anode |
| Luna-Avelar et al. (Luna-Avelar, et al., 2021) | 2021 | Mango peel (MP) and mango seed (MS), and microalgal residue biomass (MRB) | Anaerobic digestion (AD) | Biogas | Energy |
| Siddiqui et al. (Siddiqui, et al., 2022) | 2022 | All fruit waste | Black soldier fly larvae (BSFL | Higher value biomass | Animal feed |
| Jacqueline et al. (Jacqueline, et al., 2022) | 2022 | Pomegranate peel (PP) | Catalytic microwave preheated co-pyrolysis | Biomass | Bio-oil/Biochar |
| Jahid et al. (Jahid, Gupta, & Sharma, 2018) | 2018 | Banana, Papaya, Pineapple and Mango Peels | Enzymatic hydrolysis and fermentation | Bioethanol | Bioethanol |
| Gunarathne et al. (Gunarathne, et al., 2019) | 2019 | Coconut waste | Bio based process | Coconut Milk | Coconut Milk |
| Mota et al. (Mota, da Boa Morte, Cerqueira eSilva, & Chinalia, 2020) | 2020 | Rambutan fruit peels | Lypholization | Ethanol | Sunscreen |
| Schmidt et al. (Schmidt, et al., 100047) | 2021 | Coconut shells | Homogenisation | Cement | Concrete |

1. **Discussion**

The systematic review process employed in this study has culminated in the selection of a range of relevant papers which assess the extent to which agricultural waste (particularly fruit waste) can be upcycled as an ingredient item to produce value added consumer products. The studies included in Table 1, each represent a researched assessment of how different kinds of fruit waste can be upcycled. In populating Table 1, the research team has focused mainly on studies which reported the upcycling of selected specific fruit wastes such as coconut shells, pomegranate peels, pineapple peels, as well as mango seeds and peels. In addition to these, the research team have also included papers on the upcycling of other fruit and agricultural wastes may provoke some interest in other wastes which can be upcycled.

From the reviewed studies, there is a considerable focus on getting energy out of the fruit waste. Three of the studies, outline processes and activities the lead to the generation of biogas as a by-product for methane (Aili Hamzah, et al., 2022), and energy production (Krishnan, Agarwal, Bajada, & Arshinder, 2020) (Luna-Avelar, et al., 2021). Two other included studies also focused on the production of energy from the fruit waste, yet the value-product in these articles were not necessarily biogas (Basak, et al., 2020) (Ghosh, Kar, Chatterjee, Bar, & Das, 2021). Historically, there have been several attempts to recover energy from waste materials. Municipal solid waste (MSW) is an instance of these attempts for generating refused-derived fuel (Reinhart, Podder, & Bolyard, 2022), although inefficient traditionally, many endeavours have been provided to optimise the process.

From our Systematic Review, it is also evident that some attempts are being made on producing carbon-based products out of fruit wastes. In two studies (Zhu, et al., 2022) (Ahmed, et al., 2021), processes for obtaining biochar from the waste are outlined. In another piece of research (Muruganantham, Wang, & Liu, 2022), carbon is produced out of pineapple peels to be used as Sodium Ion batteries. Availability of Lithium as key material required for manufacturing lithium-based batteries is critical (Egbue, Long, & Kim, 2022), thus research and innovation in the field of Sodium Ion batteries as an alternative is like to gain further attention by many manufacturers. In another study, the process for converting palm oil to graphene was presented (Atub, Othman, Yusop, Khan, & Zakria, 2021).Considering the high carbon content on organic waste, producing carbon-based value-added materials is a sensible practice.

Our study has also revealed other diverse material outputs created from fruit and vegetable wastes. Bioethanol (Jahid, Gupta, & Sharma, 2018), coconut milk (Gunarathne, et al., 2019), biomass (Jacqueline, et al., 2022) (Neenu, et al., 2022), organic cement from coconut shells (Schmidt, et al., 100047), bio sorbents (Wang, et al., 2022), lipid (MarketLine, 2020), enzymes (Elegbede, Ajayi, & Lateef, 2021), biohydrogen (Ndayisenga, et al., 2021), Phenolic (Gómez-García, et al., 2022), Biohythane (Basak, et al., 2020), nature-based Polypropylene (Kengkhetkit & Amornsakchai, 2014), and citrus oil (Banerjee, Vijayaraghavan, Arora, MacFarlane, & Patti, 2016) where the other examples of by-products from our study. Such diversity of final waste-derived products in our study is in-line with the reported results of other similar systematic reviews (Magama, Chiyanzu, & Mulopo, 2022).

Over the last decade, the publication of systematic reviews of methods and applications of upcycling fruit waste has been on the rise. The upward trajectory of systematic reviews in this area has been fuelled, in large part, by the universal embrace of the United Nations Sustainable Development Goals (UNSDG’s) and the need for industries to reduce and repurpose waste (Caldera, Jayashinge, Desha, Daws, & Fergusen, 2022). The UNSDGs challenge business to make their processes more sustainable by doing more and better with less through upcycling and industrial symbiosis. Taken in its most basic form, upcycling is defined as the reuse, repair or repurposing of waste material to avoid conventional endpoint disposal. Whilst research studies and applications are on the rise in this area, the concept of upcycling, and the opportunities it presents businesses to enhance their sustainability credentials and expand their revenue streams remains somewhat of a niche practice (Caldera, Jayashinge, Desha, Daws, & Fergusen, 2022).

Findings from the review show the potential of repurposing fruit waste through bioscience into several bioeconomy products such as bioethanol, biohydrogen, ethanol, fertilisers, bio-oil and sanitary pads. As global population is projected to grow 9.7 billion people by 2050 (Sadigov, 2022), these products generated from fruit waste can play a key role in replacing finite fossil resources. This presents an opportunity for several businesses in the fresh produce manufacturing sector, as well as in hospitality and food sectors to adopt new business models to capitalise on the upcycling of the fruit waste that they generate from their day-to-day operation, potentially leading to new revenue streams and equally important, contribute to solving global sustainability challenges.

* 1. ***Limitations***

To search and identify relevant studies, only the Science Direct, and MarketLine databases were searched. A more comprehensive search plan can be conducted on other relevant resources management systems and repositories, including Scopus and Web of Science. Additionally, one of the exclusion criteria for study selection was omission of articles written and published in languages other than English. This limits the comprehensiveness of the search.

1. **Conclusion**

In this systematic review, reported results of 27 selected articles that had assessed development and manufacture of valuable by-products from fruit waste, were extracted. The added-value materials, and sectors, or products that use the converted material are very diverse, ranging from Carbon, and Graphene for manufacturing nano-sheets or battery anodes in sodium ion batteries, to lipids being used for manufacturing bio-compostable packaging materials. Nonetheless, the viability of the introduced upcycling value chains in the existing studies require further investigation i.e. to: a) examine the availability of the fruit and vegetable wastes for the emerging supply chain, and avoidance of unnecessary pressures for the creation of more waste, b) conduct market analyses to analyse the cost-effectiveness and the desirability of the final manufactured value-added product within the market, and c) thoroughly and systemically scrutinise the environmental and social impacts of the newly introduced value chain.

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