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A critical review on food waste management for the production of materials and biofuel

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ABSTRACT

Increasing demand for fuels and chemicals, exacerbated by factors such as overpopulation, the threat of global warming, and the scarcity of fossil resources, puts a strain on our resource system and necessitates the development of sustainable and innovative chemical industry strategies. Due to the abundance of food waste that have been generated globally, food supply chain waste has emerged as a resource with significant potential for use as a raw material in the production of fuels and chemicals. In general, food wastes can be classified into various categories depending upon their nature, i.e., they can be "intentional" or "unintentional", and on the other hand, they can also be classified as "avoidable", "partially avoidable" and "unavoidable". The complete study focuses on the entire realm of food wastage and the major highlight of this review article is the recent development of textile and biofuels areas to bring the novel technologies that are now being employed to valorize food waste products to yield other useful products. This article also iterates about the use of such practices (e.g., production of fiber materials and biofuels from food wastes) and their significance is not just in making complete use of food products or products that are related to food, but it also implies the positive effects that these have on the environment and the economy in general. The prospects and perspectives on the management of various fruit wastes for real-time practical application for future generations are also highlighted.

1. Introduction and current context in food waste management

In order to garner a firm perception of the terms “food waste” and/or “food loss”, it is imperative to understand the moral, ethical, socio-economical, and nutritive significance of the concept of “food”. "Food" is any item that could be raw, semi-processed, or processed, that is majorly intended for the purpose of human (or any other animal) consumption. "Food" is often found with its associated counter “inedible parts” which are/might not be suitable for utilization. Quite understandably, food is an essential commodity, as it is one of the major sources of our survival, hence factors like "food loss" or "food waste" should be brought under serious consideration and addressed in order to minimize their occurrence and the impact that they happen to incur on not just humans but the overall balance of the ecosystem and the environment (Lin et al., 2022). Food wastes could be solid, semi-solid, or in liquid forms; solid wastes mainly include the food items themselves, parts of the food items, or other parts or items associated with particular food items, which are usually rich in starch, cellulose, lignin, and monosaccharides (Yahia et al., 2019).

Delving into the subject matter, it is often encountered that the aforementioned terms are often used synonymously, but when juxtaposed, it can be understood that while "food losses" refer to the unintentional loss or deterioration of quality and/or quantity of the food as a result of food spills, spoils, bruising and other damages caused due to limitations and impediments that occur during harvesting, processing, distribution, storage, etc. (Kennard, 2020), "food wastage" implicates any

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Abbreviations: FAO, Food and Agriculture Organization; FPW, fruit processing waste; FSSAI, Food Safety and Standards Authority of India; SDG, Sustainable Development Goal; FLI, Food Loss Index; FWI, Food Waste Index; LCA, Life Cycle Assessment; ISO, International Standards Organization; PAN, Polyacrylonitrile; CNF, Carbon nano fiber; PALF, pineapple leaf fibres; CNC, Cellulose Nano Crystals; FESEM, Field Emission Scanning Electron Microscopy; HRTEM), High-resolution transmission electron microscopy; AFM, Atomic Force Microscopy; DLS, Dynamic Light Scattering; α-, Alpha; Kg, Kilogram; BBM, banana bract mass; SHF, Separate Hydrolysis and Fermentation; SSF, Simultaneous Saccharification and Fermentation; β, Beta; HFW, Household Food Wastes; EPA, Eicosapentaenoic Acid; DHA, Docosahexaenoic Acid; FAME, Fatty Acid Methyl Esters; FFA, Free Faty Acid.

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food or inedible parts of food that is removed, disposed or discarded from the food supply chain before it can be consumed (Niutanen and Korhonen, 2003; Lam et al., 2020; Isah and Ozbay, 2020; Alexander et al., 2013; Chauhan et al., 2021). Hence, food loss is considered a postharvest phenomenon wherein it is mainly concerned with the food that is either discarded or incinerated, which results in an extensive reduction in the upgrading strategy of food waste into valuable components. Additionally, food wastage mainly occurs as a result of retail operations, food service providers, and consumer behavior, which this phenomenon is predominantly attributed to the discarding of spoilt food items or inedible or partially inedible parts of food items, etc. (Niutanen and Korhonen, 2003; Guggisberg, 2021; Tonini et al., 2018).

As per studies conducted by FAO, the losses of food that occur in the different stages of the food supply chain refers to the plethora of stages that every food item is required to pass through from the time of agricultural harvest (or slaughter), till it reaches the consumer-as per their life cycle assessment, are discrete from one another as there are various factors like economic development of a particular region and social and cultural practices that play a role in it (Alexander et al., 2013; Chauhan et al., 2021; Tonini et al., 2018; Kennard, 2019; Guggisberg, 2021). As per the data acquired in the year 2009 by FAO, the percentage of food loss or waste generated accounted for nearly 32% of the total global food production. In developing and underdeveloped countries, it has been observed and reported by the FAO that nearly 14% to 21% of the food losses occur during processing stages (a large portion of post-harvest sorting and grading losses, e.g., fruit and vegetable waste), while the values for the same in developed and industrialized nations have been reported to be below 2% (Balaji and Arshinder, 2016; Di Marcantonio et al., 2021; Pappalardo et al., 2020). Despite highly mitigated levels of post-harvest and post-processing losses, according to FAO conclusions from various studies conducted in 2011, an estimated amount of 222 million tonnes of food waste was analyzed to have been produced or generated globally at the consumer level by developed countries, which when compared to other significant values turned out to be nearly the same amount of total food that was produced (Al-Rumaihi et al., 2020). According to the United Nations Food and Agriculture Organization, gross food waste accounts for nearly one-third of total world food production, leaving nearly 690 million people hungry worldwide. Consequently, as per reports made in the year 2014, approximately 1.3 billion metric tonnes of food were calculated to be wasted worldwide (Jain et al., 2018). Hence, from the aforementioned values and data, it could be conceptualized that "surplus" food production leads to higher levels of "leftovers," “food wastage," and "food losses,” which are mostly what are witnessed in rich, developed countries, while the scenario in developing countries mainly suggests food losses occurring due to improper machinery and facilities. Certain unexpected calamities and unprecedented circumstances also lead to changes in normal patterns of consumer behavior, which in turn affect the food supply chain and thereby lead to food loss and/or wastage.

Fruit waste has been recognized as a major concern among the various factors that have recently contributed to the environment’s impact. For example, depending on the location and technique of harvest, the proportion of wasted materials in the majority of fruit processing industries is often extremely high (e.g., mango 30–50%, banana 20%, pomegranate 40–50%, and citrus 30–50%) (Laufenberg et al., 2003; Parfitt et al., 2010). Due to the moisture and microbiological contents of this fruit waste, it has a strong adverse effect on the ecosystem. Processing companies are constrained by financial and geographical constraints, as well as frequently stringent waste disposal regulations, particularly in developing countries. Since the majority of these organisations are small and microsized and mostly operate in the unorganized sector, the value of food processing waste (FPW) is considered to be insignificant in comparison to the value of processed fruit. Although FPW is now classified as "general waste," it is a globally disregarded feedstock. In developed countries like Europe, fruit and vegetable processing waste were found to be the fifth largest contributor to overall food waste (8% of total food waste) (Fava et al., 2015). In addition to that, the production of fibres and other feedstocks from the fruit waste materials is relatively easier than the other sources of food waste that originate from the food industries.

The outline of this manuscript is to provide a basic overview of the latest and most innovative uses of food supply chain waste, as well as a variety of global case studies from across the world. These studies will focus on examples of using orange, banana, and pineapple waste to make fabric and, similarly, food and fish waste to upgrade alcohol (biofuel) and biodiesel, respectively. Furthermore, the manuscript emphasizes 2nd generation food waste valorisation and re-use methods rather than traditional food waste processes (incineration for energy recovery, feeding, or composting). Additionally, the impact of food regulations on the valorization of food supply chain waste and societal perspectives toward food supply chain waste have been discussed systematically. Hence, based on the knowledge acquired from the detailed recent literature survey, this present review highlights the recent advances in the importance of waste food materials as valuable components and their strategies to build the technology for the effective management of food waste materials for the future bio-based economy.

2. Purpose of this review - impact of food waste in current scenario

As per the recent data collected by FSSAI (2022), India stands as the world’s second-largest producer of food, contributing nearly 10.1 percent of the total world food production. Notwithstanding such values, India records nearly 196 million undernourished people, which accounts for the second-highest number in the world, as India has been interpreted to house 25% of the world’s hungry people and statistical studies (predominantly carried out and reported by the Food and Agricultural Organization) were observed that as of 2021, the amount of food waste generated in India accounts for nearly 40% of its total food production (by weight), which includes household wastage of every individual throwing away an approximate cumulative total of 50 kg of food every year (Roe et al., 2021).

Over the last several decades, scientific interest in studies focused on food waste management has grown, particularly in the generation of value-added products from vegetable waste. As a result of this consideration, an extensive review article on food waste management has been published. In light of these remarks, this contribution aims to provide a comprehensive and multidisciplinary approach on the fundamentals of cutting-edge and innovative food valorisation strategies, offering a variety of case studies that highlight the potential of food waste valorisation and its contribution to a future bio-based economy.

3. The origin of food wastes

Iterating more specifically on “food wastes,” extrapolating from FAO descriptions, it fundamentally involves the reduction of food quality or quantity as a result of decisions and conclusions made by retailers, food service providers, and consumers. There are a plethora of ways food waste is produced, as shown in Fig. 1. Obtaining data and particulars from the information reported by the FAO, it has been estimated that approximately 1.6 billion metric tonnes of food are wasted every year, of which 1.3 billion metric tonnes comprise edible food items, parts, or products. According to Caldeira (2019) and Seberini’s (2020) data and FAO observations, nearly 46% of the fruits (including orange and pineapple waste), vegetables, roots, and tubers grown are wasted, while 35% of fish and seafood are wasted, and 30% of cereals are wasted (Caldeira et al., 2019; Seberini, 2020). This value accounts for the food that is produced over nearly 1.4 billion hectares of land worldwide, which makes up for 28% of the world’s agricultural area, as per data acquired and analyzed by the FAO. Food wastage in such high amounts has been observed to incur a grim toll not just on humans (leading to

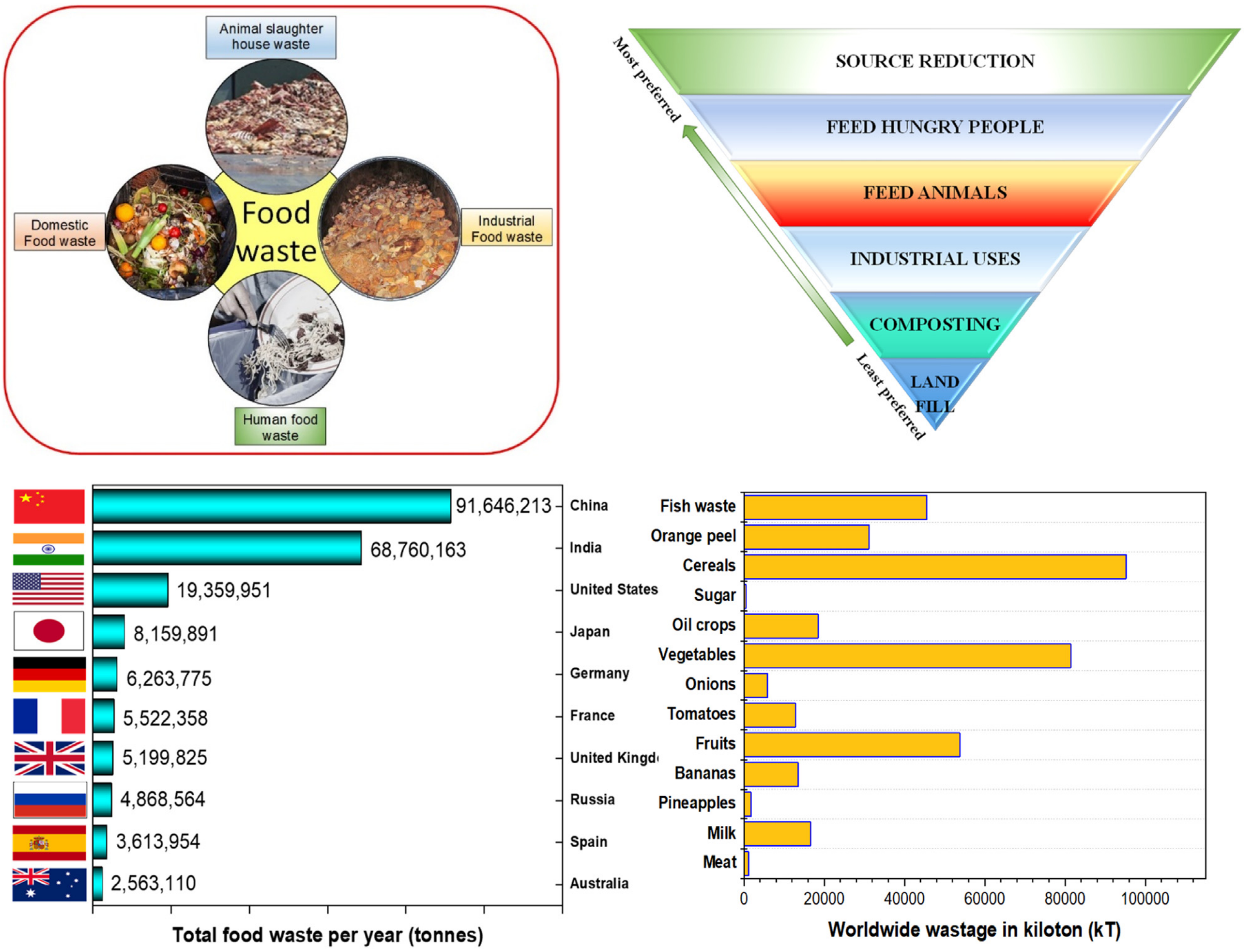


Fig. 1. General categories of sources of food waste generation and total annual household food waste produced from various countries (source files UNEP food waste index report 2021, https://thewire.in/food/global-food-waste-index-china-india, CarlaCaldeira et al. Ref. No. (Tang et al., 2023)).

malnutrition in many parts of the world), but also on the overall environment and the balance of the ecosystem, which consequently has led to food wastage being a global concern.

The agenda 2030 SDG 12.3 suggests that “by 2030, halve the per capita global food waste at the retail and consumer level, and reduce food losses along production and supply chains including post-harvest losses”. The FAO has also come up with two indices for more efficient progress towards attaining the SDG, which include the FLI and the FWI, that aid in calculating the levels and ratios of these factors in order to study their statistics and compare and contrast as to whether or not any progress is being made with regards to these aspects.

Using these indices and factors, various sustainable methods could be imbibed and implemented to not only reduce food waste but also to derive sustainable outcomes from waste produced in order to reduce the environmental impact of the same. Food wastes could thus be classified as "avoidable," "potentially avoidable," or "unavoidable" in order to categorize and analyze the levels at which food waste could or could not be reduced. According to Papargyropoulou et al., 60% of total food wastes are avoidable (such as bread crusts, leftovers, spoilt fruits and vegetables, expired food items, and so on), 20% are potentially avoidable (such as bread crusts, vegetable skins, and so on), and the remaining 20% are unavoidable (such as bones from animal products, eggshells, banana skins, and so on) (Papargyropoulou et al., 2014). Studying demographics, with the rate of population growth taking place at this very moment, it has been estimated that by the year 2050, the world will have an approximate count of 9 billion people. To meet the nutritional needs of this large population, a 15% increase in global food production has been estimated (taking into account increased levels of food waste). Given such circumstances and projections, concern about reducing food waste and making sustainable choices and developments becomes all the more pressing in this case.

