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Strategies and Tools for Pollutant Mitigation

Research Trends in Developing Nations

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Contents

Part I State of Art and Sustainable Remediation Approaches

Part II Waste Management for Cleaner Environment

Part I

State of Art and Sustainable Remediation Approaches

Chapter 1

Utilizing Organic Wastes for Probiotic and Bioproduct Development: A Sustainable Approach for Management of Organic Waste

Raghuvandhanan Kumarasamy Sivasamy, Kumaresan Kuppamuthu, Lokesh Krishnasamy Nagaraj, Sakkthy Pradhieksha Manikandan, Raghul Kulandaivel, and Jenifer Gabriella Bastin

Abstract In recent years, organic waste, specifically food waste, has become a growing concern with the increased population. This surge is negatively impacting the environment. These food wastes have emphasized the importance of employing sustainable waste management strategies so that these wastes can be transformed into some value-added goods. Most of the food waste is rich in nutritive supplements that hold massive significance for bioconversion to value-added products and the growth of various microorganisms. One such type of microorganism is probiotics. Probiotics are not pathogenic microorganisms and have potential health benefits to the host when administered in modest amounts. It has proven benefits for humans and animals. This chapter widely focuses on and discusses the environmental impacts that are caused by different organic wastes, assess the existing methods for organic waste management and their limitations, probiotic strategies such as the utilization of organic waste as a supplement in the media for their growth, probiotic fermentation of organic waste. The microbial approaches discussed in this chapter offers a sustainable way for managing food waste by converting it into valuable bioproduct.

Keywords Organic waste · Bioconversion · Probiotics · Food waste · Organic waste management

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1.1 Introduction

Organic wastes are materials that originate from living organisms. These wastes include food waste, agricultural waste, and sewage waste from the treatment of wastewater. Among organic wastes, food waste is a significant source of organic waste (Raksasat et al. 2020). Food is an essential and indispensable part for the survival of any form of life. Organisms from different evolutionary levels take in food in various forms. Microorganisms take food in the form of macromolecules and higher eukaryotes take food in complex forms. Concerns about food develop when there is a considerable amount of waste produced from it which can be used for various purposes. Food and Agriculture Organization (FAO) describes food waste as the reduction in the quality or quantity of food resulting from actions and decisions by retailers, food service providers, and consumers. It is estimated that about 1.3 billion tons of food waste are spawned per year (FAO 2015), that is, one-third of the food produced for human consumption, either lost or wasted globally (FAO—Notícias: Food Wastage: Key Facts and Figures 2015).

Food waste generation is increasing and has much impact on the environment and the economy. It is estimated that food waste accumulates about 3.3 billion tonnes of CO_2 into the atmosphere per year (Paritosh et al. 2017). The negative impact has drawn attention to managing food waste. Food waste management has become a key to all the activities identified with reducing, avoiding, or recycling waste, throughout the production and consumption chain. Bioconversion and biotransformation of food waste by microbial methodologies using probiotics is one significant way of managing food waste. The key requisites for the use of food-based waste as a resource to develop value-added products are shown in Fig. 1.1.

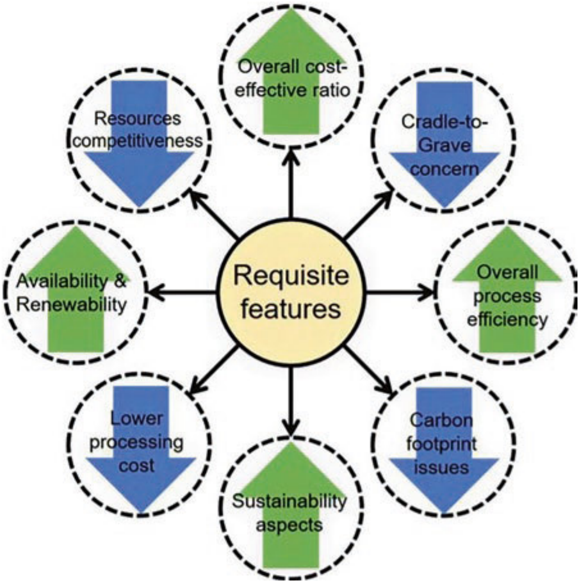

Fig. 1.1 Key requisite features that enable the use of food-based waste materials to develop value-added products of interest. (Reprinted from Bilal and Iqbal 2019 with permission from Elsevier)

