https://doi.org/ 10.48047/AFJBS.6.5.2024.11163-11186

African Journal of Biological Sciences

Food Waste Valorisation: A Pathway to Sustainable Productivity and Environmental Stewardship

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Article History
Volume 6, Issue 5, 2024
Received: 22 May 2024
Accepted: 03 Jun 2024
doi: *10.48047/AFJBS.6.5.2024.11163-11186*

ABSTRACT

The achievement of sustainable development in the circular economy relies solely on using modern technologies to enhance food waste. This technique can simultaneously tackle the resource and environmental problems arising from capital depletion and greenhouse gas generation. The integrated biorefinery technique enables the synthesis of diverse chemicals, biofuels, and materials from food scraps. This enhances the bioeconomy and aids in developing eco-friendly and sustainable approaches to material production, thereby contributing to achieving environmentally-friendly objectives. A waste biorefinery can strategically produce a high-value product by maximising the use of materials and resources and minimising or eliminating adverse environmental effects. Using food waste has prospects for economic growth, as waste can be an unprocessed product for bioprocesses that generate biodegradable products from organic sources. This report concisely summarises the pros and cons of many sophisticated methods used to convert food waste into valuable commodities. It also examines how food waste might contribute to generating revenue as value-added products.

KEYWORDS: *Sustainable development, Valorisation, biorefinery, bioprocess*

1. INTRODUCTION

The most challenging issue of today is the environmental problem, where the rapidly growing world population consumes more food and other basic needs, which tends to bulk accumulation of waste biomass. This problem is the root cause of the increasing cost of waste disposal. The United Nations Food and Agricultural Organization predicts that one-third of the food produced was lost in the harvesting and supply chain, contributing to an annual loss of USD 1 trillion (Tsegaye et al., 2021). The most generated biowaste around the world is food waste. According to the FAO, the amount of food suitable for human consumption decreases as it moves through the various supply chain stages. Nearly one-third of the total food is wasted each year, increasing the cost of the world economy by about $750 billion or INR 47 lakh crore. From 2005 to 2025, the range of food waste projected was around 278 to 416 million tonnes (Paritosh et al. 2017), India is ranked eighth in terms of overall food wastage, with the Russian Federation being the country with the highest food waste. The production of food waste has a substantial influence on the emission of Greenhouse gases (Venkata Mohan et al., 2017). Engaging in the many stages of food manufacturing, transportation, preservation, transformation, shipping, or consumption within the economy generates significant food waste. One solution is to categorize edible and non-edible food waste before discarding it. Strict production and consumption precautions can reduce edible food waste, and waste management policies help reduce non-edible food waste.

Agricultural waste in the food sector, which is abundant in proteins, carbs, and lipids, serves as a favourable environment for the growth of numerous microorganisms. The occurrence of dioxins during food waste generation is attributed to the presence of nutrients and a high level of moisture in the food waste, resulting in a range of health and environmental problems. Researchers are diligently striving to discover methods to transform garbage into high-value items (Bilal and Iqbal., 2019; Ong et al.,2018; Sindhu et al.,2020).

Implementing the circular bioeconomy idea provides an economical way to mitigate the adverse consequences of food waste disposal. The main goal of the circular economy is to minimise ecological, social, and financial expenses while enhancing economic competitiveness and reducing poverty and hunger. The economy aims to harness renewable biological resources for producing valuable commodities, including bioactive compounds, bioplastics, and bioenergy. Furthermore, it aims to conserve the value of these resources for an extended duration to minimise waste creation and decrease greenhouse gas release (Rathna et al., 2018; Mak et al., 2020).

The concept of a circular bioeconomy is a promising option for reducing the economic consequences of the discharge of food debris. The main goal of the circular economy is to minimise ecological, cultural, and industrial expenses while enhancing economic competitiveness and addressing food insecurity and poverty. The economy enables the efficient utilisation of renewable biological resources to produce valuable commodities, including bioactive chemicals, bioplastics, biopolymers, and bioenergy. Additionally, its objective is to save resources for a prolonged duration, limit the production of waste, and decrease the release of greenhouse gas emissions (Rathna et al., 2018; Mak et al., 2020).

2. THE ECONOMICS OF FOOD WASTE

The food distribution network leads to the annual loss of around 89 million tonnes of food, excluding agricultural output (Monier et al., 2010). Food loss or waste occurs throughout the supply chain, starting with primary production and ending with household consumption. The leading causes of food loss and waste in developing or economically deprived countries are constrained harvesting methods, inadequate storage and cooling infrastructure, unfavourable weather conditions, inadequate facilities, and insufficient preparation, packing, and distribution systems. In developed or affluent nations, a shortage in the later stages of the food supply chain leads to more accumulated food waste (Grethe et al., 2011). The FAO reports that households in developed nations waste a far greater quantity of food in comparison to those in poor countries. According to the FAO, individuals in developed nations discard an estimated 80 kg of produce annually. (Monier et al., 2010).

The act of wasting food has emerged as an ethical concern affecting nearly one billion individuals who experience starvation (FAO, 2010Food wastage is considered an ethical concern for two primary reasons. Firstly, the nutrients that are wasted could have been used to alleviate hunger problems in impoverished nations. Secondly, the wastage of resources has detrimental effects on the well-being of humans, animals, plants, and ecosystems. Food waste results in the depletion of essential nutrients required for survival, along with the consumption of scarce resources like water, energy, and agricultural land that have been utilised in the production, processing, and transportation of food. Efficiently managing food will not only help conserve resources but also lead to a reduction in agricultural emissions. Scientists have found that fruits, veggies, and bread items make up the majority of food waste. However, beef products are the most significant contributors to resource use and greenhouse gas emissions per kilogramme compared to other meat products (FAO, 2013; Fritsche and Eberle, 2007; Göbel et al., 2012; Lee and Willis, 2010; Noleppa and von Witzke, 2012; Venkat, 2011).