3.1. The impacts of food wastage in the current scenario

The current situation of increasing magnitude of food waste eventualities has resulted in a slew of social, economic, and environmental consequences that now require immediate attention and resolution of the issues. As already discussed, when calculating the statistics of the total amount of food wasted on a global level, it accounts for the food grown over billions of hectares of land worldwide. Hence, this implies that large amounts of energy, water, and other natural resources that have been exploited to grow the food are also wasted when the food is wasted. This, therefore, can be juxtaposed to the enormous environmental effects and distress that food wastage is capable of incurring. According to the UN Environment Programme’s FWI report 2021, India alone contributed approximately 68.7 million metric tonnes of food waste in the year 2021 (Fig. 1).

According to studies, food waste in some countries may account for nearly half of total solid waste produced or generated (Balaji and Arshinder, 2016). The Food Wastage Footprint (FWF) is a project implemented by the FAO that helps survey the global footprint of food wastage and analyze its impact on the environment (water, soil, atmosphere, and biodiversity). This project established the parameters of an LCA to assess the extent of environmental impacts incurred by each of the waste management techniques commonly used to treat waste generated at various stages of the food chain. The methodology of the same, which was initially developed during the 1990s, is primarily used to conduct an environmental comparison of the proposed food waste management techniques proposed by the ISO guidelines, ISO 14,040 (2006) and ISO 14,044 (2006) (Pallas). It is commonly used as feedstock to develop upgrading technologies and is primarily used to investigate the treatment of food wastes generated by four distinct sectors of the food supply chain: processing, wholesale and retail, food service, and households. The data obtained through LCA suggests that the major techniques most usually employed to treat food wastes, as iterated by the ISO guidelines, are anaerobic digestion, composting, incineration, sewerage, and landfilling (Pappalardo et al., 2020; Uçkun Kiran et al., 2014; Edjabou et al., 2021; Ahmed et al., 2022). In many instances, it has been observed that these wastes are dealt with principally by dumping them in landfills (as it is the easiest and cheapest waste treatment method of all), which paves the way for severely concerning land and air pollution (and sometimes even water pollution). Decomposition of these wastes leads to the production and emission of the harmful methane gas, which is a greenhouse gas that possesses a potential much stronger than that of carbon dioxide, into the atmosphere, goading the environment further towards global warming (Tang et al., 2023). Composting and incinerating are also waste treatment methods that are more commonly employed when compared to anaerobic digestion due to their cost effectiveness (Pallas; Uçkun Kiran et al., 2014; Edjabou et al., 2021; Ahmed et al., 2022; Tang et al., 2023). These techniques too lead to the production of large amounts of greenhouse gasses and other harmful chemicals, which, when released into the environment, cause varying degrees of imbalances and malfunctions (Ke et al., 2023). Around 7% of the greenhouse gas emissions occurring worldwide are a consequence of food waste dumping (Di Marcantonio et al., 2021). Tonini et al. reported that nearly 70.5 percent of the total wastes generated from the food processing sector and 50 percent of the wastes collected from the wholesale and retail sectors are incinerated; 21% of the total wastes from foodservice sectors are incinerated, while 54% of it is dumped in landfills; and while 33.4 percent of the total volume of food wastes accumulated from households are incinerated, 27.5 percent of it is dumped in landfills (Tonini et al., 2018) as shown in Fig. 2. Similarly, Fig. 1 also shows the current context of the food waste hierarchy, which was initially set out in the Directive 75/442/EEC (amended by 91/156/EC and recast as 2006/12/EC) and most recently revised according to the Directive 2008/98/EC (the ‘rWFD) (Adetunji et al., 2022). The hierarchy prioritizes the various ways in which food waste can be avoided and relegates disposal to technologies that are more suitable for upgrading.

The results clearly indicate the unacceptability of using "landfilling" as a resort to treat wastes generated from the food sector. As indicated in the diagram, the moderately acceptable methods for treatment of food wastes are the reuse and recycling processes that are widely referred to as incorporating the various commercialization techniques for the production of many value-added products from the waste food materials, in an attempt to make the treatment procedure more environmentally sound. From all this information, it can be concluded that even though enough efforts are being made to treat food wastes, the development of "strong" sustainable methods to mitigate the production of food wastes and the treatment of the same is required in order to save the environment from the deleterious repercussions of the same. This article majorly focuses on the different ways in which food wastes can be or are being utilized to produce other products that, in turn, could be put to use for other sustainable purposes. This not only lowers the environmental impact of the food wastes but also diminishes the levels of losses and would reinforce the "reuse" and "recycling" of the same.

3.2. Utilization of food waste feed stocks in fabric industries

As a consequence of the extensive increase in the levels of food waste production and the environmental, economic, and socioeconomic effects that are tarnishing the face of the earth in a myriad of ways, modern technologies that utilize these wastes to yield or produce fabrics have been put into practice in recent years, and the various routes for the manufacture of fiber materials are shown in Fig. 3.

The term "textile" or "textile fabric" refers to a thin, flexible sheet made by tying or interlacing "yarns" in a variety of ways, such as, crocheting, knitting, weaving, and braiding (Humphries, 1999). Typically, polymeric chains found in fibers have a fixed chemical sequence that repeats themselves along the length of the molecule. In general, fibers are categorized as either natural or man-made, depending on their sources. Protein fibres (wool and silk), cellulose fibres (cotton and linen), and mineral fibres (asbestos) are examples of the former category. Instead, man-made fibres are either formed from natural fibres that have undergone chemical treatment or regeneration to create a fiber with the desired qualities (synthetic fibres) or they are created by chemical synthesis followed by fiber production. Polyamides, polyesters, polyolefin, acrylics, vinyl, and elastomeric fibres are examples of synthetic fibres, whereas rayon and cellulose acetate fibres are examples of regenerated fibres. The technique used to create these fibres is known as coagulation spinning, which was first used to create Kevlar, acrylic, and PAN fibres (Radishevskii and Serkov, 2005). These fibers materials are then twisted to convert yarn, which is subsequently knitted, woven, or braided to create the finished textile product made from diverse food waste.

The ideology behind such an initiative is primarily to alleviate the impacts that result from food waste generation by recycling it to manufacture products that could enter the market and be put to use on some other aspect or level, which would not just mitigate the economic losses that are incurred by food wastage but also help in producing a higher yield from a given harvest (that is, the harvest primarily serves the purpose of being used as food and the waste generated from the same is being used to yield fabric, hence augmenting the overall yield and instilling a sense of higher socioeconomic upliftment from the given scenario). Ergo, this could be termed as a means for attaining sustainability and a circular economy by reusing and repurposing food wastage.

Due to factual statements and data suggesting that plant materials are a rich source of fiber, this technology is more commonly applied to agricultural food wastes. In many studies conducted on the subject matter, data suggested by observations obtained suggests that an estimated total of nearly 250 million metric tonnes of fiber are generated every year worldwide through crops like bananas, pineapples, flax, hemp, and sugarcane (Karimah et al., 2021). While the global demand for the same is restricted to less than half of this value, the majority of this fiber contributes largely to the food waste produced. Alarming values from various studies suggest that huge quantities of waste are obtained from banana cultivation alone every year; rice straws and oilseeds (like flax and hemp) cultivated over approximately 32 and 1.5 million acres of land, respectively, also contribute to the food waste that is wasted every year (Cecci et al., 2019; Pappu et al., 2015). Hence, by means of exercising various technologies, provisions have been developed to utilize these food wastes to extrapolate fiber, which in turn (when explained in simple terms) is spun to produce fabric.

Due to its potential uses in the areas of packaging, composites, electronic films, medicine delivery, water treatment, etc., the use of cellulose (CNF) has significantly grown in the food-based waste industries. In addition to that a large surface area of CNF makes excellent reinforcements with variety of polymer nanocomposites. Extensive research is still being conducted to extract CNF from various sources (wood pulp, sugarcane bagasse, cotton fiber, banana peel, etc.) using various techniques (Theivasanthi et al., 2018; Tibolla et al., 2018; Feng et al., 2018; Kyle et al., 2018) and different techniques can be used to extract cellulose nanofibres (Nickerson and Habrle, 1947; Norkrans and Rånby, 1956; Bondeson et al., 2006; Nakagaito and Yano, 2004; Nakagaito and Yano, 2005; Dufresne et al., 2000). Particularly, fruit samples include significant levels of fibres that are mostly made up of cellulose (81.27%) and hemicellulose (12.31%), with smaller amounts of lignin (3.46%) and other components (Rahman, 2011). PALF has su-

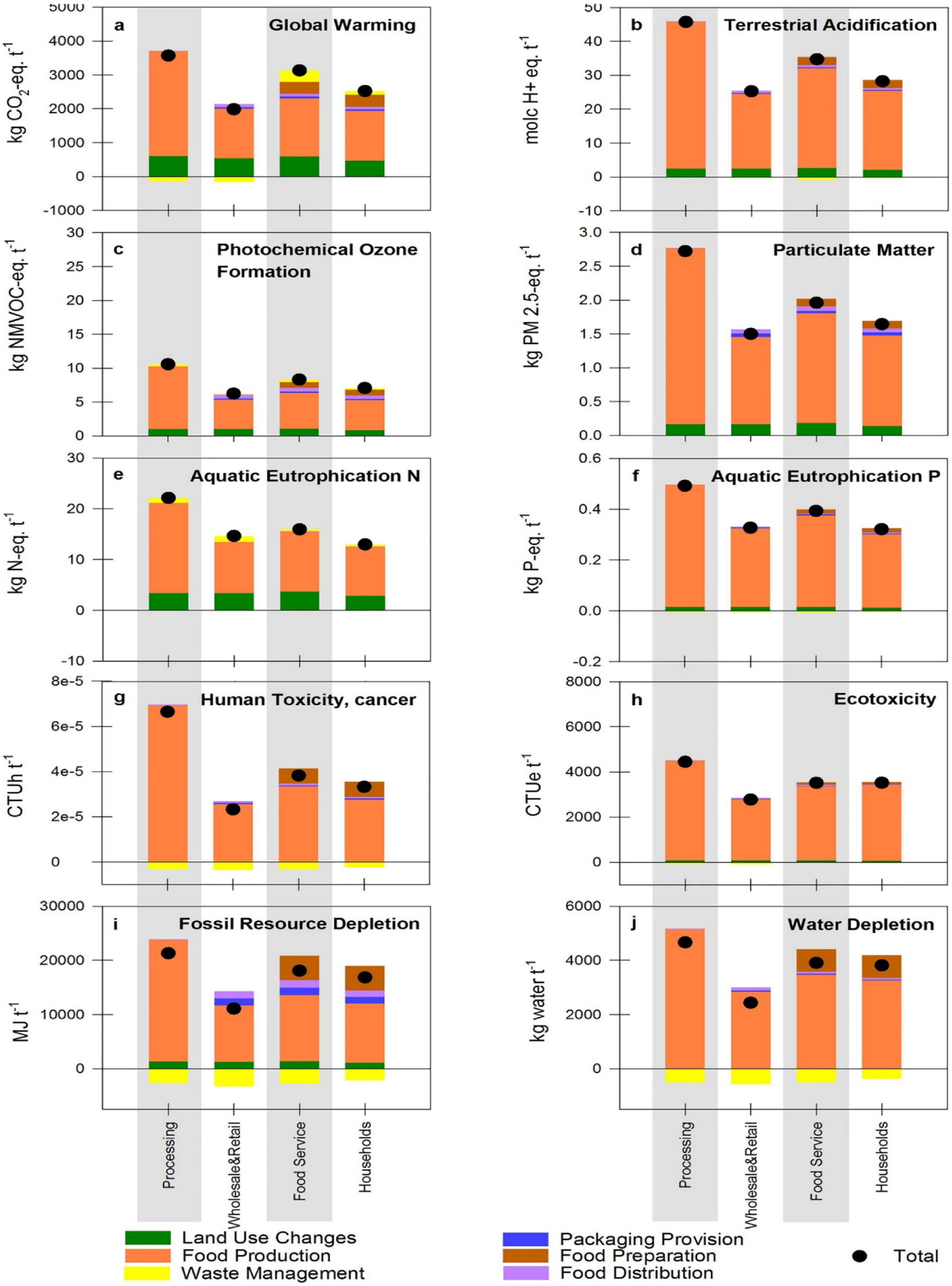


Fig. 2. Characterized life cycle assessment results of the environmental categories addressed by DavideTonini et al. (Reproduced with permission, (Di Marcantonio et al., 2021) Copyright © 2018, Elsevier).

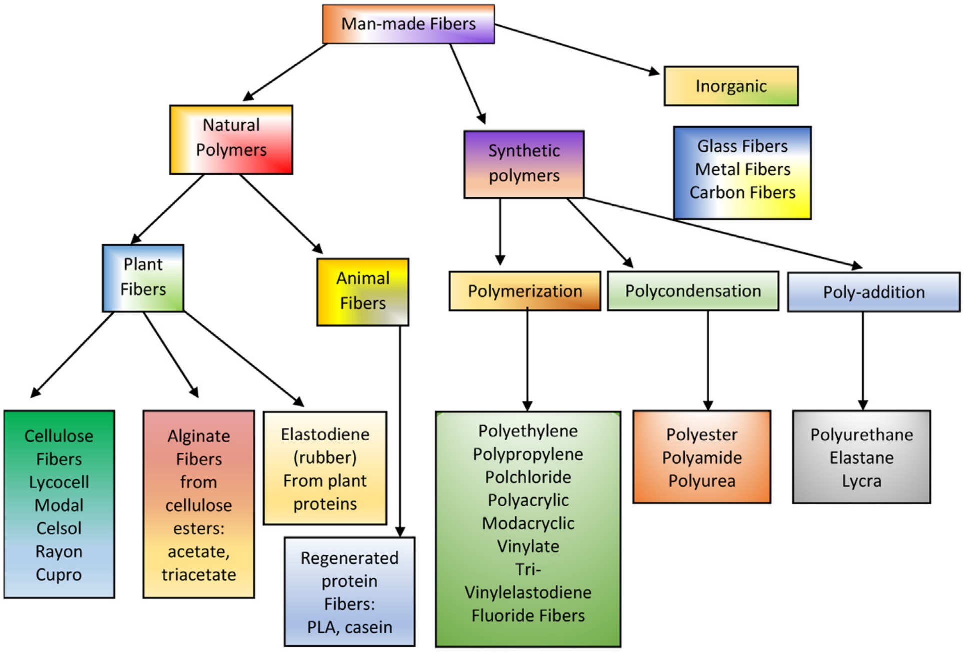


Fig. 3. Categorization of various routes for the manufacture of fiber materials (source file https://textilelearner.net/classification-of-textile-fibers/).

perior mechanical qualities to other sources of food waste due to its large quantity of cellulosic content. In this connection, the high generation of fruit wastes were focused to prepare the highly nano fiber materials.