In recent times, there has been a rapid rise in interest in probiotics and their applications. This chapter aims to present how organic waste, especially food waste, could be managed and utilized efficiently as a media for the growth of probiotics, bioconversion of the waste to bioactive compounds using probiotics, and the application of those bioactive compounds.

1.2 Organic Waste and Its Environmental Impacts

1.2.1 Fruit and Vegetable Waste

Fruit and vegetable waste (FVW) are commonly defined as waste intended for disposal from fruit and vegetable processing and production areas (Plazzotta et al. 2017). FVW is rich in energy, nutrition, and moisture content consisting of carbohydrates (glucose and fructose), polyphenols, fibers, minerals, and other bioactive compounds. Fruits and vegetables are considered waste only when the degree of acceptance from the consumer tends to reduce. This acceptance is reduced by many factors, including the degree of ripening, biochemical reaction, microbial attack, and discoloration.

About 59 million tonnes of fruit and vegetable waste is generated, which costs 2 trillion annually (Singh et al. 2007) and thus poses a threat to the environment due to high biodegradability, which will deplete valuable biomass and causes a financial burden to industries. Anaerobic digestion is one of the most commonly followed techniques to manage fruits and vegetable waste. Improper utilization of the digestate obtained through anaerobic digestion can pose serious environmental problems that include over-fertilization and pathogen contamination (Nkoa 2014). Most of the fruit wastes are decomposed in landfills and emit harmful greenhouse gases causing environmental burden (Gowman et al. 2019; Kumar 2012).

1.2.2 Agricultural Waste

Agriculture waste is an organic, biodegradable, and unwanted product produced by agricultural practices which include molasses, straw, spent grass, husk of rice, wheat and maize, shells of coconut, groundnut and walnut, the skin of avocado and banana, plant waste, livestock and poultry waste which is used as a manure. Nonedible waste from various sources is considered agro-industrial waste. For producing multiple high-valued commodities, a natural substitute can be agricultural wastes. Agricultural waste is rich in lignocellulose, which can be used to produce many microbial enzymes (Ravindran et al. 2018).

About 350 million tonnes of agricultural waste is produced, which imparts a negative impact on the environment. Runoff from the land has high amounts of nitrogen and phosphorus that can speed up the process of eutrophication in lakes and ponds (Atallah Abouelenien et al. 2014). Furthermore, the decomposition of agricultural waste like the organic matter in crops emits gases like hydrogen sulfide and methane which can cause air pollution by generating greenhouse gases (Qi et al. 2020).

1.2.3 Food Waste

Food waste (FW) is food products that do not get consumed; they are either nonedible parts or leftovers. FW mostly takes place in the consumption stage of the food supply chain (Parfitt et al. 2010). Food waste majorly consists of carbohydrates, lignin, lipids, and proteins. The carbohydrates can be broken down into oligosaccharides and monosaccharides; these are fermentable and can be used to develop bioproducts such as biopolymers, bioplastics, hydrogen, methane, and various enzymes (Uçkun Kiran et al. 2014).

About 67 million tonnes of food is wasted. There are several methods for managing food waste but, anaerobic digestion and composting are widely used methods. The gas emitted from this process is the main contributor to acidification, photochemical oxidation, and eutrophication (Al-Rumaihi et al. 2020).