3. CONSEQUENCES OF FOOD WASTE

Food waste is a worldwide problem that has negative effects on our food system, resulting in harm to the ecosystem, biological diversity, and natural assets, while also causing economic and social expenses to rise. Minimising food loss and waste is a pressing and crucial measure in the endeavour to establish more sustainable food systems. Food waste leads to the degradation of all resources linked to manufacturing, transportation, and supply of food. Food waste is commonly categorised according to its environmental, economic, and social impacts, as depicted in Figure 1.

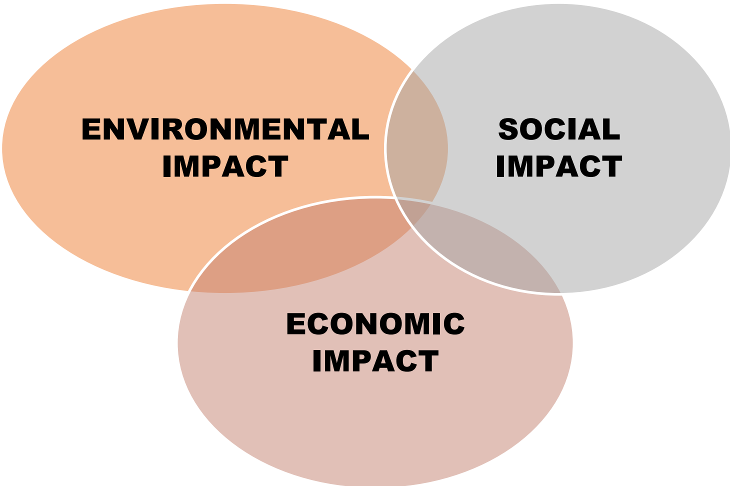

Fig 1. Consequences of food waste

3.1 ENVIRONMENTAL IMPACTS

When uneaten and discarded food components are disposed of in landfills, these practices have adverse environmental effects and contribute to global warming. The primary factor is centred on the release of methane and the depletion of resources. Food waste discarded in landfills undergoes decomposition, resulting in the production of methane gas. Methane, a dangerous air pollutant and greenhouse gas, diminishes the available oxygen in the air when produced in significant quantities. Methane exhibits approximately 25 times greater heat-trapping capabilities than carbon dioxide. The FAO has initiated the Food Wastage Footprint (FWF) project, which showcases that prioritising the reduction of food waste is a rational approach to establish more sustainable methods of food production and consumption. Additionally, it offers a comprehensive assessment of the environmental impact throughout the entire food supply chain on a worldwide scale.

Another environmental impact, in addition to methane emissions, is the transportation of food across greater distances and its subsequent disposal. Agriculture necessitates substantial resources, including water, energy, and land. Wasted food signifies the improper consumption of resources, which is often referred to as resource depletion. These activities demand a substantial amount of fuel, which is greatly influenced by the emissions produced by the exhaust gases over an extended period of time (Golian et al., 2016). Wasted food signifies an inefficient utilisation of water resources. Environmental organisations, policymakers, analysts, and researchers have all become increasingly concerned with food waste in recent decades.

3.2 ECONOMIC IMPACTS

The utilisation of resources is determined not only by the technological processes involved in production, distribution, and redistribution, but also by the scale of final consumption relative to the size of the population. It is evident that every individual consumer bears responsibility for the environmental consequences. Food waste leads to increased food costs for consumers. When food is wasted at the retail or consumer level, individuals and households basically lose the money they spent on acquiring that food.

For food businesses, food waste directly affects their profitability (food loss and food waste.,2019). Whether it’s due to overproduction, unsold inventory, or discarded products, food waste translates into lost revenue and increased disposal costs. Food waste along the supply chain leads to inefficiencies and increased costs for businesses. Farmers may experience losses due to surplus crops left unharvested or rejected by buyers for cosmetic reasons, and retailers may discard products close to their expiration dates, contributing to significant financial losses. Governments and organizations implementing policies and initiatives to reduce food waste can also create economic benefits by saving resources, reducing disposal costs, and alleviating pressures on food prices. Ultimately, reducing food waste is an economic opportunity that can positively impact various sectors and contribute to a more sustainable future.

3.3 SOCIAL IMPACTS

While food is being wasted, many people worldwide suffer from food insecurity and hunger. The amount of food wasted could otherwise be redirected to those in need, helping to alleviate hunger and malnutrition. When food is wasted, it's not just about the lost calories but also the lost nutrients. A balanced diet is essential for good health, and when food is wasted, it affects the ability of individuals and families, especially those with limited resources, to access nutritious meals. The main problem of developing country is one part of the country is rich in access to food and the other lacks the opportunity to buy enough quality of food. The disparity between wasted food and those who lack access to it raises ethical questions. Wasting food while others go hungry highlights societal inequalities and challenges the fairness of resource distribution.