In general, the extraction of cellulose nanofibres involves alkali treatment, bleaching, acid hydrolysis, and defibrillation by either traditional or non-conventional processes. Here, we provide a technique for isolating cellulose nanofibres from pineapple leaf fibres which is both economical and eco-friendly. In general, acid hydrolysis reactions were commonly employed by using nitric acid, sulphuric acid, phosphoric acid and their combinations which produces hazardous waste, corrosive to the metals and require large quantity of water for neutralization. However, the usage of mineral acids may form the needle like cellulose nanocrystals by the breaking of cellulose units in their respective amorphous regions (Chauve and Bras, 2013). More importantly, the cellulose materials were extensively used to extract from CNF using organic with the help of milling technique was widely employed (Song et al., 2018). Due to its ability to disrupt the longitudinal axis of the cellulosic structure, ball milling is proven to be a successful approach for the synthesis of nanocellulose (Moon et al., 2011; Mayer-Laigle et al., 2014). As a result, there is a reduction in the crystallinity of cellulose, which leads to the separation of cellulose nanofibers (Kim et al., 2013; Avolio et al., 2012; Feng et al., 2004; Ouajai and Shanks, 2006). In addition, ball milling can generate a large amount of CNF at ambient pressure and temperature compared to other mechanical equipment with minimal overall costs and energy consumption (Sofla et al., 2016). Based on the limitations of the aforementioned reports, a study emphasized on the separation of CNF from pineapple leaf fibres (PALF) through an eco-friendly and inexpensive approach using ballmilling for defibrillation and lime juice for acid hydrolysis. The resultant isolated CNF were characterized using various microscopic and spectroscopic analyzes (XRD, FT-IR, FE-SEM, AFM, HRTEM, and Thermal analysis). The study concluded that acid hydrolysis of cellulose materials using organic acid (lime juice) and ball milling technique is an effective route for the isolation of CNF.

The green technology proposed will reduce the pollution (air, water, soil) of the nature by turning the useless agricultural residue to a highly potential resource. Wastes obtained from various food products like Oranges, Pineapples, Bananas, and a variety of other crops are majorly used as sources for the application of this technology to convert the fiber extrapolated from them to generate fabric.

3.3. *Orange wastes to fabric*

Orange is a citrus fruit that is very commonly consumed and is also a product that possesses prime utility in food industries for manufacturing a variety of food products. According to studies conducted, a rough value of 51.8 million metric tonnes of oranges were recorded to be produced worldwide in the year 2014, while more recent data suggests that an estimated amount of 15 to 25 million tonnes of peel wastes from the same are either thrown in landfills or incinerated without proper recycling alternatives (Sachidhanandham, 2020). The reported chemical characterization of the orange peel waste was summarized in Table S1 and it was showed that majority of the portion was made by fiber material (de la Torre et al., 2019). The orange peel is primarily composed of two portions, namely the epicarp or flavedo, which is the coloured portion of the peel that comprises essential oils and pigments, and the mesocarp or albedo, which is the inner white portion of the peel that is highly rich in cellulose, as shown in Fig. 4; however, the polysaccharide molecule is a polymer of glucose units connected by 1,4-glycosidic linkages. The fiberous wastes generated after pressing whole oranges to obtain juice are intended to yield cellulose after the pressing of whole oranges in juice extraction processes. The obtained cellulose, by way of various processes, can be spun into filaments used for the formulation of fabric (Fig. 5).

Under mild chemical sequential extraction conditions, orange bags from nature and industry were both examined as starting materials for the manufacture of nanocellulose materials. The other part accounted for acid (5% v/v and 100 °C) and/or alkaline treatments (NaOH, 1.6–4.0% m v^{-1}, 120 °C), and further bleaching with $NaClO_2$ (1–3% m v^{-1}, 80 °C). Ultrasound treatment produced cellulose nanofibers with 60–70% crystallinity and excellent purity (above 98%). According to field emission scanning electron microscopy, cellulose nanofibers separated from natural bagasse had mean diameters of 18.4 nm 6.0 nm, while nanofibers isolated from industrial bagasse had mean diameters of 20.5 nm 7.0 nm, respectively. X-ray diffraction and solid-state nuclear magnetic resonance (CP-MAS 13C NMR) data were used to calculate the crystallinity of the obtained materials. The materials identified have a wide variety of possible uses and constitute a green option for the treatment of orange fruit biomass (Mariño et al., 2018).

Experimental data proves that alpha-cellulose is the major constituent of cellulose fibres that are employed for the manufacturing of

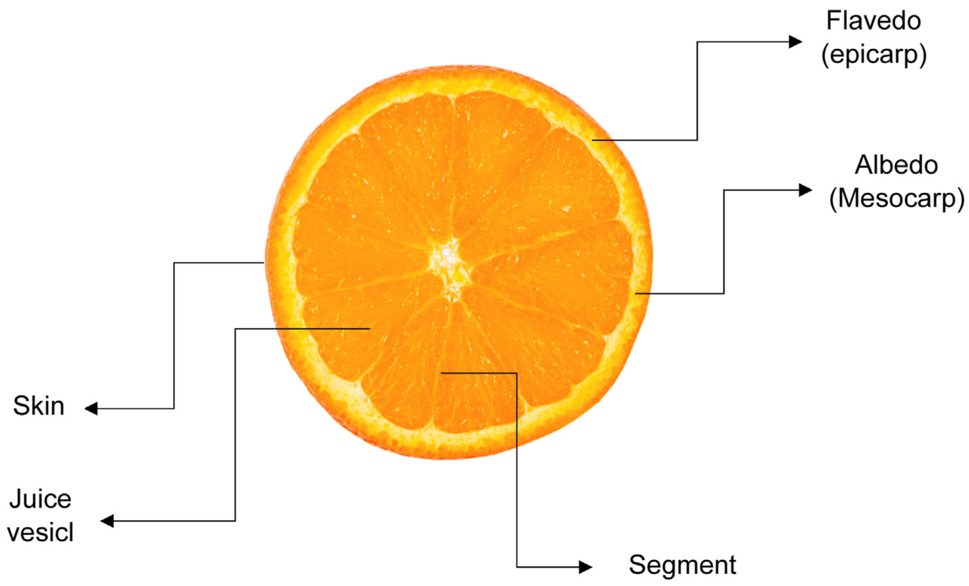


Fig. 4. Labelled transection of orange.

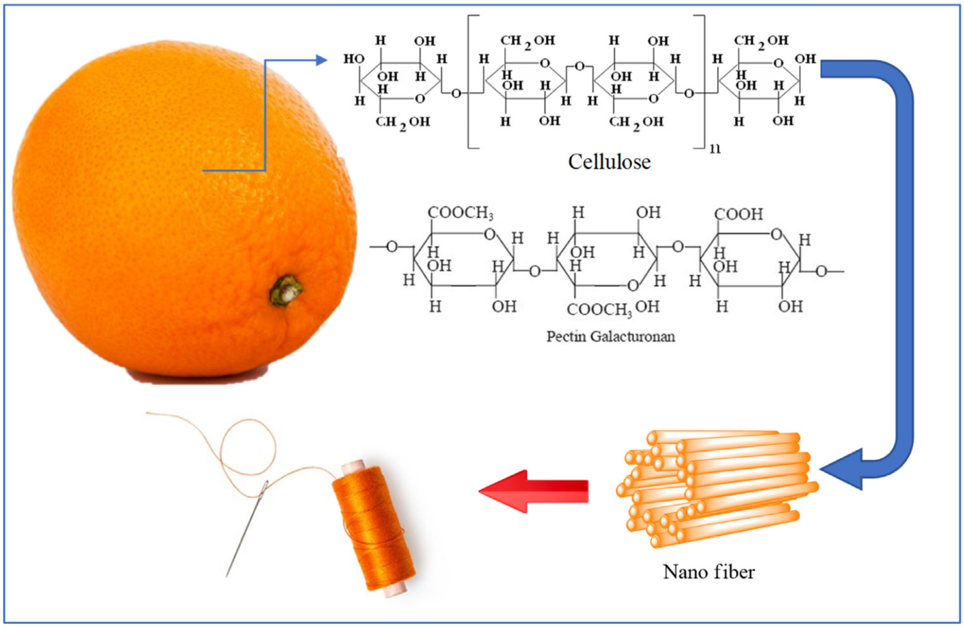
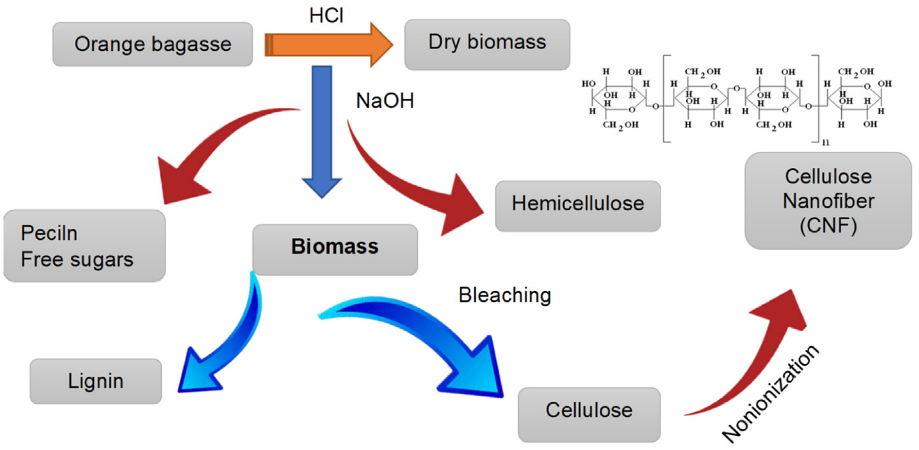


Fig. 5. Production of nano fiber materials from the orange peel waste.



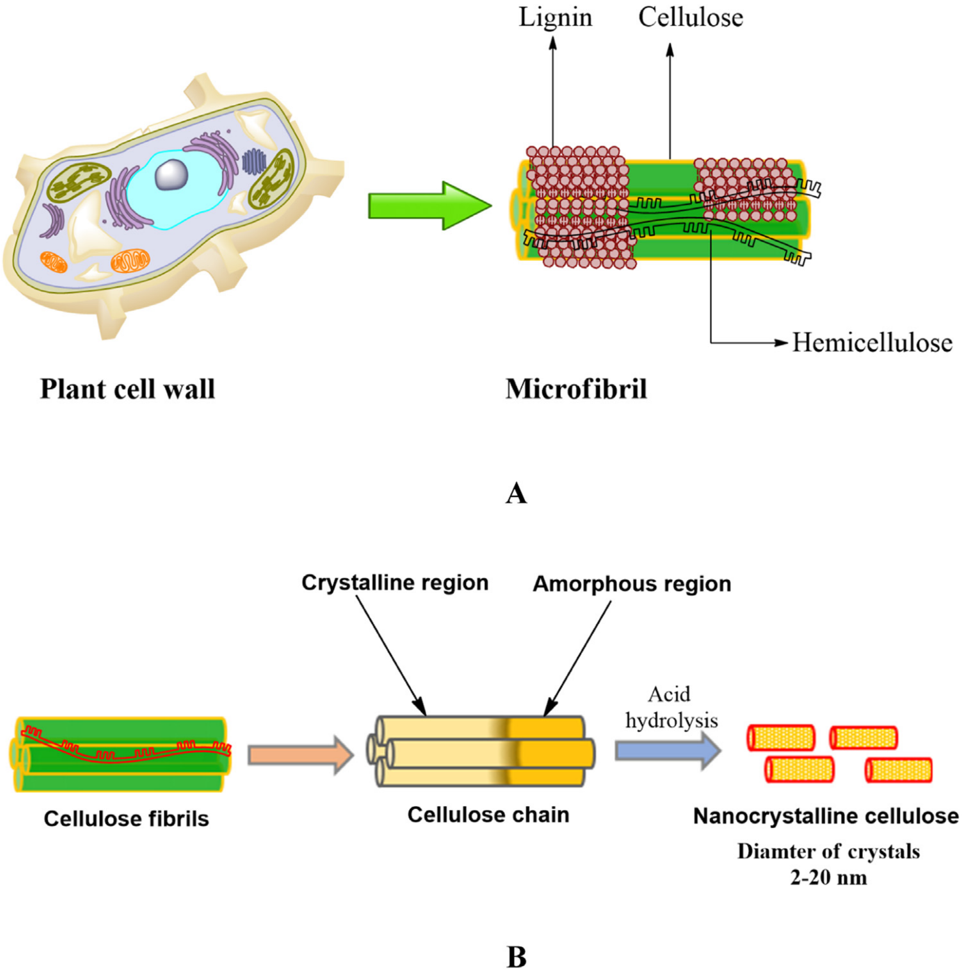


Fig. 6. A. Composition of lignocellulosic biomass and the particle size distribution of CNF (Source: Phanthon, P. et al. (2018) (Theivasanthi et al., 2018)). B. Acid hydrolysis of cellulose fibril.

fabric or textiles. However, the strength of the cellulose fibers predominantly depends on factors like the crystallinity of the polymer and/or its chain length or degree of polymerization. Yang et al.'s study concluded that fabric synthesized from wastes obtained from oranges necessitates the micro- or nano-crystallization of these alpha-cellulose molecules. In order to garner a perception of how the fabric is manufactured from the said wastes, the extraction of the raw material and the mechanisms employed for the same have to be understood (Yang et al., 2022).

Plant cell walls are majorly composed of lignocellulosic biomass, which comprises lignin (10–25%), hemicellulose (20–35%), and cellulose (35–50%), as depicted in Fig. 6A (Schuler et al., 2022). The monomers that formulate the structure of cellulose, anhydrous glucose units, consist of several hydroxyl groups that participate in forming inter- and intramolecular hydrogen bonds within the cellulose fibers, which provide for its significant toughness and high tensile strength. The monomers that formulate the structure of cellulose, anhydrous glucose units, consist of several hydroxyl groups that participate in forming inter- and intramolecular hydrogen bonds within the cellulose fibers, which provide for its significant toughness and high tensile strength (Fig. S1). These hydrogen bonds are further strengthened and tightly packed or aggregated in intensively ordered zones, which are termed the "crystalline regions" of the cellulose fibers. At these crystalline parts, the fibres incur extensive stiffness and strength, which is why nanocellulose or nano-crystalline cellulose can be obtained from naturally occurring cellulose fibers, which in turn can be utilized for the manufacturing of fabric. It has a high stiffness of up to 220 GPa of elastic modulus, which is greater than that of Kevlar fiber. Furthermore, nanocellulose's tensile strength was found to be 10 GPa, which is relatively larger than cast iron, and its strength-to-weight ratio was eight times stronger than stainless steel. Besides that, nanocellulose is transparent and contains a reactive surface of hydroxyl groups that can be functionalized to produce a variety of surface properties (Dufresne, 2012; Dufresne, 2013; Abdul Khalil et al., 2014). Santanocito's method of extracting the cellulose from orange peels involves treating the raw material with hydrogen peroxide under certain conditions, which can be achieved with the use of sodium hydroxide solution (Santanocito, 2016).

Nevertheless, bases like hydrogen peroxide, sodium hydroxide, and calcium hydroxide (the most commonly used being sodium hydroxide) help in the solubilization of lignin from the lignocellulosic biomass by affecting the acetyl groups in hemicellulose and the linkages of the lignin-carbohydrate ester (Yulina et al., 2020). This solubilization helps in leaving behind the cellulosic mass, which can then be attained by consecutive filtration and washing. The pH of this treatment is usually preferred to be in a range of 11 to 12, at a temperature range of 65 °C to 90 °C (more specifically 80 °C), for a given period of time, which is usually approximately around 30 min (Mandal and Chakrabarty, 2011; Jee and Tan, 2021). This solid cellulosic component is then treated with a carboxylic acid, most preferably acetic acid and/or formic acid, at a temperature range of 50 °C to 100 °C (more specifically at a temperature of 80 °C) (Nur Hanani et al., 2017; Jee and Tan, 2021; Lundahl et al., 2017). In this reaction, acid is mainly used for the purpose of hydrolyzing the amorphous portions of the cellulose fibres to leave behind the crystalline parts, which form the short rod-shaped nanocrystals (with a 2–20 nm diameter) (as depicted in Fig. 6B) that could be spun to produce fabric. This protocol of procedure for alpha-cellulose extraction is primarily applicable to scenarios when only the albedo of the orange peel is being utilized as the source; when both the albedo and the flavedo are treated, further steps are followed after the acid treatment. These following steps involve again filtering and washing the mass obtained post-acid hydrolysis, which is then again made to undergo the aforementioned alkali treatment (performed at the beginning of the protocol) until it is finally filtered again and dried to yield cellulose nanocrystals that comprise 90 wt.% of alpha-cellulose (Yadav et al., 2022).