1.2.4 Dairy Waste

Dairy products are the most cherishable products due to their complex organic constituents. Dairy products are diverse and include yogurt, cheese, butter, ice creams, and various milk products. Milk production has increased in the last few years as a result of industrialization. The processing of dairy products has also increased and is considered the primary source of industrial food wastewater (Slavov 2017).

About 5 million tonnes of dairy products are wasted. Dairy effluents that are sent out contain milk constituents like casein and inorganic salts, along with detergents and sanitizers. All of these components cause a rise in BOD and COD (Sinha et al. 2019). Dairy effluents have suspended solids and soluble organics. They promote the release of certain gases and eutrophication (Raghunath et al. 2016). Some chemicals like ammonia, nitrates, and nitrogen are present in raw milk, which are known to cause methemoglobinemia. When this is converted to nitrate, they pollute groundwater (Ahmad et al. 2019).

1.3 Management of Organic Waste

There are different types of managing organic waste based on the nature of the waste. The most common type of organic waste is food waste. The primary and the most followed way of managing food waste is through landfills (about 90%), then composting (about 1–6%), and anaerobic digestion (0.6%) (Thi et al. 2015).

1.3.1 Solid Waste Management

Anaerobic Digestion (AD) overcomes the traditional food waste management method, and it is comparatively cost-effective to other waste treatment options. In AD, anaerobic microorganisms convert various organic waste and biomass into biogas like carbon dioxide, methane, and small amounts of other gases like hydrogen (Xu et al. 2018). Complex organic polymers are converted into simple soluble biomolecules by hydrolysis and then into fermentation to form a volatile fatty acids mixture further converted into acetate (Kibler et al. 2018). The rate-limiting step of the AD is the hydrolysis process (Zhang et al. 2014). A successive co-digestion of food wastes with organic substrates by physical, thermochemical, and biological methods is performed to improve hydrolysis. The mesophilic and thermophilic conditions are suitable for the effective digestion of food wastes: higher buffer capacity and ammonia yield higher amounts of methane.

1.3.2 Incineration

Incineration is the combustion of food waste by supplying thermal energy source that occurs in a grate furnace. Incineration is not appreciated compared to other conventional food management systems because of the environmental and economic impact. The high capital requirement is due to the energy source, furnace designing, and minimizing the release of smoke into the atmosphere (Thi et al. 2015). The recovery of available nutrients and other valuable chemical compounds is hindered in this process, a notable economic impact. The time requirement is less in the incineration process and also a high volume of food waste is incinerated quickly. Potential health effects regarding inhalation of airborne pollutants resulting from incineration is possible (de Titto and Savino 2019). Burning food waste with moisture content leads to the release of dioxins and mercury compounds which causes several environmental problems and even acts as a carcinogen (Melikoglu et al. 2013).

1.3.3 Hydrothermal Carbonization

Hydrothermal Carbonization (HTC) is a wet process of thermal conversion technology that produces valuable energy-rich sources from food wastes under autogenous pressure and relatively low temperature (180–350 °C) (Lu et al. 2012). The reaction time of HTC is less than an hour, so it continuously degrades waste material daily, improves the food waste (FW) management, and high throughput of products. The carbonization process integrates more than 70% of carbon in the FW into carbon and results in hydro char with a higher density of energy source. It can be applied to the soil amendment process for plant growth, locks the moisture in it, and enhances the soil moisture content by increasing soil porosity (Li et al. 2013a). Studies on life cycle assessment of HTC treated water and emission of CO_2 can pose a significant footprint (Venna et al. 2021).

1.3.4 Landfills

Landfills are one of the traditional and most widely used methods for managing food waste and solid waste. The waste generated is dumped in a particular area separated from the living areas and requires many resources like land and money (Kim and Kim 2010; Xu et al. 2018). Landfilling method is known to have a more considerable effect on climate change; it is ten times as much as anaerobic digestion, composting, and incineration combined (Gao et al. 2017). Methane is usually emitted from landfills because of the degradation of organic waste (Kibler et al. 2018). Methane, when released into the atmosphere, causes global warming at a higher rate than carbon dioxide. Leachate, a potent toxic liquid, is also leaked into the soil and groundwater because of landfills (Melikoglu et al. 2013).