4. INNOVATIVE TECHNOLOGIES FOR FOOD WASTE VALORISATION

There are several innovative techniques for food waste valorisation, aimed at minimizing waste and creating value from discarded food. Some of the popularly used techniques are, laser ablation, electro-technologies, ultrasound, high hydrostatic pressure, nanotechnology and radio frequency drying.

a) Lase ablation is a surface decontamination technique used for removing the contaminated layers from food products without disturbing its quality. This technique is widely used to extract various flavours by targeting certain parts of food and increasing its heat and mass transfer rates steadily. Lase ablation improves digestibility and increases shelf-life time s (Panchev, Kirtchev, & Dimitrovet al.,2011).
b) Electro-technologies are emerging techniques of converting food into valuable product and energy. These include techniques like pulsed electric fields, non-pulsed electric fields, high voltage electrical discharges, plasma treatment etc… Pulsed electric field are used to inactivate the microorganism in liquid food which enhances the extraction of food additives and supplements from the fruits and vegetables (Gabric et al., 2018). Non-pulsed electric field uses either low of controlled temperature for extraction of essential oils from biomass. This method is also called ohmic heating as it is assisted with the conventional distillation s (Barba, Koubaa, do Prado-Silva, Orlien, & Sant'Anaet al.,2017; Knorr et al., 2011).
c) Ultrasound technique gains attention due to its reduced energy consumption. Low frequency ultrasound waves are used for microbial inactivation preventing the early spoilage of food items (Zhu et al., 2017). Ultrasound waves with higher frequency disrupts cell structure resulting the breakdown of organic compounds triggering anaerobic digestion to facilitate biogas production.
d) High Hydrostatic Pressure (HHP) involves compression of food materials under high pressure(1000MPa) to pasteurize and inactivate bacterial spores (Barba et al., 2017).

This method preserves the nutritive quality of food, which helps to repurpose the food items into nutritional supplements and extract bioactive compounds.

e) Nanotechnology offers innovative ways to tackle food waste valorisation by providing tools to modify and enhance food waste at the nanoscale level. Packaging food by nanomaterials prevents the augmentation of moisture to increase the shelf-life time. Nano-encapsulation allows for the encapsulation of bioactive compounds extracted from food waste, protecting them from degradation and enhancing their stability (Vincekovic et al., 2017). These compounds can be utilized in functional foods, supplements, or pharmaceuticals. The nano-delivery systems can enhance bioavailability and stability, enabling their incorporation into various food and beverage products.

FEED STOCK	BIOPROCESS	REACTOR TYPE	PRODUCT	YIELD	REFERENCE
Food waste	Dark fermentation	Lab-scale fermenter	H_2	1.25 mol/mol of glucose	Jung et al.,2021
Orange peel waste	Ensiling + centrifugation	Freezing + thawing	Bioethanol	120 g/kg TS	Fazzino et al., 2021
Waste cooking oil	Immobilization of lipase	Hydrolysis and esterification	Biodiesel	91.8% fatty acid	Vescovi, V et al.,2016
Brewery waste	Lactic acid fermentation	Flask-500 mL, incubator 37 ◦C, pH 6.5, 100 rpm, *Lactobacillus delbrueckii*	Protease	145 U/g	dos Santos Mathias et al.,2017
Gac peel	Microwave assisted extraction	120 W, 25 min	Carotenoid and Antioxidant	262 mg/100 g and 716 μmol/L TE/100 g	Chuyen.,et al 2018
Grape stalk	Solvent extraction		Phenols	4.44 g/kg dry solid	Leite.,et al 2019
Pastry and cake waste	Hydrolysis and fermentation	Lab-scale fermenter	Succinic acid	(96–98% purity) 0.35–0.28 g/g of substrate	Zhang.,et al 2013

5. GREENER MATERIAL PRODUCTION

Table.1 Products from bio-waste refinery

Food waste valorisation is a programme aimed at creating sustainable environmental practices by developing goods with added value. Advanced technologies and techniques such as ultrasound, microwave, and microbial systems can be utilised to convert food waste into beneficial chemicals and

CO_2 through a process called biorefinery. **Table.1** provides instances of this transformation (Zabaniotou and Kamaterou, 2019). Nevertheless, it is crucial to recognise that there are specific difficulties and constraints linked to this approach. For example, the release of greenhouse gases has encouraged academics to prioritise seeking for potential solutions to address these problems. (Ong et al., 2018). In order to extract certain components from food waste, certain optimal circumstances must be met. The requirements involve the utilisation of ecologically sustainable solvents, the facilitation of solvent retrieval, and the assurance of heat-sensitive component safety in waste disposal. However, it is not always possible to fulfil all of these requirements in the process of food waste valorisation. Researchers are currently operating under the zero waste paradigm in order to enhance the economic value of the nation. The process of food waste valorisation faces additional expenses for transportation and electricity, hence diminishing its profitability. For instance, the utilisation of food waste in the manufacturing of bioplastic presents some constraints such as raised processing expenses, limited stability, potential toxicity, compromised mechanical qualities, and reduced tensile strength within the food packaging sector. In order to create a food waste derived product without any obstacles, it is necessary to overcome the problems.

6. WASTE BIOREFINERY: A TOOL FOR SUSTAINABILITY

A waste biorefinery is a facility that utilizes various biological processes to convert organic waste materials into valuable products, such as biofuels, biochemicals, and other bioproducts. Contrasting traditional refineries that depend on fossil fuels, waste biorefineries focus on the sustainable and environmentally friendly conversion of biomass or waste materials. This method concentrates on the principle of circular economy where, maximum value from the materials are obtained by considering waste as a resource rather than a problem. Biorefinery reduces the dependence on non-renewable resources, reducing environmental pollution, and promoting a more sustainable approach to resource management.