These CNC/CNF are then suitable for treatment to produce cellulosic filament material, which has a variety of desirable properties such as being strong, lightweight, chemically versatile, and biodegradable, indicating that products made from these filaments have high mechanical competence (Hendriksz, 2017). Sarah et al. proposed a variety of methods, including wet-, dry-, melt-, and electro-spinning techniques, could be employed for the formulation of fabric filaments from cellulose nanofibers attained from orange peel wastes (Sarah et al., 2018). While this is the way orange peel wastes could be processed and recycled to produce fabric, the same peel wastes could be boiled (fresh or sundried) to obtain a light orangish-yellow dye, which too has been observed to possess significant application in the fabric or clothing industries. In terms of quality, softness, shiny surface, and color, a fabric made from orange peel waste textiles resembled silk. Most commonly, citrus fruit properties were retained on fabric using nanotechnology and microencapsulation, and the technology-aided in retaining these properties for up to 20 washes (Jadoun et al., 2020). The results showed that biodegradable material was well-suited for mixing with cotton, silk, elastane, and orange. The pair decided to present this in a variety of forums to increase the demand, scope, and market for the developed textile.

3.4. Pineapple leaves to fabric materials

Pineapple is an extensively cultivated fruit around the globe due to its high nutritional value, which grades it as a highly desirable product, while at the same time, as a result of its high fiber content, the wastes that it yields are of prime utility in the textile manufacturing industry. The global production of the said item was approximately calculated to be around 16.6 million metric tonnes in the year 2004, which rose to 21 million metric tonnes by the year 2007, and ended up at a figure of 51 million metric tonnes in the year 2016 (Pandit et al., 2020). As pineapples are predominantly harvested along with their associated leaves, during consumption, even though the fruit is utilized to its maximum most of the time, the leaves are always observed to be discarded and are regarded as "agricultural" or "consumer wastes." As a result, these waste materials are typically treated through processes such as incineration or decomposition (both of which have severe environmental consequences).

"Pina Clothing" basically describes clothes that are manufactured from pineapple leaves. As reported earlier, it was initially started in the Philippines and was later adopted by several countries in Europe, which made it quite a popular product in the nineteenth century; however, its acceptance and demand declined with the increased utility of the other conventional fabric materials (Jose et al., 2016; Jain et al., 2018). Currently, the extensive increase in food demand leading to a surge in the global production levels of pineapple has resulted in the generation of high amounts of waste in the form of pineapple leaves, which in turn has again invited the culture of using fabric manufactured from the said discarded materials. These textiles are made from the strong, white silky PALF extracted from discarded pineapple leaves and can be spun on jute or cotton spinning systems (Fig. 7A). Pineapple leaves, on average, have been calculated to have a length of 55 to 75 mm and a weight that is usually in the range of 15 to 50 g. The percentage fiber yield from pineapple waste leaves is usually around 1.55–2.5% (Siregar et al., 2012).

Deriving information from a study that was conducted by Ravindran et al., it can be concluded that cellulose nanofibers can be easily obtained from pineapple leaves and can be thoroughly studied by subjecting them to various analytical techniques like FESEM, HRTEM, AFM, DLS, and thermal analysis (Ravindran and Thomas, 2019). From the same literature work, it can be stated that the crystallinity of the amorphous regions of the pineapple leaves could be augmented by nearly 77% by the removal of lignin and hemicellulose (a result that was obtained from X-ray diffraction). The extracted cellulose nanofibers have been observed to be excellent components to formulate polymer nanocomposites with. Table S2 shows the physical and chemical composition of fresh and dried pineapple peels based on literature reports. Contemplating the various chemical analyzes conducted on pineapple peels, they are primarily observed to be composed of cellulose, lignin, hemicelluloses, and other carbohydrates; thus, they are desirable candidates for functioning as adsorbents and the preparation of carbons with well-developed micro- and microporosity (Agarry, 2012). According to a cost-benefit analysis, the various green methodologies that have been suggested for the cost-effective production or extraction of nanofibers are also capable of producing carbon nanofiber (CNF) that can be used in the food industry, paper manufacturing, biomedicine, and machinery tools (Ravindran and Thomas, 2019).

Analysis and elaborate determination of the chemical and physical properties and composition of pineapple peels have been of prime significance as they are mainly composed of cellulose, hemicelluloses, lignin, and other carbohydrates. Hence, as already observed from other food waste compounds exhibiting similar chemical properties and having a wide array of usability in the fabric industry, pineapple peels also have been observed to possess qualities that make them potential agents for the formulation of adsorbents as well as the preparation of carbons, probably with well-developed micro- and microporosity (Dai et al., 2018).

In the year 2017, globally, an approximate area of 1098,705 hectares of land was used for the cultivation of pineapples, which yielded 1318 thousand tonnes of PALF. According to estimations, the amount of PALF generated only in India is roughly around six lakh metric tonnes per year (Jain et al., 2018). Table S3 shows information pertaining to the average yield of pineapple fruit in different nations and the consequent approximate levels of PALF that could be manufactured from the wastes generated from the same.

The extraction of fibers from these waste leaves can be done manually or mechanically. The manual technique, also known as "hand stripping" or "scraping," predominantly involves manually scraping the fibers off the leaves using broken porcelain plates, which are thoroughly washed in running water and then air- or sun-dried. These extracted fibers are removed off of their associated pectic substances, which are present in the soft cells, by treating them with microorganisms (Bondeson et al., 2006; Nakagaito and Yano, 2004). The mechanical process of extracting fibres from waste pineapple leaves involves the use of decorticating machines. The developed machines make use of a pair of rollers (performing a crusher-like technology), one metal knife scrapper roller, and one serrated roller of specific sizes arranged at certain angles to remove the waxy layer on the leaves in order to extract the fibers (Yusof et al., 2015).

The functionality of the machine is such that, when the leaves are entered into it, the aid of the rollers aids in the grinding and crushing of the outer waxy layers of the leaves; when the leaves are removed or pulled out of the machine, the rollers function again to further grind the presence of any waxier layers on the leaves, which are then removed (as depicted in Fig. 7B) to yield the desired PALF (Jain et al., 2018). This extracted PALF is usually again scoured and dried and put through various treatments like retting (in which bacteria or fungi are used) and degumming (using dilute acids, bases, or enzymes) to remove the variety of other associated matter that exists alongside PALF, which include cellulose, lignin, pentosans, fat, wax, ash content, nitrogenous matter, and pectin. Extrapolating from information derived from various studies conducted, PALF can be described as a soft fiber possessing a desirable white luster that has a scaly structure with a high degree of crystallinity (which contributes to its high flexural and torsional rigidity) and a low tolerance to moisture (Ravindran and Thomas, 2019). Hence, this fiber

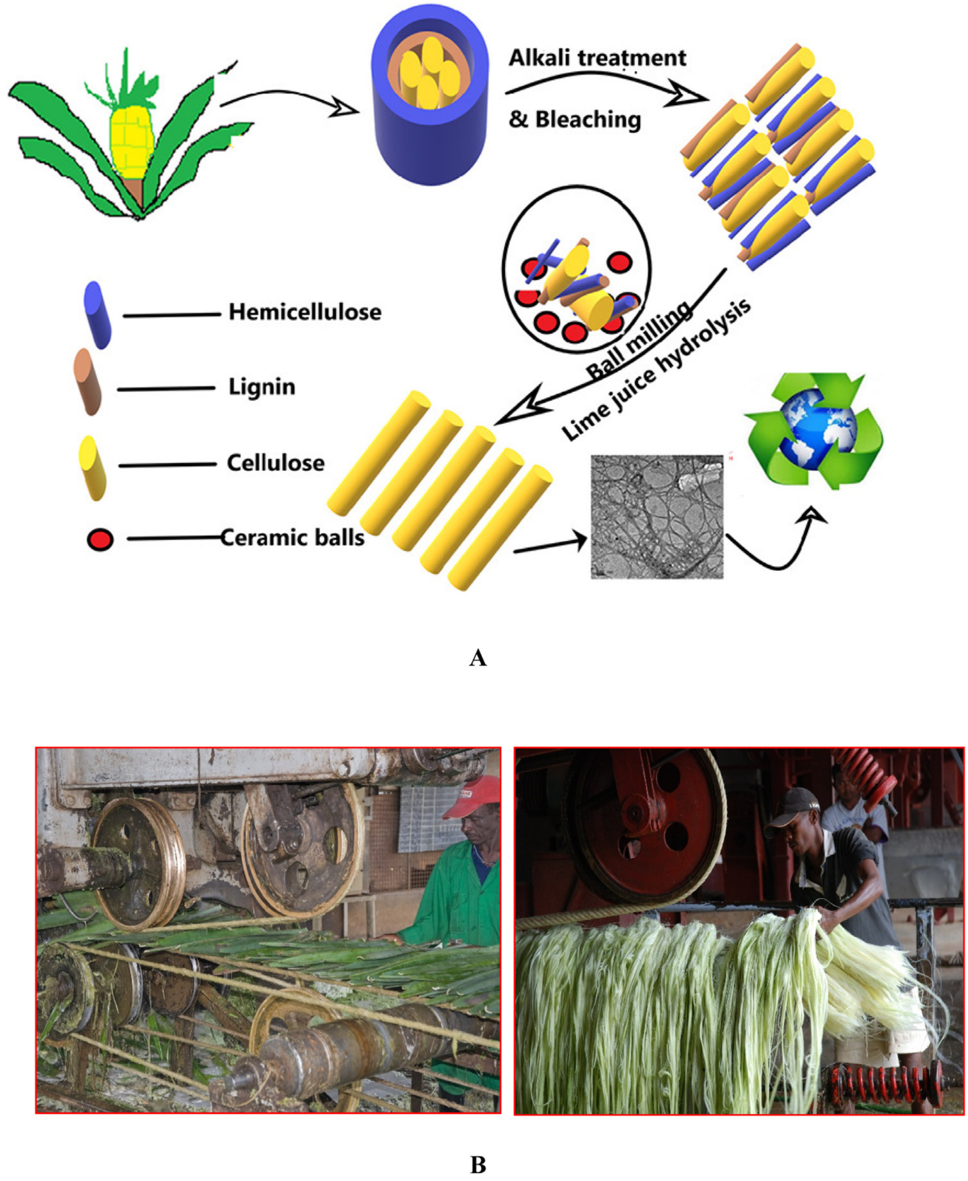


Fig. 7. A. Depiction of the different categories of fiber that can be extracted from Pineapple Leaf Fiber. Reprinted with permission from ref. [55a]. Copyright 2019, Elsevier. B. Functioning of Decorticating Machines Source: Pandit, P. et al. (2020) (Mayer-Laigle et al., 2014).

has proven to be of decent utility in the textile industry, where it is used for the formulation of fabric, usually in combination with silk and other fabric materials. It is used for the manufacturing of clothes, table linens, bags, etc., which thereby leads to sustainability as the wastes (from the pineapple cultivation industry) are recycled and a higher outcome from a given harvest is generated. In addition to that, Table 3 gives information pertaining to the content of insoluble fiber that can be extracted or derived from pineapple peels (a quantitative comparison between fresh peels and dry peels). It also gives a generalized idea pertaining to the overall composition and yield of different components that can be derived from either fresh or dried pineapple peels.

3.5. *Wastes from bananas to fabric*

Bananas have been observed to be abundantly grown in tropical and subtropical countries while being graded as one of the oldest cultivated crops and the fourth most important crop grown in the world due to the banana fruit's being of prime nutritional significance and the plant itself having various other utilities as banana flowers, stems, peels, and leaves are all put to use for different consumptions or related purposes (Maleque et al., 2007). However, based on data accumulated from certain literature, even though the consumption and utilization of banana trees are significantly high, billions of tonnes of banana tree stems are thrown away or wasted every year (de la Torre et al., 2019; Mariño et al., 2018; Yang et al., 2022; Schuler et al., 2022; Dufresne, 2012). That is, once bananas are harvested, the rest of the plant (unless put to use for some other purpose) will be discarded. Information from various studies has concluded that for every tonne of banana fruit harvested, an approximate figure of 4 tnes of waste from its plants is generated every year, which is traditionally and more commonly disposed of by incineration or dumping in landfills (Aurore et al., 2009; Chauhan Gupta and Srivastava, 2022).

Whilst already having established that such techniques not only impose a detrimental effect on the environment but also lead to wastage of materials that could be utilized for other purposes, it has been observed that nearly 37 Kg of banana tree wastes (stems) can be used to yield a kilo of banana fibers which in turn could be employed for the production of fabric, papers, etc. Aurore et al. (2009) that would attribute to being a rational alternative method of treating wastes generated from banana plants. A significant portion of a banana plant is made up of a pseudo-stem that predominantly comprises a soft central core and tightly wrapped leaf sheaths that unwrap from the stem to form dis-

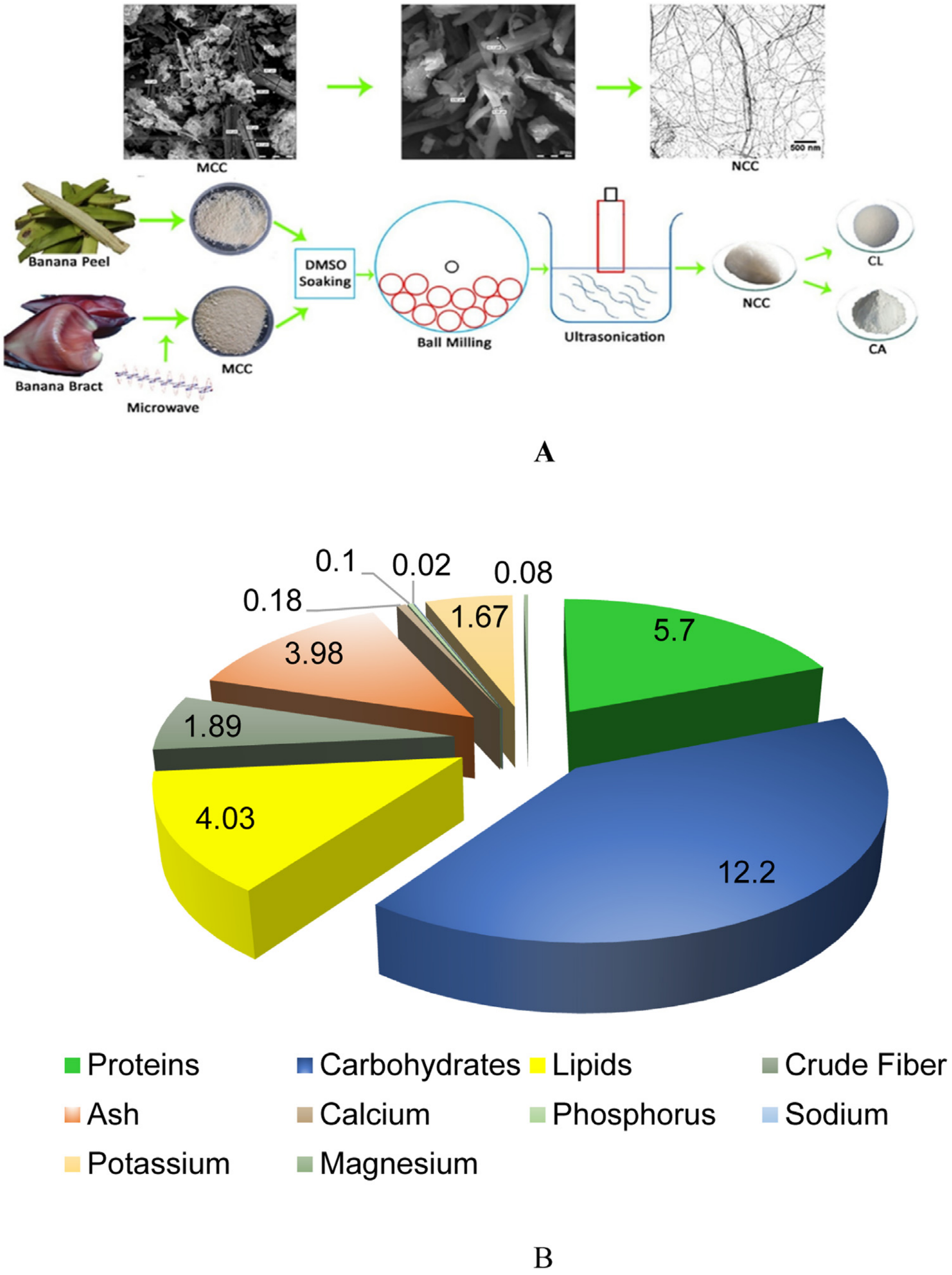


Fig. 8. A. Method for the production of cellulose nanofibers from the banana peel (BP) and bract (BB). Reprinted with permission from ref. (Schuler et al., 2022). Copyright 2018, Elsevier. B. Composition comparison of Pineapple fresh peels and dried peels.