1.3.5 Composting

Composting is a process of the biological decomposition of organic waste under aerobic conditions. The end products of this process are fertilizer, fuel, or biofilter material. Unlike landfills, composting does not threaten underground water because the chemical pollutants are low comparatively (Ayilara et al. 2020). During composting, some factors can be considered, such as the addition of moisture during the process (Kibler et al. 2018). There may be some chemical changes and metabolic changes of the microorganism. Compared with other waste, food waste has particular physical and chemical properties like loose physical structure, high nitrogen content, low C/N ratio. So composting became an essential method for managing organic waste (Li et al. 2013b).

1.3.6 Animal Feed

Organic waste like food waste is generated during the consumption phase of the supply chain is rich in nutrients (Bakshi et al. 2016), which can be used for livestock feed, and modern treatment technologies can be used to convert food waste that is high in moisture content and susceptible to deterioration into feed that is safe for animal feed (Dou et al. 2018). Waste is treated to become free of contamination; it is sterilized and dehydrated by hot air at 390 °C. It should be heat treated at greater than 80 °C for 30 min. The animal feed ingredients are dependent on the feed consumption of the pigs for pork production (Salemdeeb et al. 2017).

1.3.7 Biovalourization

Food waste biovalorization converts food waste or its byproducts into higher-value products that contribute to the food supply chain. It is one of the recycling pathways for food waste that will help to close the food waste loop. This technique is aimed at the generation of biofuels and biomaterials. The production of biofuels from organic waste has become necessary because of the depletion of fossil fuels (Nayak and Bhushan 2019). Organic waste can be used to produce biogas with a yield of 150 Nm^3/ton of waste. It is used to produce electricity (Cristóbal et al. 2016).

1.3.8 Dairy Waste Management

The milk industry has a more significant environmental impact because it consumes large amounts of water and produces effluents. Different types of dairy waste management methods include mechanical treatment, physiochemical treatment, and biological treatment.

1.3.8.1 Mechanical Treatment

Mechanical treatment involves removing suspended solids from dairy wastewater. These are removed by using screens. The removed material is collected in the bottom and is known as sludge (Slavov 2017).

1.3.8.2 Physiochemical Treatment

The physiochemical treatment removes colloidal particles and reduces milk fat. Electrocoagulation and adsorption are two widely used methods for removing dissolved organic waste (Birwal et al. 2017; Slavov 2017).

1.3.8.3 Biological Treatment

The preferred way of managing dairy waste is biological treatment. This method is mainly used for removing organic material. Biological treatment is classified into aerobic process and anaerobic process based on the oxygen requirements.

In aerobic process, the microorganisms used in this process grow in an environment rich in oxygen. The microorganism breaks down the organic compound into the water, carbon dioxide, and cellular material. The aerobic process is not as efficient as the anaerobic process because of acidification and filamentous growth (Birwal et al. 2017; Slavov 2017).

In anaerobic process, The microorganisms used are grown in the absence of oxygen. Organic matters are converted to biogas and are cost-effective than the aerobic process. So, the anaerobic process is preferred to the aerobic process (Birwal et al. 2017; Slavov 2017).

1.4 Sources of Probiotics

Probiotics that are helpful for human beings' well-being can be isolated from various sources such as dairy products, wastes like vegetable and fruit waste, kitchen waste, plant material, animal material, human guts, human feces, and human milk (Sornplang and Piyadeatsoontorn 2016) (Fig. 1.2).