Disposing of food waste by dumping it onto bare land is useless, since the creation of food requires a significant amount of energy and nutrients. Food waste might be considered a viable raw resource due to its composition, which typically consists of 30-60% carbohydrates, 5-10% proteins, and 10-40% lipids (w/w). Transforming food waste or by-products into a more valuable product makes a greater contribution to the food supply chain. This supports the circular economy framework, in which valuable materials that were previously considered

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waste are reintroduced into the supply chain to produce new products. Food waste is recycled by different bioprocess to obtain various useful products (**Fig.2**).

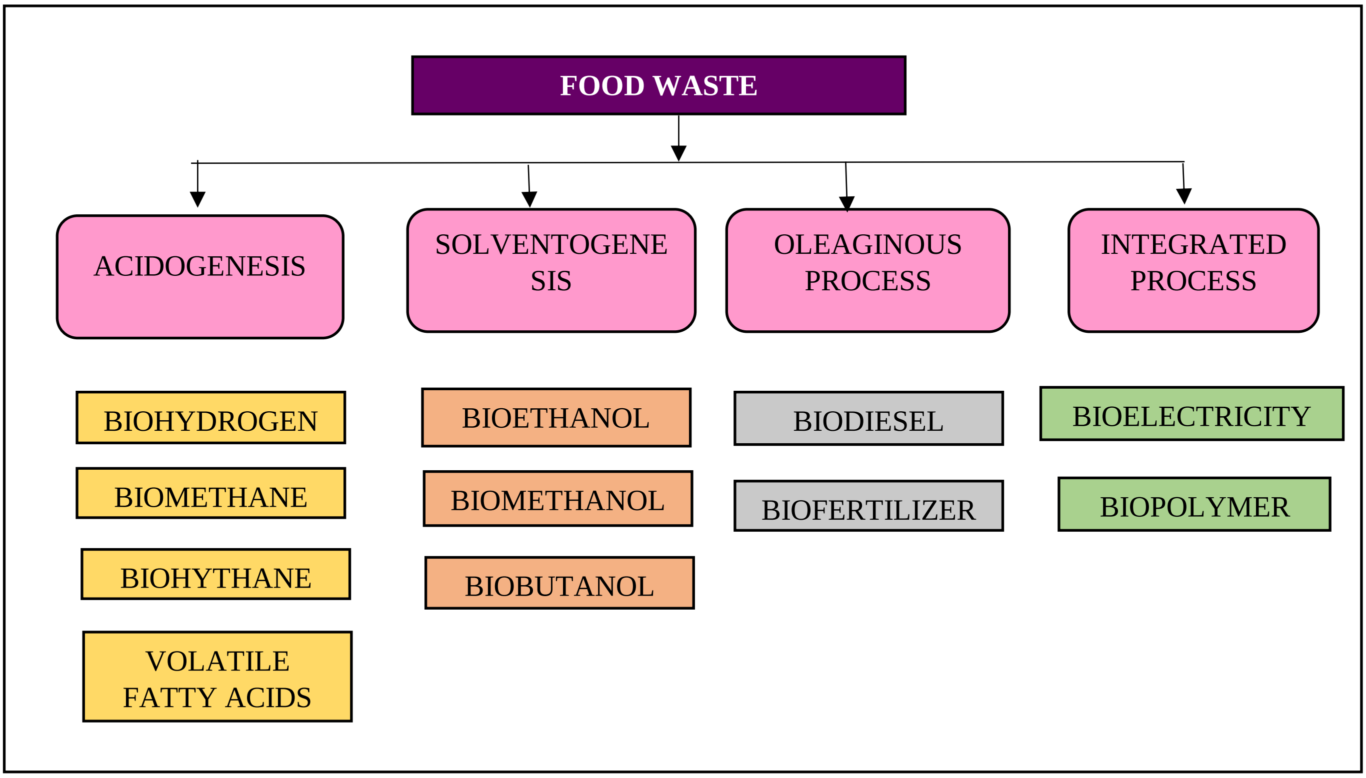

Fig.2 Diagram showing various bioprocess for food valorisation

6.1 ACIDOGENESIS

Acidogenesis is the conversion of biological organic compounds into numerous bio-based products like biohydrogen (H2), Biohythane (Mixture of CH_4 and H_2) and other trace elements.(Venkata Mohan et al., 2016).The acidogenesis depends on the quantity and composition of carboxylic acid present during the reaction and its consumption pattern. The calculation of production/consumption rates of carboxylic acids can be done using the formula

Production rate of carboxylic acids:

$$(PR_{CA}) = (VFA_{MAX} - VFA_{INT})/T_{PROD}$$

Consumption rate of carboxylic acids:

$$(CR_{CA}) = (VFA_{DROP} - VFA_{MAX})/T_{DROP}$$

where,

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VFA_{MAX} represents the maximum Volatile Fatty Acid (VFA)concentration (g/l),

VFA_{INT} is the initial VFA concentration (g/l),

VFA_{DROP} denotes the drop/consumption in VFA concentration due to its consumption (g/l),

T_{PROD} represents fermentation time in hours and T_{DROP} represents VFA consumption time (hours). (Sarkar et al., 2016)

Acidogenesis also involves the investigation of degree of acidification. Degree of acidification (DOA) means calculating the amount of acid/ammonia nitrogen in the sample. Degree of acidification (DOA) represents the extent of acidification achieved due to the production of carboxylic acids in relation to substrate (as COD) degradation,