tinguishable mature leaves. Post-harvest, when the banana plant is considered a waste product, the pseudo-stem is mainly used to yield fibres that could be used in the production of textiles, papers, ropes, etc. These fibers, which contain 50–60% cellulose, 25–30% hemicelluloses, 3–5% pectin, and 12–18% lignin, are chemically similar to those extracted from pineapple leaves (or pineapple waste products) (Zhang et al., 2022) (Fig. 8A). The chemical composition of the banana along with its peel was summarized in the pie chart (Fig. 8B).

These fibers can be extracted by methods similar to the ones used for the extraction of fibers from pineapple leaves; that is, they can be extracted with the aid of decorticator machines or by hand. As reported by Harini et al., (2018), the manual process involves cutting the pseudo-stems into pieces and then using blunt blades to scrape out fibers, while the mechanical process involves the coordinated functioning of a pair of rollers and a beater that split the pseudo-stems into 2–4 parts, from which they separate the fibers contained therein. These extracted fibers are then treated with bio enzymes and other chemicals to achieve the desired lightweight and high strength properties, as well as a good elongation factor and spinnability. Various methods of spinning could be adopted to spin banana waste fibers into the fabric, which include open-end spinning, bast fiber spinning, semi-worsted spinning, and ring spinning (Gupta et al., 2022; Bello et al., 2018; Basak et al., 2015; Jordan and Chester, 2017; Benítez et al., 2013; Bajpai et al., 2012). This technique of extracting fibers from banana wastes to produce fabric or textiles has been investigated and may have been in practice since the 13th century. However, with the increasing utility and popularity of conventional fabric materials, such sustainable approaches were no longer given any attention. Now, with the socioeconomic sector facing a major downslope due to high amounts of food wastage, the application of these innovations is being done again to produce textiles that include disposable fabrics, filter cloths, tea bags, and light-density woven fabrics (Mohiuddin et al., 2014).

A study conducted by Harini et al. analyzed the microcellulose fibres that were extracted from banana peel (Harini et al., 2018). The corre-

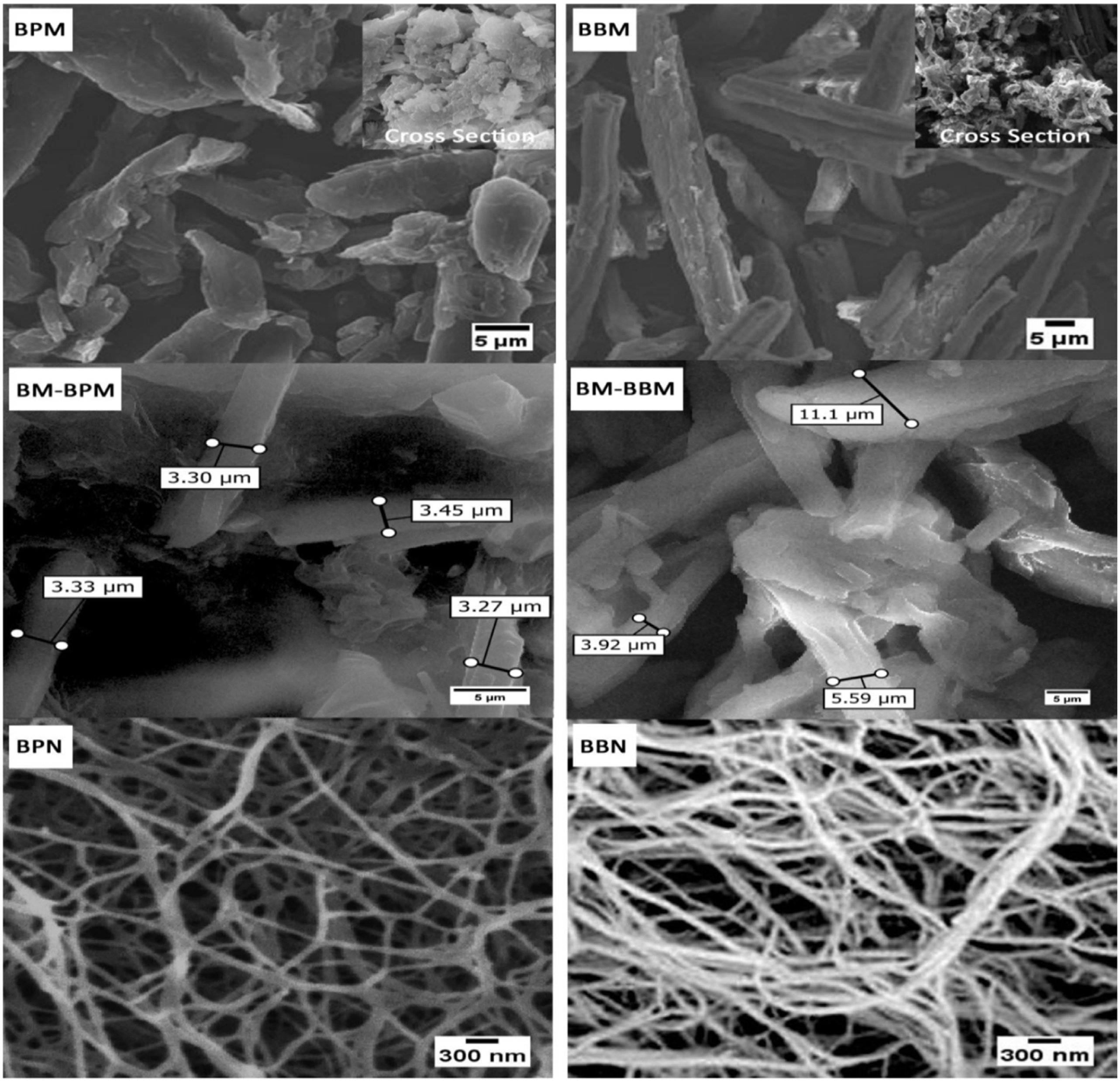
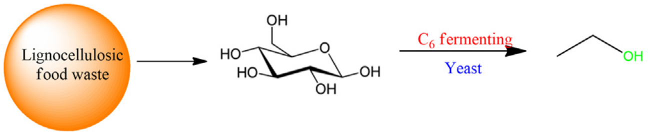


Fig. 9. Scanning electron images of micro [M] & nano cellulose fibers [N] [BP – Banana peel BB – Banana Bract; BM – Ball milled. Reprinted with permission from ref. (Schuler et al., 2022). Copyright 2018, Elsevier.

sponding SEM images revealed irregularly arranged bundles of cellulose fibres with particle sizes ranging from 19.2 to 30 m (Schuler et al., 2022). The DLS particle size analysis of banana peel mass yielded an approximate particle size range of 520–26 m with an average particle size of 351 m, as shown in Fig. 9. Linear bundles of crystalline cellulose were observed to have been extracted in the same study from BBM, which, when visualized, had a particle size ranging between 15 and 45 m in diameter and 274 and 434 m in length. When the same crystalline cellulose fibres were analyzed by the process of DLS analysis, the approximate particle size was estimated to range between 51 and 743 m and 431 m, respectively. Bajpai and Pappu et al. reported that the use of naturally sourced fibres is more advantageous than using synthetic ones due to their numerous advantages, such as weight reduction, enhanced performance, and biodegradability (Bajpai et al., 2012). Especially when fibres are extracted naturally (Mohiuddin et al., 2014). Despite the various technical challenges involved, natural fibers such as jute are becoming more prevalent in composite materials. Due to their eco-friendly nature, they are replacing synthetic fiber in various applications (Thakur et al., 2022; Rana et al., 2021). Several major sectors, including automotive, packaging, and construction, have shown a strong interest in the development of novel bio-composite materials using advanced manufacturing techniques such as 3D/4D printing over the last decade (Joshi et al., 2020; Daminabo et al., 2020). Natural fibers can be used in a composite material in the form of raw fiber, woven fibers, textile fiber, or short fibers, and some research has shown that fibers modified to 'particles form' have higher strength.

Recent literature reports have even demonstrated the extraction of cellulose nanocrystals from natural fibers, which might be useful as a composite in the automotive and water treatment industries (Alothman et al., 2021; Beluns et al., 2021; Rana et al., 2021; Zielińska et al., 2021). To achieve better properties, many studies have used a combination of natural and synthetic fibers or two different types



Scheme 1. Ethanol production from lignocellulosic food waste.

of natural fibers. Many researchers have also reported an increase in certain composite properties. The surface of natural fibers was modified various chemical treatments in order to increase the Adhesion with the binder at the interfacial level (Thakur et al., 2022; Supian et al., 2021; Asim et al., 2021).

4. Food wastes to alcohol (Biofuel) biodiesel from fish wastes

In general, liquid wastes are generated in the form of whey (that is usually pressed out of yogurt or cheese), wastewater that is utilized for various purposes, brewery effluents, oils, etc. (Thakur et al., 2022). In spite of such a high magnitude of variability amongst the different kinds of food wastes, it is apparent that the nutrient composite of them all would include Carbohydrates, Proteins, Lipids, Minerals, and Vitamins which make them appropriate for performing microbial activities. Hence, both solid and liquid wastes could be utilized for alcohol production purposes by the action of microbes breaking down these waste products to in turn generate renewable fuels.

While Food Wastage stands as a concerning predicament from the socioeconomic point of view, another major issue that asks for an equal amount of gravity and importance is the rapid exhaustion of fossil fuels for the generation of energy. Production of biofuels, more specifically bio-ethanol, from lignocellulosic matter by the action of microorganisms, is an area of study and literature that has hence been able to garner much attention and contemplation in recent years. The process of producing fuels in the form of alcohol from lignocellulosic matter is itself an economically exhausting procedure which is why, with the augmenting levels of food wastage that is incurred, technologies are/have been developed and employed to use these wastes (as a cheap raw material) to have microbial activities performed on in order to produce bio-ethanol (Scheme 1).

The production of bioethanol, which could be used as a potential source of energy or fuel was first discovered by Alexander Graham Bell, in the year 1917 stating that any vegetable matter, crop residues, farm waste that are capable of supporting fermentation can be used to yield bioethanol (Prasoulas et al., 2020). As per records made in the year 2013, the largest producers of the said alcoholic compound were the US, Europe, Brazil, Canada, and China giving a total yield of 23.4 billion gallons while as per global statistics made in the year 2020, United States, Brazil, European Union, China, and India were the largest producers giving a total yield of 13,800, 7930, 1250, 880 and 480 million gallons, respectively (Fig. 10). Liquid food wastes like whey water, tofu processing wastewater, Pulp from different fruits and vegetables, Wastewater released from fruits and vegetables as a result of cutting, grinding, mashing, cooking, etc. are all rich in sugars, amino acids, and other nutrients that are required for the sustained growth of fermentative microorganisms. Solid wastes like rejected whole food items, skins, peels, seeds, leaves, etc. too are rich in all the same said nutrients, especially in Carbohydrates; data extrapolated from various literature suggest that whilst nearly 65% of solid food wastes majorly comprise of Carbohydrates, they are usually also rich in other carbon-containing compounds (Maleque et al., 2007; Aurore et al., 2009; Chauhan Gupta and Srivastava, 2022; Zhang et al., 2022); hence both solid and liquid wastes serve as suitable substrates for the growth of microorganisms that, through biodegradation pathways, can produce fuel alcohols like ethanol, butanol, and propanol (Muhammad and Rosentrater, 2020).

Various microorganism species have been identified and proven to be utilitarian for such processes which include, Aspergillus sp., Penicillium sp., Trichoderma sp., Neurospora sp., Fusarium sp., Saccharomyces sp., Escherichia sp., Zymomonas sp., etc., the primary function of these microorganisms being to breakdown such food waste products to yield biofuels in the form of alcohols (Ebrahimi et al., 2008; Hegde et al., 2018; Zou et al., 2020). For these wastes to fully get metabolized by such bacterial and/or fungal species to yield alcohol, they need to undergo various steps and stages of processes that comprise pretreatment, enzymatic hydrolysis, fermentation, and bio-ethanol recovery (Zhang et al., 2013). The process flow diagram for the production of bioethanol from food waste was illustrated in Fig. 11.

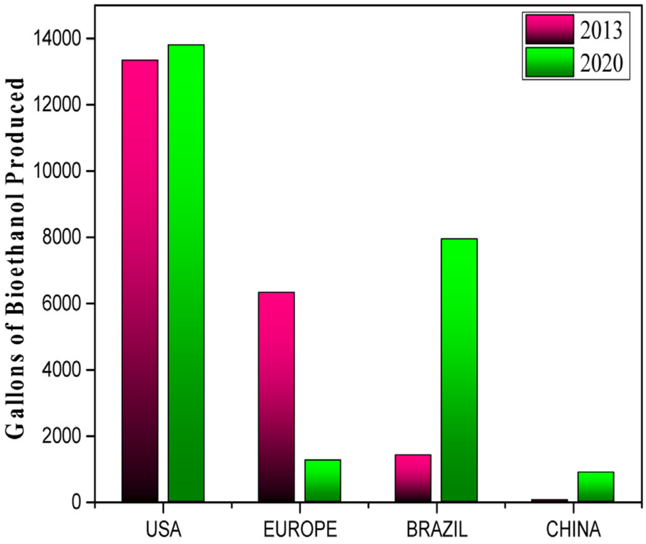


Fig. 10. Million gallons of bioethanol produced in the years 2013 and 2020 in different countries.