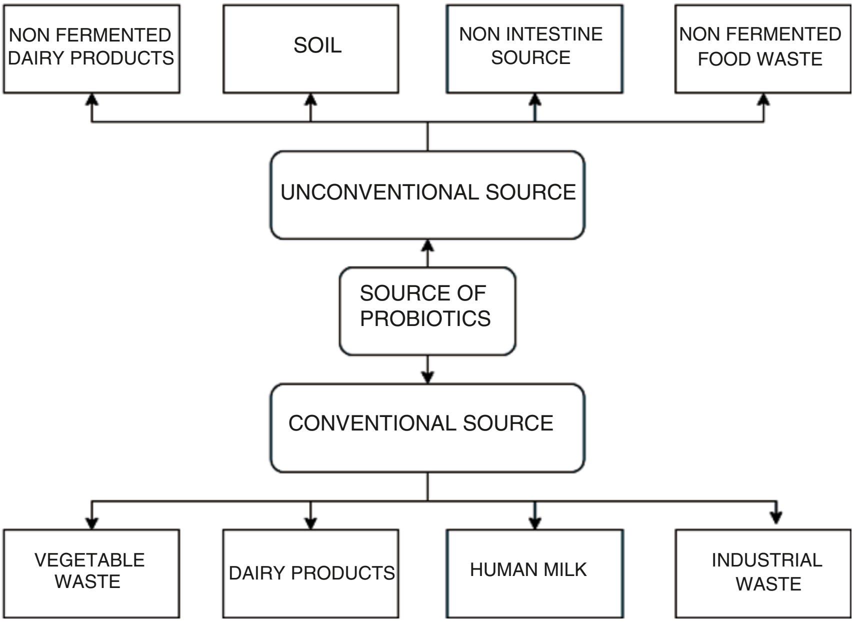

Fig. 1.2 Different conventional and unconventional sources of probiotics

1.4.1 Fruit Waste

During the processing of fruits and vegetables, thousands of tonnes of solid and liquid waste are produced. Solid waste is generated in the form of skins, pips, and stalks. Fruit waste and vegetable waste may contain many valuable sources for the growth of bacteria. Fruit and vegetable waste are rich in many nutrients like iron, magnesium, and carbohydrates which are the primary source of the growth of probiotic bacteria. Some strains of Lactobacillus were isolated from byproducts of fruits. *L. fermentum 139* and *L. fermentum 141* were isolated from the byproducts of *Mangifera indica*. *Lactobacillus plantarum 60*, *Lactobacillus fermentum 56*, and *L. fermentum 53* were isolated from the byproducts of *Malpighia glabra* (Barbados cherry). *Lactobacillus paracasei 106* was isolated from the byproducts of *Annona muricata* (soursop). *L. fermentum 250* and *L. fermentum 263* were isolated from the byproducts of *Ananas comosus* (pineapple). *L. fermentum 296* was isolated from the byproducts of *Fragaria vesca* (strawberry). These strains were identified using the 16S rRNA sequence (De Albuquerque et al. 2018). The bacteriocin-producing bacteria such as *Lysinibacillus JX416856* was isolated from the fruit and vegetable waste and was identified phenotypically and molecularly (Ahmad et al. 2014). The probiotic strain *Lactobacillus rhamnosus AW3* was isolated from the date processing wastewater. Wastewater was collected from a date fruits processing center, the bacterial strain was isolated from date effluent, and complete 16S rRNA was done to identify the strain at the molecular level (Al-Dhabi et al. 2020). The probiotic strains such as *Pichia kudriavzevii* and *Issatchenkia terricola* were isolated from pomegranate and grape seed, respectively. These were identified by the 18S rDNA sequence using ITS1 and ITS4 method (Prabina et al. 2019).

Fermented vegetables and fruits are some of the potential sources of probiotics because they nurture various lactic acid bacteria. Some of which include *Lactobacillus pentosus*, *Lactobacillus plantarum*, *Lactobacillus fermentum*, *Lactobacillus acidophilus*, *Lactobacillus mesenteroides*, and *Lactobacillus brevis* (Swain et al. 2014). Fermented vegetables predominantly contain *Lactobacillus plantarum* and *Lactobacillus brevis* because of their ability to break down phenolic acids present in food (Viridiana et al. 2018).