Degree of acidification: (DOA)% = $(S_f / S_i) \times 100$

where, S_i represents the initial substrate concentration measured in COD as mg/l and S_f is the net VFA concentration (final - initial) expressed as theoretical equivalents of COD(Venkata Mohan et al., 2016)

6.2 SOLVENTOGENESIS

Solventogenesis refers to the production of commercially used solvents, primarily by ABE (Acetone Butanol Ethanol) fermentation. It has been widely favoured because to its cost-effective efficiency and higher protein content. During the period of rapid growth, the acidogenesis phase commences and coincides with the alterations in the internal microenvironment resulting from the accumulation of butyrate and acetate. As a result, Adenosine triphosphate is generated without the presence of oxygen, which helps maintain a balance in the utilisation of reducing agents, namely the ratio of reduced to oxidised nicotinamide adenine dinucleotide (phosphate) ($NAD(P)H/NAD(P)^+$). The presence of an acidic environment and elevated levels of ATP and $NAD(P)H/NAD(P)^+$ stimulate the production of solventogenic enzymes, leading to a swift transition from the acidogenesis phase to the solventogenesis phase in the later stages of acidogenesis. The solventogenesis enzyme, such as the one found in Clostridium sp-strain HN_4, has demonstrated a noteworthy ability to enhance the production of biobutanol from food waste. Other cues that can activate the gene network include the synthesis of compounds such as butyryl-phosphate and formic acid. These stressors induce alterations in cellular processes that contribute to the generation of solvents. Therefore, acetate and butyrate are recycled to generate coenzyme A (CoA) derivatives, specifically acetyl-CoA and butyryl-CoA. This process involves the use of acetyl-CoA as the provider of CoA, as well as the use of ethanol and butanol, which are produced through various processes and are limited by the availability of reducing equivalents (Patakova et al., 2019). The process of converting food waste (FW) into bio-solvents by biological means can effectively decrease organic pollution by 70-75%, provide energy, and attain self-sufficiency (Li et al., 2020).

6.3 OLEAGINOUS METABOLISM

Presently, there is a notable surge in the demand for triacylglycerols (TAGs) in the market, mostly due to their extensive variety of applications in many industrial sectors. TAGs have diverse applications, such as the production of biodiesel and numerous valuable commodities. The specific application depends on the composition of the TAGs. Microbial lipids have multiple applications, including their use in chemical processes and their utilisation for the production of animal feed components. Vegetable oils and animal fat are the main sources of TAGs. Nevertheless, it is impractical to depend only on these sources because of the substantial land area required for cultivation and the competition with food production. Regardless of geographical location, seasonal fluctuations, and surroundings, TAG can be easily produced using efficient and controllable techniques, demonstrating a similar composition to vegetable oil. Oleaginous bacteria possess an exceptional ability to amass lipids, specifically triacylglycerols (TAGs), which can constitute over 20% and even up to 70% of their dry cell mass. These lipids are referred to as Single Cell Oils (SCOs). Lipid production can be influenced by multiple parameters, includes pH, oxygen concentration, temperature, and the availability of phosphate and sulphate. The C/N ratio in the growth media is the most important element. When nitrogen levels are low and sugar content is high (resulting in a high C/N ratio), the flow of carbon is usually shifted towards the synthesis of fatty acids. The process commences with the conversion of acetyl-CoA into citric acid. Specific oily species have undergone genetic modification to bypass strict metabolic regulatory systems, broaden their range of usable chemicals, and modify their fatty acid composition. These alterations are especially noteworthy considering the increasing significance of microbial oils production. Specific strains of lipid-producing yeasts are employed to grow various forms of carbon, including those present in garbage dumps of the agro-food industry. Yeast-based techniques have been employed to extract oils from various forms of lignocellulosic waste, such as desiccated sorghum stalks, cardon stalks, trash generated by oil palm enterprises, assorted vegetable waste, and cheese whey. Presently, the production of agro-food wastes is steadily escalating as a result of the explosive rise of global economies and population. Waste management is a growing concern, leading to the idea that waste can be converted into a profitable resource (Donzella et al., 2022).

7. ECONOMIC GROWTH AND OPPORTUNITIES

Food waste valorisation simply means converting food waste into a valuable product, thereby creating economic opportunities and contributing to sustainable development. The apparent economic growth can be identified from various factors such as resource recovery, bioproducts and biochemicals, waste management, job opportunities, space for innovations by creating an eco-friendly environment (**Fig.3**).