In a study conducted by Alok Patel et al., food wastes were predominantly utilized in two stages; in the first stage, the carbohydrates and proteins from the food waste were extracted by following the enzymatic hydrolytic pathway by cultivating heterotrophic microalgae on the food waste products, which resulted in a biomass yield of 0.346 ± 0.09/g sugars and lipid yield of 0.216 ± 0.06 / g sugars. In the second stage, oil (14.15% w/w) was extracted from the same food waste by adopting the methodology of hydrolysis, and it was converted into biodiesel by a simple two-step transesterification reaction, which generated 135.8 g of fatty acid methyl esters/kg of food waste and 13.8 g of crude glycerol/kg of food wastes, respectively. Finally, crude glycerol obtained from both processes was used at 20 g/L to cultivate heterotrophic microalgae, resulting in a cell dry weight and total lipid concentration of 6.23 g/L and 2.91 g/L, respectively. A total of 248.21 g of fatty acid methyl esters were obtained from the 1 kg of food waste through this integrated process. This was one of the recorded successful methods of biodiesel production from food wastes (Patel et al., 2019).

Innumerable studies that have been conducted to gain perception of the activity of fermentative microorganisms suggest that these aforementioned bacterial and/or fungal species majorly act on simple sugars to convert them into alcohol and other byproducts. The said process could occur aerobically or anaerobically by direct conversion of sugar into alcohol and carbon dioxide or by first degrading the sugar to a separate product, like pyruvate (in the case of Entner-Doudoroff Pathway), which is then further broken down to yield alcohol and carbon dioxide (Spector, 2009; Patel et al., 2021) and the schematic representation was shown in Fig. 12. Hence, as already observed, food wastes are complex materials composed of a multitude of large compounds like starches, fatty tissues, and cellulosic materials, which initially need to be broken down or hydrolyzed by pretreatment processes in order to capitulate simpler substances, or more specifically “fermentable sugars” (as fermentation process primarily acts on sugars to yield appropriate

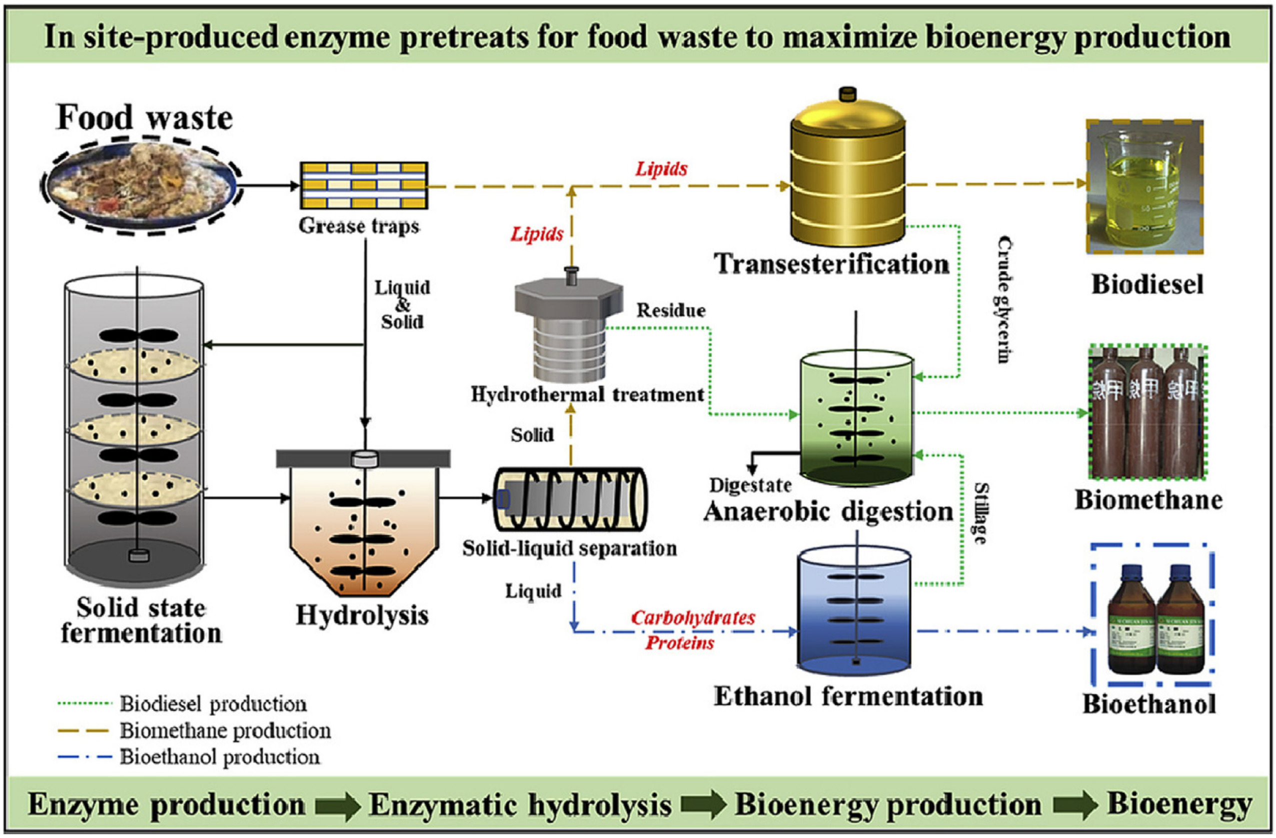


Fig. 11. Process of breakdown of a simple sugar molecule like glucose to intermediate products which further breakdown to produce alcohol (ethanol).

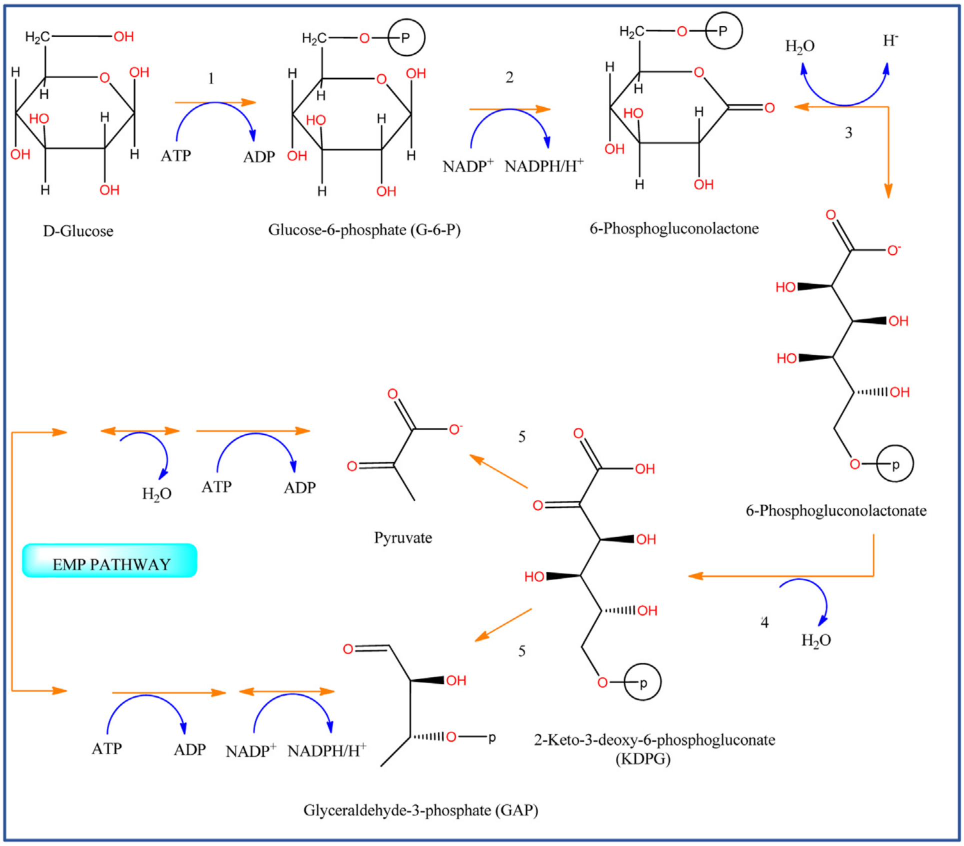


Fig. 12. Valorization of food waste to multiple bio-energies based on enzymatic pretreatment: A critical review and blueprint for the future. Reprinted with permission from ref. (Jadoun et al., 2020). Copyright 2018, Elsevier.

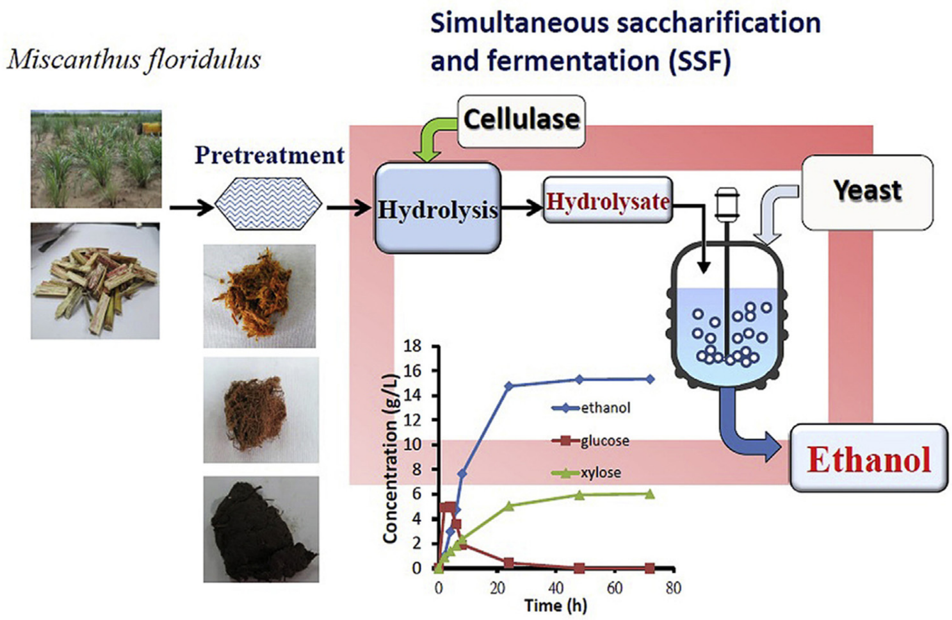


Fig. 13. Process of treating solid food waste by chemical hydrolysis followed by microbial growth to yield ethanol which could be utilized as a biofuel. Reprinted with permission from ref. (Aurore et al., 2009). Copyright 2016, Elsevier.

end products), that would hence result to be more pertinent to support the sustained growth and multiplication of the desired microorganisms in order to produce alcohol. This process is more commonly termed as “Saccharification”. Acid, Heat, and Enzymatic Hydrolysis are methods that are most commonly employed as pretreatments for such processes; Enzymatic hydrolysis being the most commonly practiced of all (which utilizes enzymes like amylases, amyloglucosidases, cellulases, lactase, invertases, pectinases, etc.) due to the cost-benefit that it incurs over the other processes in aspects of requiring milder conditions and not having any corrosion hazard hassles (Kádár et al., 2004; Mahmud et al., 2022).

The process of enzymatic hydrolysis of food wastes comprising complex carbohydrates predominantly involves the utilization of a mixture of enzymes like carbohydrates which is a concoction of a number of enzymes namely, beta-glucanase, arabinase, cellulase, hemicellulase, xylanase, glucoamylase, or other enzyme mixtures that might be composed of other additional enzymes like alpha-amylase, beta-amylase, etc. (enzymes selected on the basis of the composition of the food wastes) to breakdown the complex molecules into simpler fermentable sugars like maltose, amylose, glucose and fructose (Nieto-Veloza et al., 2021; Matsakas et al., 2014; Karmee and Lin, 2014; Demirbas, 2008; Yeh et al., 2016). Whilst having established the importance of sugars for the production of ethanol, too high concentrations of the same too might result to be deleterious for the process, thus food wastes that are observed to contain high levels of sugars in them are usually diluted to a concentration of 15% - 20% which is apt for fermentative procedures (Tareen et al., 2021). Studies also suggest that food wastes, prior to being subjected to enzymatic treatment for saccharification, should/has to be put through thermal pretreatment which leads to partial breakdown of the food wastes, thus improving product yield and purity (Tareen et al., 2021).

Fermentation of food wastes to produce bio-ethanol, as iterated hereinabove, can be done using various microorganisms. As per data acquired from various literature sources and studies conducted, there are predominantly two major operations that are adopted for this process of treating food wastes, these include SHF and SHF technique, the substrates are first pretreated with enzymes (like β-glucanase, arabinase, cellulase, hemicellulase, xylanase, glucoamylase, etc.) to undergo saccharification, and then once the intended/desired concentration of sugar has been attained, it is inoculated with the fermentative microorganisms which act on the sugar to break it down and yield alcohol (Fig. 13).

In a particular study conducted, the production of ethanol from fast-growing perennial C_4 grass Miscanthus floridulus was investigated by using a SSF route. M. floridulus biomass was analyzed and was found to be composed of 36.3% glucan, 22.8% hemicellulose, and 21.3% lignin (based on dried mass). Prior to being treated with SSF, harvested stems of M. floridulus were pre-treated separately by using alkali at room temperature, alkali treatment at 90 °C, steam explosion, and acid-catalyzed steam explosion. The delignification rates, as the study was conducted, were determined to be 73.7%, 61.5%, 42.7%, and 63.5%, respectively, by these four methods, and the hemicellulose removal rates were 51.5%, 85.1%, 70.5%, and 97.3%, respectively. The SSF of residual solids after various pre-treatments was performed with dried yeast (Saccharomyces cerevisiae) and cellulases by using 10% water-insoluble solids (WIS) of the pre-treated M. floridulus as the substrate. The extracted ethanol from SSF of M. floridulus after the 72 h were found to be 48.9 ± 3.5, 78.4 ± 1.0, 46.4 ± 0.1, and 69.0 ± 0.1% (w/w), respectively; however, the ethanol concentrations after 72-h SSF were determined to be 15.4 ± 1.1, 27.5 ± 0.3, 13.9 ± 0.1, and 30.8 ± 0.1 g/L, respectively. The overall results were concluded that the highest amount of ethanol (0.124 g/g-dried raw material) was generated from the dried raw material of M. floridulus after the alkaline pretreatment at 363 K. The acid-catalyzed steam explosion pre-treatment also resulted in a high ethanol yield (0.122 g/g-dried raw material). Pre-treatment resulting in high lignin and hemicellulose removal rates could make biomass more accessible to enzyme hydrolysis and lead to higher ethanol production (Tareen et al., 2021; da et al., 2022).

While on the flip side, the procedure for Simultaneous Saccharification and Fermentation (SSF) includes adding both the hydrolyzing enzymes and the fermentative microorganisms to the substrate at once (Nieto-Veloza et al., 2021). Suggestions made based on proven theoretical data state that SHF garners a better alcohol yield when compared to SSF as, in this process the enzymes fully get to act on the larger carbohydrates present in the food and then break them down into simple sugars which are then fermented separately (which gives a higher yield), unlike in SSF wherein the enzymes break down the carbohydrates to yield fermentable sugars which get used up instantly by the microbes that are already present the reaction environment (Zhang et al., 2013). Despite the higher yield that is observed in the process of SHF, it is considered to be comparatively slightly more inconvenient as it imposes the requirement of two separate tanks for the two processes of saccharification and fermentation to occur separately unlike SSF (Nieto-Veloza et al., 2021).