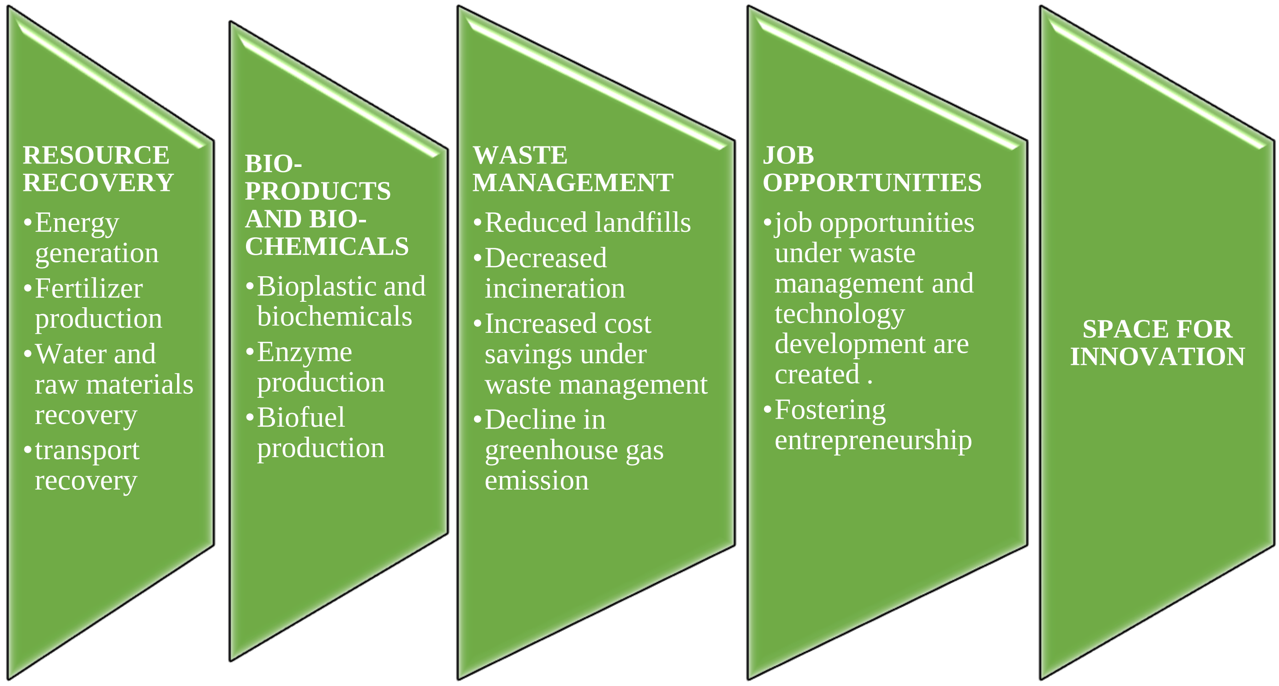

Fig.3 Economic growth and opportunities

8. TURNING FOOD WASTE INTO VALUE-ADDED PRODUCTS

Depletion of fossil fuels and environmental pollution are the major setbacks solved from turning food waste into valuable products. By utilizing food waste to create valuable products(**Fig.4**) and resources, the circular bioeconomy helps to reduce environmental pollution, conserve natural resources, and promote sustainable economic growth. However it is essential to ensure that these processes are conducted responsibly, considering potential environmental and social impacts, to achieve a truly sustainable circular bioeconomy.(Leong et al., 2021)

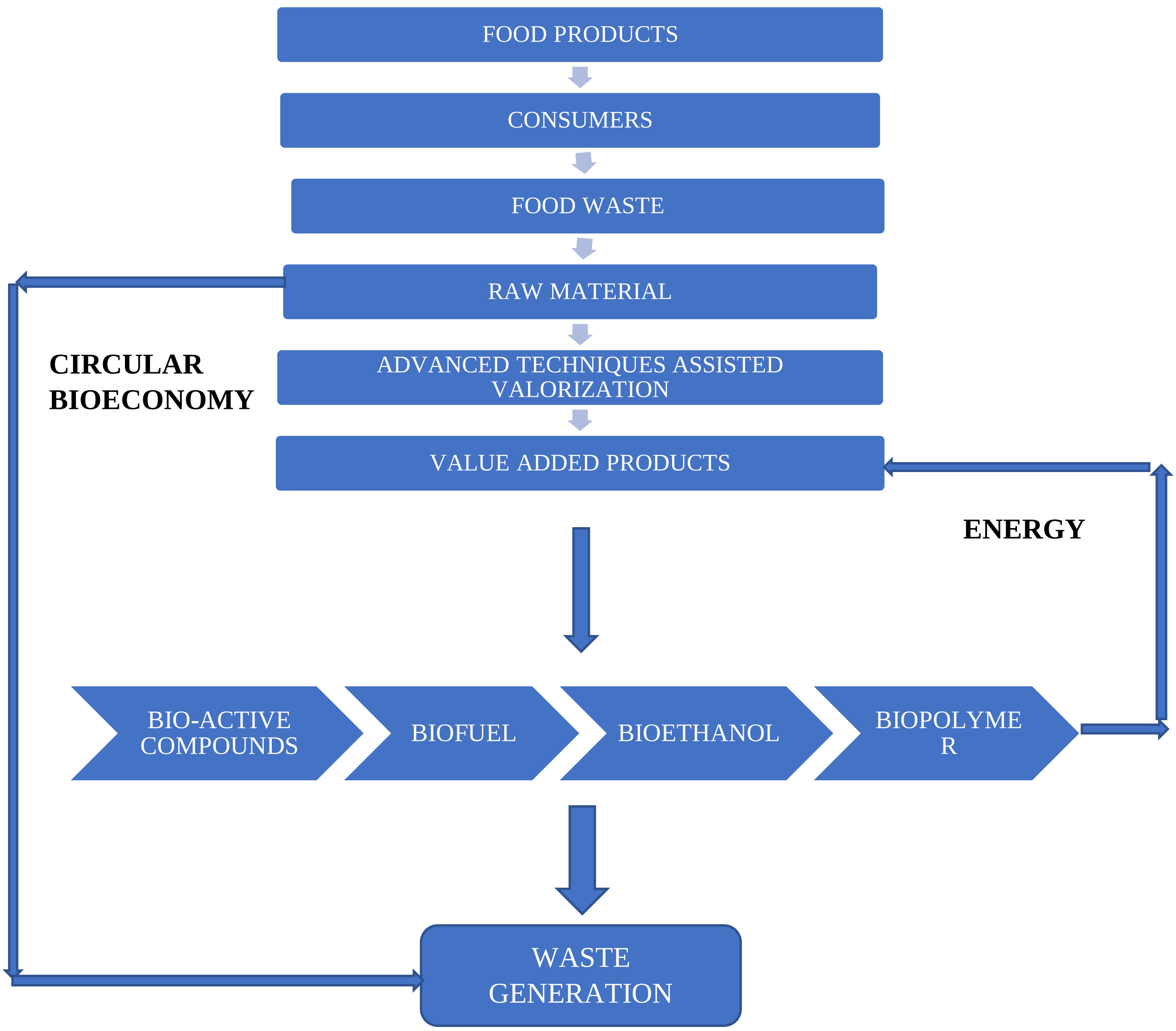

Fig 4. A simple diagram for food waste to value added products and its linkage

8.1 BIO ACTIVE COMPOUNDS

The FAO (Food Administration Organization) reports that around 1.3 billion tons of food waste is generated every year globally (Sharma et al., 2021). Food waste implies the best replacement for synthetic chemicals as it has various opportunities to nutraceutical industries. Plants are known to be the valuable reservoir of bioactive compounds which is substituted with synthetic medicines along with a chemically stable formulation and more effective towards its action (Ullah et al., 2016; Sharma et al., 2020a). These bioactive components are seen in our day-to-day life intakes such as fruits, vegetables, grains and meat sources with health promoting benefits and are rich in extra nutritional values among the food items. Bioactive compounds are composed of possess antioxidant, cardio protective, anti-cancerous, anti-inflammatory, immuno-modulatory, and, anti-microbial properties as pharmaceutical drugs (Jimenez-Lopez et al., 2020).

Some of the examples like skin of grapes is an absolute by product from vineyard and it is enriched with resveratrol (3,5,4′ -trihydroxystilbene). Resveratrol aids in hepatic detoxification and it build up anti-inflammatory response of NF-κβ cells to reduce inflammatory responses, free radicals scavenging activity, cytochromes P-450 enzyme activity enhancement. It also lessens the cellular damage, genomic mutations and mitochondrial dysfunctions (Ortega and Campos, 2019).

8.2 BIOFUELS

Biofuels has the potential to reduce the world's dependency on limited fossil fuel supply. Oil takes a minimum of 50 years to form though is burned in combustion engines in a matter of seconds. In comparison, matter sourced from crops such as corn and soyabeans are regularly replenished. This makes biofuel a renewable source of energy that doesn't drain the world's natural resources. And one of the eco-friendly and economic approach to circular bioeconomy is the production of biofuel using food waste as a substrate (Aswin Jeno et al., 2021). On an average food waste contains plenty of nutrients including carbohydrates (35.5–69%), proteins (3.9–21.9%), lipids (6–30% dry matter), and organic acids. Biofuel is obtained by recovering and decomposing available fermentable sugar and free amino nitrogen with the help of microorganisms (Patel et al., 2019). The biofuel produced are of various kinds such as bioethanol, biohydrogen, butanol, biodiesel, biohythane, and biomethane(Sharma et al., 2021). In current decades bioethanol and biodiesel are most commonly produced from food waste. Sources such as sugar cane, bagasse, sugar beet, grain, switchgrass, barley, potatoes, molasses, corn, stover, wheat and many other sources rich in carbohydrate are being chosen(Mirabella et al., 2014).

8.3 BIOETHANOL

In 2015, the bioethanol demand has grown up to 100 billion litres as it fulfils tremendous demands. Production of bioethanol process involves pre-treatment, enzymatic hydrolysis,

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fermentation and distillation steps. Bioethanol can be prepared from both edible and non-edible compounds. Some of the non-edible compounds such as Jatropha and Pongamia. Mostly low-cost agricultural residues viz., wheat straw, rice straw, sugar cane bagasse and other cellulosic biomass are involved in bioethanol production. A major limit to the production of ethanol is lignin interferences in the conversion of cellulose and hemicelluloses into monosaccharides that can be rectified soon by researchers. Maximum ethanol production with vacuum fermentation (357.5±5.4 g/kg FW) was reported than the conventional fermentation (326.5±5.4 g/kg FW). Food waste with higher organic contents were used to get optimum bioethanol production (Dahiya et al., 2018).

8.4 BIODIESEL

Biodiesel is vital resource utilized as a biofuel by maritime, agricultural, aviation and transportation sectors, as in the case of the heavy-duty vehicle sector (IRENA, 2019). Oleaginous yeast and fungi are used in the production of biodiesel. The feedstocks are received from food supply chain as a food waste which includes flour rich waste, lipids and so on. Recent studies show that genetically engineered oleaginous yeast and fungi are chosen for enhancing microbial oil production from food waste (Ma et al., 2019). Food waste containing the tri-,di- and monoglycerides react with methanol in the presence of a catalyst to produce biodiesel , and this complete process of producing chemical biodiesel is called transesterification. Normally lower than 3% (w/w) of free fatty acid is needed in the standard production of biodiesel. Substrates have higher fatty acid level aids in decrease of biodiesel quality and leads to environmental pollution. Microbial oil can't be preferred as a source because it contains fatty acid content up to 5% of total lipids and gradually increase during purification and storage conditions (Martinez-Silveira et al., 2019). Yeast cell is free from nitrogen oxides derivatives and becoming the best source of biodiesel production (Bharathiraja et al., 2017).