Observations also prove that mixed cultures give a better yield of alcohol instead of mono-cultures of bacteria or fungi (because different species are capable of fermenting different types of sugars, for example while *Saccharomyces cerevisiae* is capable of acting on glucose, it lacks the ability to hydrolyze lactose which in turn could be broken down by *Klyuveromyces* sp.) whilst also taking into account that it is highly imperative to have the composition of the food waste (that is being treated) analyzed correctly to help identify and select the appropriate microorganisms for inoculation (Nieto-Veloza et al., 2021; Zhang et al., 2013).

The activity of microorganisms depends on a multitude of factors that need to be perceived, analyzed, and controlled. Amongst these factors, the nutrient composition of the food waste is one of the most significant fermentation-rate determining conditions. As already mentioned before, a decent Carbohydrate content is most imperative for the process of fermentation to take place. Alongside of Carbohydrates, Proteins and Lipids are also usually present in all food items (their content and ratio varying greatly depending on the food waste type) which play a major role in affecting the fermentative activity. While in certain scenarios it has been observed that proteins and lipids enhance the rate of fermentation, in several cases it has also been recognized that they hamper the rate of fermentation by either hindering the saccharification process or thwarting the activity of the microorganisms acting on the waste food products; the content of inorganic compounds (minerals) also play a major role in determining the amount of bio-ethanol production (Patel et al., 2019; Spector, 2009; Patel et al., 2021). Hence, while adopting such practices of production of alcohol from food wastes, first their composition needs to be analyzed and consequently, the deduction and establishment pertaining to the species of microorganisms that would function the best in such conditions to give the best yield require attention, which is followed by thermal pretreatment and the main operations of either SHF or SSF to execute the fermentation process and finally retrieve alcohol/bio-ethanol. Novel methods that are being applied in recent years for obtaining/extracting ethanol from food wastes include the Vacuum Recovery Process for attaining a better yield from a given amount of raw material (Huang et al., 2015).

Alcohols like butanol, methyl butanol, propanol, are all gaining increasing attention for being used as biofuels, however, ethanol stands as the highest produced and the most used of all. Even though the idea of producing ethanol from food wastes and using it as a biofuel is an innovation that was made a long time ago, it is now being put to practice to a higher extent due to the increasing levels of food waste production (Kazemi Shariat Panahi et al., 2022). Inconveniences are majorly a branch out of the high magnitude of heterogenicity and composition variability that exists amongst food wastes, depending on its nature, season, geographical location, etc.

Whether the food wastes being treated to produce bio-ethanol are HFW, FPW, or derived from any other sources like retail, cafeterias, etc., it is mandatory for them to have a minimum solid content of 35% w/w to undergo the said process of fermentation to produce ethanol, and the substances that are commonly subjected to this process are wastes from potatoes, corn, cereals, and cereal products, sugarcane, bagasse, molasses, banana peel, and other fruit wastes, whey, etc. all of which are majorly rich in Carbohydrates (Kazemi Shariat Panahi et al., 2022). While ethanol stands as the most-used alcohol as a biofuel, butanol too has a major role to play, as it is produced by the fermentation of wastes acquired from dairy products, fruit products (like apple pomace), potatoes, whey, etc. and has proven to be an effective biofuel that bestows a superior quality over ethanol in terms of non-corrosiveness, non-hygroscopicity, and clarity. The production pathway of Butanol or Biobutanol is more-or-less the same as the ones that are followed for the synthesis of bioethanol from food wastes, except the enzymes used are different (Rana et al., 2021).

As fossil fuels continue to deplete and the predicament of food waste management persist, it has been recorded that the Energy Independence and Security Act of the United States has set a target and expects to achieve a production of 16 million gallons of cellulosic ethanol by the year 2022 as reported by Uçkun Kiran et al. (2014). Biofuels obtained from food waste biomass are categorized as Second-Generation biofuels which can be of various kinds, ranging from bioethanol to biogas and biomethane (Alam and Tanveer, 2020; Ringer et al., 2006; Alam and Tanveer, 2020; Vamvuka, 2011; Isah and Ozbay, 2020). Second Generation biofuels are considered to be cleaner when compared to the other kinds as this utilizes the thrown away materials to yield products that not just prevents the depletion of fossil fuels but also intercepts the occurrence of repercussions of food waste production.

4.1. Biodiesel from fish wastes

Saleh et al. (2022) investigated the production of fish protein hydrolysate from waste fish scraps and marine species such as horse mackerel, white croaker, flying fish, chub mackerel, and sardine using enzymatic treatment (Saleh et al., 2022). They attempted to demonstrate in the study that fish protein hydrolysate could be used as a cryoprotectant to prevent protein denaturation during storage of various other food products. According to the same study, collagen or keratin is found in livestock and fish waste, which can be converted to useful products via enzymic hydrolysis to produce a new physiologically functional food material. To prove the concept, yellowtail fishbone and swine skin, both high in collagen, were used as waste materials to produce protein hydrolysates and peptides and these hydrolysates could be of potential use as food ingredients (Singh et al., 2022). Various enzymes and bioactive peptides can be (and also have been) obtained from fish waste. In a study published in 2022, Desai et al. studied the auto-hydrolysis of waste fish viscera to peptone hydrolysates and found that it can be used in microbiological media to support growth and bacteriocin production by lactic acid bacteria (Desai et al., 2022). There are several alternatives uses for fish processing waste, including the production of fish mince, the use of fish gelatin, the use of fish as a source of nutraceutical ingredients, the production of fishmeal, and the potential use of fish and protein concentrates as a food source. The potential uses of fish waste are depicted in Table 1.

As a result of this still not being as a part of the mainstream vehicle market, electric cars are considered to be luxury items. According to the statistical values, it can be concluded that globally the total number of electric cars in use is less than 0.1% of the total number of cars in use. Electric cars are on the pathway of gaining massive popularity in recent years due to the fact that they are highly eco-friendly, do not produce any harmful emissions, and also have not been attributed to the cost of fuelling. The cumulative total number of electric cars that are in use in the year 2021 has been anticipated to be around the approximate figure of 10 million, the cost of each one of which is around 7–10 thousand dollars, that accounts for an amount that is significantly less than the amount that is usually spent on fuels (Gelmanova et al., 2018). Ergo, this as an alternative is considered to be highly preferable not just due to its high compliance with the environment, but also due to its economic friendliness. Going through data that have been documented over a range of literature, it can be concluded that over the past two decades researchers have been suggesting the use of biodiesel as an alternative to the diesel that is obtained from fossil fuels, as they are cleaner and also attribute to mitigated depletion of our natural non-renewable fossil fuel reserves. Biodiesel being a renewable source of energy that can be synthesized in large amounts, hence a scenario of the scarcity of the same is unlikely. Thus, the military and defense are now considering using biodiesel as a source of fuel as not only is it clean and supportive to the environment, it is also non-perishable, unlike the diesel that is obtained from fossil fuels.

Table 1
Potential use of fish wastes (Source; Ajay S. DesaiD et al. (2022), (Desai et al., 2022)).

Final waste product	Treatment	Physicochemical characteristics
Mainly heads, bones, skin, viscera, parsley	Heat treatment at 65 °C, 80 °C, 105 °C, 150 °C for 12 h to reduce the moisture content.	High source of minerals (58%), proteins (19%), and detection of toxic metals (As, Pb, Hg and Cd) at non-problematic concentrations
Raw fish oil	Filtration treatment with and without catalysts (e.g., iron oxide and calcium phosphate monobasic) and ozone treatment	Almost identical HHV (10,700 kcal//kg) and lower flash and pour points 37 °C and 16 °C, respectively, compared to commercial diesel fuel no production of sulfur oxides, lowered or no soot, polyaromatic and carbon dioxide emissions.
Fish skin, bone and fin	Collagen isolation	36 ± 54 Collagen recovery and denaturation temperatures of skin collagen (25 ± 26.5), bone collagen (29.5 ± 30.0) and in fin collagen (28.0 ± 29.1
Fish bone	Heat treatment of raw bone at 600 °C for 24 hr or 900 °C for 12 h	Better removal capacity and well-recrystalized hydroxyapatite at 600 °C, raw bone shoed lower activity and crystallinity bone sample heated at 900 °C showed devolved similar activity with raw bone and developed crystallinity of hydroxyapatite.

By means of adapting various chemical processes and/or techniques, biodiesel can be synthesized from sources like vegetable oils and animal fats. Biodiesel is basically a liquid bio fuel which is a mixture of long-chain monoalkylic esters that could be utilized as an alternative to diesel. "Diesel" is a source of fuel obtained from the rapidly depleting fossil fuel reserves which also leads to magnanimous amounts of pollution when burnt to provide energy (mostly to power engines), obligates us to look for cleaner, more sustainable, and renewable sources of energy or fuel as an alternative for the same. While we strive in the epoch of rapid industrialization that demands augmenting requirements for fossil fuel-based oils, "Biodiesel" being a fuel that is predominantly formulated from natural and renewable resources, possesses lower toxicity and incurs highly mitigated levels of air pollution (lower levels of Greenhouse Gas and other toxic emissions) when combusted to yield energy (Ringer et al., 2006). This makes biodiesel an exceedingly desirable fuel alternative to diesel which is both sustainable as well as renewable. As understood from various literature and studies (and iterated hereinabove), the major sources for the production of biodiesel are vegetable oils and animal fats; vegetable oils like corn, coconut, peanut, and rapeseed oil leading to the majority of the biodiesel production (that accounted for nearly 95% of the overall worldwide biodiesel production as per data recorded in the year 2018). Hence, even though there is the production of a cleaner source of fuel, it tags along with a major drawback of causing an imbalance in the food supply (when considered from a large-scale point of view) (Yuvaraj et al., 2019; Samat et al., 2018; Zhang et al., 2020).

To cater to such concerns, recent studies have suggested that the usage of wastes obtained from fish can be used as alternative raw materials for the production of biodiesel. As per data reported by the Food and Agriculture Organization of United Nations (FAO), the global rise in aquaculture production from the year 1990 to 2018 has been by a total of 527% which leads to extrapolating a calculated percentage numerical of 90% of the total global fish stocks being within biologically sustainable levels in the year 1990 that, with the course of time, reduced to 65.8% by the year 2017. According to records, the inflation in aquaculture production in the past three decades has been from 5 million tonnes to 63 million tonnes (Spector, 2009). The nations with the highest production of fish in the world are China (58.8 million tons), India (9.46 million tonnes), Indonesia (6.10 million tonnes), Peru (5.85 million tonnes), and the US (5.36 million tonnes), vide the statistics reported in the year 2020 (Fig. 14); India has been leading number two in terms of global fish production for several years due to its access to a huge coastline which has resulted in it being recorded to contribute nearly 5.43% of the Global fish production since the year 2014 (Samat et al., 2018; Zhang et al., 2020; Jaiswal et al., 2014; Kara et al., 2018). As per reviewed literature, in the year 2015, the cumulative global fish production was at a value of 166.8 million whilst the percentage of human consumption of the same food commodity has been calculated to be at 50%–70% (Alam and Tanveer, 2020; Vamvuka, 2011; Saleh et al., 2022; Singh et al., 2022). As mostly the muscle/flesh parts of fish are consumed, the remaining 30%–50% of the calculated wastage from the total fish captured is usually accounted by the non-edible parts which include the dorsal fins, head, viscera, tail, skin, liver, eyes, backbone, etc. which are considered to possess no value and are usually thrown away as garbage, hence forming the huge mass of industrial fish processing wastes which are commonly dumped into landfills that in turn possess a wide array of environmental detriments (as already iterated before) (Kara et al., 2018; Mohanty and Hauzoukim, 2020; Girish et al., 2017; Monteiro et al., 2018).

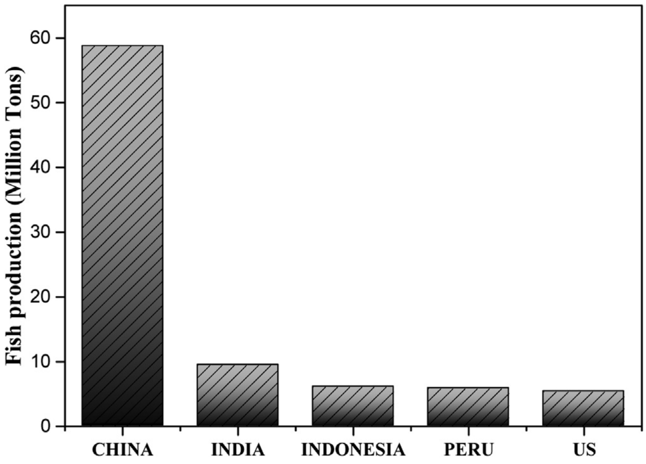
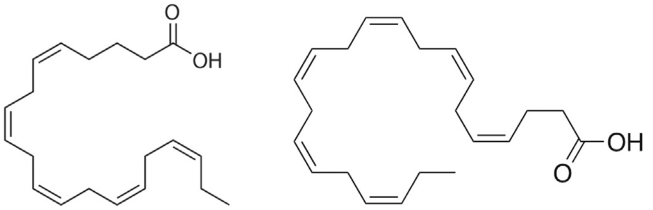


Fig. 14. Graphical representation of the countries that recorded to have the highest fish production (by capture and aquaculture) in the year 2020.

These solid wastes are generated at various levels in the value chain, starting from unintentional capturing to onboard handling, transport, processing, storage, retail, and consumption (Kara et al., 2018). Therefore, in order to pave pathways to make use of these magnanimous amounts of wastes, a plethora of valorization techniques have been brainstormed to treat the same to derive other useful products, thus transforming these wastes into economic resources (Singh et al., 2022). Such initiatives comprise of utilizing fish discards to yield Enzymes, Fish Protein Hydrolysates, Fish Meal, Fish Oil, Collagen and Gelatin production (Isah and Ozbay, 2020); off recently, it has also been observed that the oils extracted from the same wastes could be exploited as a source or a raw material for yielding biodiesel (Huang et al., 2015; Kazemi Shariat Panahi et al., 2022; Alam and Tanveer, 2020; Ringer et al., 2006). As per data recorded, fish oils have been observed to comprise more than 60 different fatty acids and the percentage of oil extracted from fish discards may vary from 1.4% to 40.1% depending on factors like the species of fish from which the wastes have been acquired (Singh et al.,



Scheme 2. Structures of Eicosapentanoic Acid (EPA) and Decosahexaenoic Acid (DHA).

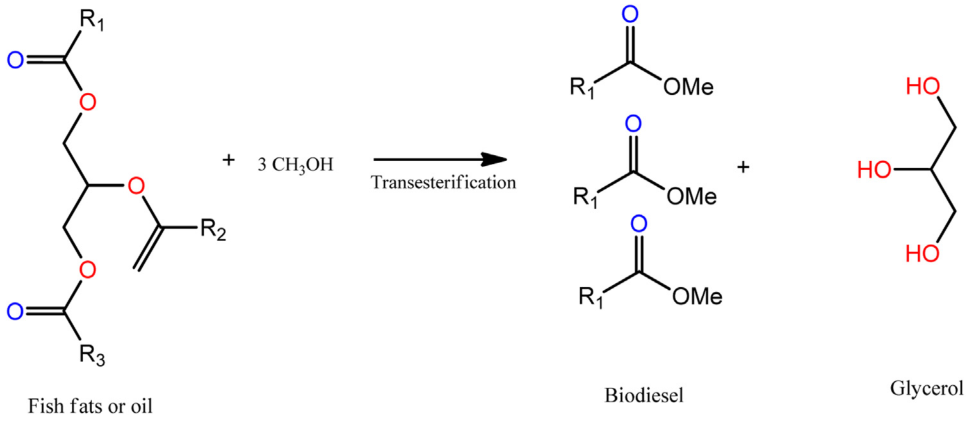
2022). Going by the aforementioned statistics, wastes (fish discards or bi-products) worth 50% of the total amount of fish captured are generated, 40% to 65% of which has been observed to constitute oil that is majorly (calculated up to 90%) enriched with omega-3 fatty acids (Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA)), which in turn could be used to produce biodiesel (Mohanty and Hauzoukim, 2020; Girish et al., 2017) and the structures of EPA and DHA was shown in Scheme 2.