8.5 BIOPOLYMERS

Biopolymers are monomeric polymers produced by living organisms and composed of monomeric polymer units. As the biopolymer is a renewable energy it became a replacement for fossil fuels and it dramatically reduces the environmental pollution like greenhouse gas emission. Mainly food waste is utilized for biopolymer production. Some of them include citrus skin and pulp from orange, grapefruit, mandarin/tangerine, lemon, lime, and seed waste from mango, grape, pumpkin, skin of potato and banana, peanut husk, coffee, sugar bagasse and cereal straw are widely used. Both fermentation and enzymatic process are used in the extraction of carbohydrates, proteins, organic acids, oils and fiber from food waste (Ventorino et al., 2016). Starch is considered to be a fundamental element of biopolymer as it only requires partial modification during the production. But some of biopolymers are produced via their monomers by fermentation and chemical processing and subsequent polymerization, some of them include like poly-lactic acid (PLA), poly-butylene succinate (PBS) and polyethylene (PE) (Hassan et al., 2013).

Polyhydroxyalkanoates (PHAs) are a group of bio-polyesters which are readily biodegradable and best source for biopolymer production(Nayak & Bhushan, 2019). They are synthesized by various prokaryotic microorganisms as energy and carbon reserve materials in response to nutrient limiting or stressful conditions. PHA production from starch by starch *by Azotobacter chroococcum* (73.9 wt% PHB), and from whey by recombinant E. coli (80 wt% PHB) (Kim, 2000), and liquid glycerol in a highly osmophilic organism (76 wt% PHA) were highly successful (Koller et al., 2005).

8.6 BIOFERTILIZERS

Food waste are involved in production of bio-fertilizer with the help of composting technology. Composting is the natural process of recycling organic matter, such as leaves and food scraps into a valuable fertilizer that can enrich soil as well as plants. Composting can be done either aerobically or anaerobically. Factors that influence the production and quality of compost are moisture content, composition, pH, temperature, aeration and carbon to nitrogen ratio(Dahiya et al., 2018). The C/N ratio plays a very important role in composting as it depicts the carbon and nitrogen source needed for the whole reaction. Researcher conclude that optimal level of C/N ratio is favourable whereas larger C/N ratio leads to deficiency of nutrients to the microbes and lower C/N ratio leads to accumulation of salts and evolution of bad odour, which affects the plant's growth (Nayak & Bhushan, 2019). The production process also gains the involvement of microorganism, some of the free-living nitrogen fixing biofertilizers like Klebsiella, Clostridium and phosphate solubilizing biofertilizers like Bacillus and Pseudomonas are used (Alfa et al., 2014).

Liquid effluent can be used to increase the soil fertility as it contains high amount of nutrients from decomposable organic matter and microbial biomass and replacing the chemical fertilizers (Alburquerque et al., 2012). Usage of biofertilizers readily reduces the negative carbon footprint from landfills and emission of greenhouse gases. Different groups of microorganisms are used depending on the temperature involved in the composting process.

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During the composting, bacteria initiate the process where fungal action also plays a remarkable role throughout the process(Nayak & Bhushan, 2019).

9. Future of Food Waste: Emerging Valorization Techniques

Recent technologies in food waste valorization are playing a crucial role in addressing the global food waste problem and creating sustainable solutions. These technologies include biorefineries, which convert food waste into valuable products such as biofuels, biochemicals, and bioplastics (Sharmila et al., 2020). Other innovative approaches include anaerobic digestion, which produces biogas for energy generation, and insect-based protein production, where certain insects are fed food waste and their protein-rich biomass is harvested for various applications. Furthermore, advancements in fermentation technologies have enabled the conversion of food waste into high-value products such as enzymes and probiotics. These emerging technologies not only offer a way to reduce food waste and its environmental impact but also present new economic opportunities. Recent innovations in food waste valorization have brought about cutting-edge solutions to tackle this global issue. These solutions include the use of smart sensors and data analytics to optimize food storage and distribution, reducing spoilage and waste. Additionally, the development of blockchain technology has allowed for improved traceability and transparency in the food supply chain, helping to identify and mitigate sources of waste (Plazzotta & Manzocco, 2019)(Nayak & Bhushan, 2019)

10. CONCLUSION

This chapter summaries that food waste valorisation is a crucial and innovative approach to address the global challenges of food waste and environmental sustainability. By converting food waste into valuable products, such as biofuels, biogas, compost, and various biochemicals, we can significantly reduce the environmental impact associated with food disposal while creating economic opportunities and promoting a more circular economy. However, challenges remain in implementing food waste valorisation on a large scale. These include technological advancements, infrastructural development, regulatory support, and public acceptance. Collaborative efforts between governments, industries, academia, and communities are essential to overcoming these challenges and unlocking the full potential of food waste valorisation. In conclusion, food waste valorisation presents a promising pathway to tackle the global food waste crisis, foster environmental sustainability, and create a more resource-efficient and resilient society. Embracing this approach can pave the way for a greener, more sustainable future for generations to come.

Funding

No funding was received to assist with the preparation of this manuscript.

Competing Interest

The authors have no competing interests to declare that are relevant to the content of this article.

Author Contributions

Rajamehala M and Rubinika P: conceptualization; Data curation; investigation; Validation, methodology; roles/writing — original draft.

Prabhu N: supervision; writing — review and editing.

Vijay Pradhap Singh and Muthu Kumara Pandian A: conceptualization; resources; supervision; writing — review and editing.

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