As already mentioned before, a large mass of the total global production of biodiesel is essentially formulated from vegetable oils or animal fats which not just poses grave distress to the aspect of food security, but acquiring such raw materials accounts for approximately 60% to 70% of the total cost for biodiesel production (Girish et al., 2017). Hence, using waste materials such as fish discards and valorizing them to produce biodiesel significantly reduces the cost of raw materials and augments profitability and sustainability. The most generally practiced method for the production of biodiesel is the process of transesterification. There are majorly two methods of transesterification that are practiced, which include, Conventional Transesterification and in-situ Transesterification; the conventional method being of prime choice for application on oil extracted from fish wastes to produce biodiesel (Demirbas, 2008). While the in-situ method does not necessitate the extraction of oils (thus being a much cheaper alternative), the conventional method does, whilst also requiring additional refining processes like degumming, deacidification, decolorization, deodorization, dewaxing, etc., and yet this method is more preferable for production of biodiesel from fish wastes as, the fish waste biomass is significantly different from that of vegetable oils; the chemical composition of biodiesel produced from fish oil being such that, as reported by Kara, K. et al., it has been detected to have a higher heating value compared to the biodiesel produced from vegetable oils or animal fat as the acid value of waste fat from aquatic animals is much higher when compared to the latter (Kara et al., 2018).

The process of manufacturing biodiesel from aquatic food wastes initially involves the process of "extraction" which is usually performed using the Soxhlet. The chronology of procedures that are commonly followed includes pulverizing the waste materials to increase its overall surface area for the drying procedures that follow (in order to reduce the moisture content of the sample), post which the process of oil extraction is carried out by treating the sample with solvents like hexane, chloroform and methanol via methods of either Soxhlet Extraction or Microwave-assisted Lipid Extraction, in order to obtain the best yield possible (Huang et al., 2015; Kazemi Shariat Panahi et al., 2022; Alam and Tanveer, 2020; Ringer et al., 2006). Another method of lipid extraction from aquatic food wastes as documented by Yuvaraj, D. et al. suggested that treating the same with high temperatures of 100 °C in an expeller, wherein the biomass content of the wastes are segregated from the liquid fraction; the liquid fraction then is subjected to solvent extraction methods to efficiently obtain fish oils (Yuvaraj et al., 2019). These extracted crude fish waste lipids are then subjected to a transesterification process to yield Fatty Acid Methyl Esters (FAME) which is the main formulating component of biodiesel (Scheme 3). Hence, the fish oil obtained from the wastes is usually directly subjected to the process of transesterification (without any further treatment) in which the molar ratio of methanol (alcohol) to oil ranges from 6:1 to 12:1 at moderately high temperatures of 60°C-65°C with constant stirring uring magnetic stirrer bar in the presence of Potassium Hydroxide as a catalyst to obtain an optimal yield of Fatty Acid Methyl Esters (FAME), which is basically biodiesel, and glycerol (Alam and Tanveer, 2020). Purification procedures mainly involve centrifugation which aids in separating the biodiesel from the glycerol which is then followed by washing with hot water to remove traces of methanol and/or catalysts or glycerol (Monteiro et al., 2018). As per suggestions made in a recent study documented by Zhang, T et al., the biodiesel manufactured from freshwater fish waste oils has higher stability as they are richer in Saturated and Monounsaturated fatty acids unlike the oils obtained from marine fish wastes that have a higher Polyunsaturated Fatty Acid content that when utilized to synthesize biodiesel yields a product that possesses a desirable low-temperature tolerance (Zhang et al., 2020).

The most common treatment method for FFAs in industrial applications is acid esterification, which is the reaction of FFAs with an excess of methanol in the presence of sulphuric acid as a catalyst to produce biodiesel and water (Anwar et al., 2018). (Chai et al., 2014) used acid esterification to reduce the FFAs content from 5 to 0.5 wt percent at a temperature of 65 C, methanol to FFAs molar ratio of 40:1, and a catalyst of 10% H_2SO_4. (Kara et al., 2018) used 1.5 wt. percent H_2SO_4 at 60 °C for 3 h with methanol to oil molar ratio of 15: 1 and a stirring speed of 700 rpm. With a maximum conversion of 92.6 percent, the FFA content was reduced from 21 to 1.5 wt.%. (Abdullah et al., 2017) used an acid treatment method to reduce the FFA of palm oil by six weight percent at a concentration of aluminum catalyst ($Al_2(SO_4)_3.14H_2O$) for 3 h at 60 °C with a stirring rate of 300 rpm and methanol to oil molar ratio of 20:1. FFAs decreased from 36 to 0.82 wt percent. Sahar et al. (Sahar et al., 2018) investigated the effect of three acids (HCl, H_2SO_4, and H_3PO_4) on used cooking oil containing 2.75 wt.% FFAs. They discovered that H_2SO_4 was the most efficient catalyst because the FFA decreased from 2.75 to 0.33 wt. percent, resulting in an 88.8 percent conversion at 60 °C and a 2.5:1 Methanol to oil molar ratio.

Glycerolysis, on the other hand, can reduce the FFA of waste raw materials in the absence of acid or methanol (Felizardo et al., 2011). Glycerolysis is the process of converting FFA into glyceride molecules and water. The glyceride produced can be processed directly into biodiesel by a basic transesterification reaction. Therefore, FFA can be regarded as a raw material for producing valuable products such as monoglycerides, diglycerides, and triglycerides through the glycerolysis reaction. Gole and Gogate suggested that the glycerolysis reaction may be an effective method for removing FFA present in starting materials with high FFA content (Gole and Gogate, 2014). Mostafa et al. studied the effects of temperature, catalytic concentration, and molar ratio of glycerin to fatty acids on the efficiency of glycerolysis of fatty acids (Mostafa et al., 2013). They concluded that the optimal conditions for the glycerolysis reaction were a temperature of 195 °C, a 1: 1 molar ratio, a 0.3 wt.% zinc chloride catalyst, and a mixing rate of 500 rpm. They concluded that the optimal conditions for the glycerolysis reaction were a temperature of 195 °C., a 1: 1 molar ratio, a 0.3 wt.% zinc chloride catalyst, and a mixing rate of 500 rpm. They found that the purity of monoglycerides, diglycerides, and triglycerides was 99%. Anderson et al. studied high FFA glycerolysis in foam oils for biodiesel production (Anderson et al., 2016). They used a 1.8 wt.% zinc-based catalyst (Zn-Al_2O_3) in 60 min to reduce the FFA content from 86 to 1 wt.% at a temperature of 238 °C. Hermida et al. studied the synthesis of glycerolysis by glycerolysis of lauric acid (a fatty acid with a 12-carbon chain) (Hermida et al., 2011). An impetus of a propyl sulfonic corrosive functionalized SBA-15 mesoporous (HSO_3SBA-15) was utilized in the glycerolysis response. The change accomplished of FFAs to glycerides was almost all the way at a temperature of 160 °C, a molar proportion of oil to glycerol 4:1, and an impetus grouping of 5 wt%. Kombe et al. applied the low temperature glycerolysis cycle to reduce the FFAs content in the rough jatropha oil. They could diminish the FFAs of feedstock from 4.54 to 0.06 wt% that was appropriate for the base transesterification (Kombe, 2015). The ideal response conditions were at a response season of 73 min, a temperature



Scheme 3. Production of biodiesel from the fish oil by transesterification reaction.

of 65 ˚C, and 2.24 g/g glycerol to oil mass proportion. Elgharbawy et al. utilized unrefined glycerol and potassium hydroxide to lessen the FFAs in various high FFAs feedstocks. The feedstocks were two kinds of utilized cooking oil that had 7.6 and 11.97 wt% of FFAs (Elgharbawy et al., 2021). The treatment could effectively decrease the FFAs content under 1 wt% that was fitting for base impetus transesterification. Glycerolysis treatment enjoys numerous upper hands over corrosive esterification treatment as it keeps away from the utilization of corrosive impetuses and the inordinate of sum methanol (García Martín et al., 2019). In this manner, it does exclude balance or liquor evacuation steps. Glycerolysis is an extremely quick response that might happen in under 1 h while corrosive treatment is a sluggish response that might happen in multiple h. Notwithstanding, the glycerolysis cycle isn't pervasive in the biodiesel business regardless of its capacity to diminish high measures of FFAs. The justification for this is that most scientists utilized costly metallic impetuses at a high response temperature (Kombe et al., 2013). The detail process and economic analysis was provided in the supplementary material.

5. Limitations of the study

Food waste signifies a waste of land, water, energy, and other resources. Poor FW management has exaggerated severe difficulties affecting the economy, ecology, and society during the last decade (Luque and Du, 2010). As a result, it is clear that transitioning from a well-established fossil-based economy to a bioeconomy will be difficult in biorefinery industries (Dessie et al., 2020). The environmental impact caused by inadequate FW management practises such as FW burning, composting, using FW as feed for domesticated animals, and dumping FW in landfills should be minimized to the greatest extent practicable. As an alternative, efficient FW valorization can provide both FW management and energy generation in the form of biofuels. In terms of social sustainability, economic growth, and adverse environmental consequences, valorizing FWs through the deployment of integrated biorefinery models to biofuels production is a viable method (Isah & Ozbay, 2020) (Isah and Ozbay, 2020). Various pilot facilities and full-scale plants have recently been developed in various countries, with the primary focus being on the technical and economic sustainability of biofuel production using FW. Another problem is the FW's inconsistency in composition and structural intricacy. Various elements, such as the location of the FW, the time of choosing the FW, and the diverse dietary habits of various individuals, are some of the primary factors that greatly alter the type and content of FW (Karmee, 2016). Because FW is so complex, it requires extensive chemical analysis to determine its nutritional composition, water content, and other factors before it can be used as a feedstock in biorefinerie (Karmee, 2016). Although FW is a resource with no value, the costs and issues associated with its collection and transportation needs are serious considerations. Food manufacturers should develop a well-defined FW collection and transportation strategy in collaboration with diverse stakeholders, such as housing societies in major cities, suppliers, associations, and local governments in rural regions. To minimize waste diffusion and to assure the collection of FW from the place of its formation, each civilization should build a shared waste dumping facility. Various major restaurants and food parks can also be connected to small and medium-sized biorefineries to reduce the cost of FW transportation (Karmee, 2016). Based on the literature reports, due to the complex nature of food waste materials, the conversion of textile materials and biofuel is not an easy task to upgrade in an economical route. Therefore, extensive research studies are required in order to understand the molecular level of complex food waste products (especially fruit based waste samples). In addition to that, a well-structured and less expensive valorization strategies for FW to biofuels must be investigated.

6. Concluding remarks and future directions

Despite the rapidly rising costs of energy supply and waste disposal, as well as growing public concern about environmental quality, converting food waste to energy is becoming an environmentally friendly and economically appealing practice. The composition of food waste materials varies greatly depending on their source and use. The characteristics of food wastes are the high moisture content, which is favorable to thermal treatments such as incineration, pyrolysis, and gasification. However, it is still considered an energetically unfavorable process. As a result, the utilization of food waste in this area is fraught with difficulties due to the variability of waste compositions, which has a significant impact on the processes. In this perspective article, we have highlighted the complexities involved in addressing this critical issue in today's society, which involves government policies and regulations, stakeholders, industrial products, and most notably, consumers and the welfare of the society. Several strategies for valorizing food waste have been executed, including recycling, composting, and associated disciplines, but these cannot achieve sufficient processing of food waste residues, which are all of the limited value in all cases. Another biggest turmoils encountered in the already exceedingly soaring levels of food wastage was when the world found itself at a crossroads with the COVID-19 Pandemic. While the causes of food waste generation could be classified into several categories, including market food waste generators, wastes caused by infrastructure flaws, environmental factors, and retail and consumer patterns (Elkhalifa et al., 2019), the COVID-19 Pandemic was not identified as an environmental food waste driver because it was a human disease with no effect on food sources (Caldeira et al., 2019).

Despite the fact that it had no direct effect on the agricultural sector (did not affect crops or animals), conclusive data accumulated from statistical studies vouches for the immense surge in the levels of food wastage that was incurred during this period (Roe et al., 2021; Elginoz et al., 2020; Kalaiselvan et al., 2022; Schmidt et al., 2015; Vandermeersch et al., 2014; Stancu et al., 2016). While the patterns of food waste are normally determined by the economic state of nations (patterns differ depending on whether a country is developed, developing, or under-developed), when studying food waste after the start of the COVID-19 period, it could be stated that the patterns completely changed. With lockdowns being imposed practically all around the world and restaurants and hotels being shut, it was predominantly the household sector that generated the maximum amounts of food waste. Data extrapolated from statistical literature reports suggested that even during the COVID lockdown period in the US, the consumption pattern of food at restaurants and hotels had declined by more than 60%, while grocery food purchases had witnessed a spike of 70% (Uçkun Kiran et al., 2014). The pandemic-driven lockdowns and limitations led to people's panic-buying and stockpiling of food products, which, when coupled with the limited shelf life of certain food products and a lack of cooking skills, resulted in a massive increase in the levels of consumer-level food wastage. That, in turn, when observed in a bigger picture, created a dent in the food supply chain and therefore significantly affected the food security status in places where food scarcity was originally not even an issue.

Therefore, a multidisciplinary approach is required to achieve a zero-waste economy for a more sustainable bio-based society. Legislation, in conjunction with another critical approach (education), can have a significant impact on driving positive behavioral changes in society. The detailed literature reports stated in this manuscript clearly showed how to develop the sustainable management of food waste on an industrial scale. Most importantly, policymakers must play an active role in this scenario, especially with regard to transportation restrictions for bioresources, which can become an important feedstock in the future. It is possible that by increasing and publicizing the use of food waste for non-food applications such as chemicals, consumers will learn to overcome any behavioral inertia and enable a new supply chain for a future sustainable society as well. Alternatively, food waste can be converted to biofuel, and this material is a potential strategy to replace the existing petroleum-based products in the chemical industry. More particularly, plastic and petroleum-based polymers significantly suffer due to their non-degradable nature, which produces high levels of polluting natural resources. Therefore, extensive research studies have been carried out in textile materials to produce high-quality nano fabric materials. According to literature reports, only a few food waste materials have been successfully employed due to the more complex nature of food waste and the process development. Hence, systematic multi-disciplinary approaches are required to manage food waste materials into valuable chemicals to meet the direct public domain. Deriving conclusions from the overall study that was conducted by gathering information from a wide range of referral articles and literary works, what can be connoted is that, the major amounts of food wastage occur from developed countries due to their higher purchasing power and food being available in excess, while on the other hand, nations that are either developing or under-developed, face a paramount shortage of food. Food wastages have also been observed and concluded to have crucial detrimental effects on the environment and the economy. For every food item that is grown, cultivated and yielded, wastages of any kind lead to the loss of the initial investment that is made.

In order to cater to this issue, as elucidated in the aforementioned review, various methods of yielding fabric from food wastes and producing biofuels of various kinds from food items, etc. are techniques that are being employed to valorize these wastages so that these could be utilized to produce other new products which in turn leads to the usage of the food products or the food-related products that would otherwise have been wasted, hence, preventing losses and enhancing the economy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hazadv.2023.100266.

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