1.4.2 Dairy Products

Dairy products are one of the essential sources of probiotic microorganisms. In the Asian market, fermented milk and yogurt is an essential probiotic product. *Streptococcus thermophilus*, *Streptococcus cremoris*, *Lactobacillus acidophilus*, *Lactobacillus casei*, *Lactobacillus rhamnosus*, *Lactobacillus bulgaricus*, *Lactobacillus kefir*, and *Streptococcus lactis* were isolated from a variety of dairy products like yogurt, cultured buttermilk, acidophilus milk, lassi, kefir, and leben (Oh 2015). Certain probiotic species like *Enterococcus* and *Bacillus* were isolated from raw milk and identified using the 16S rRNA method (Panda et al. 2017).

1.4.3 Human Sources

The human gut microbiome harbors many microorganisms like probiotics. Potential probiotic bacterias like *L. rhamnosus*, *L. fermentum*, *L. plantarum*, and *L. paracasei* were isolated from the feces of infants less than 24 months. These bacteria were examined for probiotic characteristics like acid pH resistance, bile tolerance, adhesion assay, and inhibition of enteric pathogens (Jomehzadeh et al. 2020). In healthy women, vaginal microbiota is rich in probiotics. This microbiota is dominated by *Lactobacillus* species and certain species such as *L. gasseri*, *L. salivarius*, *L. crispatus*, *L. helveticus*, *L. fermentum*, *L. rhamnosus*, *L. paracasei*, and *L. plantarum* (Er et al. 2019; Pino et al. 2019). Breast milk is recognized as one of the primary sources of potential probiotic bacteria. There is vast biodiversity of bacterial species in human milk. Certain probiotics like *Lactobacillus casei* and *Lactobacillus rhamnosus* were isolated from human milk and identified using the 16S rRNA sequencing method (Riaz Rajoka et al. 2017). Seven strains of Lactic acid bacteria were isolated from human milk (Kavitha and Devasena 2013). Some major probiotic species isolated from human milk include *Streptococci*, *Staphylococci*, *Lactic acid bacteria*, *Bifidobacteria*, and *Corynebacteria* (Martín et al. 2003, 2009, 2012).

1.4.4 Fish Intestine

The fish intestine is a rich source of probiotics. Lactic acid bacteria (LAB) were isolated from the kitchen waste and fish intestine. About five strains such as KT1T, KT2W, KT1B, KA2, and FS was identified as *Lactobacillus casei*, and KT1 strain was identified as *Lactobacillus delbrueckii* (Rauta et al. 2013). Five strains of the *Lactococcus lactis* subsp. *lactis*, one *Lactobacillus plantarum*, two *Enterococcus* spp., and one *Leuconostoc mesenteroides* were isolated from the guts of 12 marine species (Alonso et al. 2019).

1.4.5 Soil

Probiotics that are usually found in soil are called soil-based probiotics. *Bacillus amyloliquefaciens* is a probiotic bacteria and it has been isolated from North East Himalayan Soil (Hairul Islam et al. 2011). Soil (rhizospheres) samples from Taiwan and Japan had possible probiotic bacterias like *Lactococcus lactis*, *Enterococcus faecium*, *Enterococcus mundtii*, *Lactobacillus plantarum*, and *Sporolactobacillus inulinus*. These strains were identified using the 16S rDNA sequence method (Chen et al. 2005) (Table 1.1).

Table 1.1 Probiotic organisms isolated from different sources, the media used to cultivate them, and the identification techniques

Source	Probiotic strain	Identification techniques	Medium	Reference
Human milk	*Lactobacillus casei*, *Lactobacillus rhamnosus*, seven strains of lactic acid bacteria	16S rRNA	MRS agar, TPY agar, MRS cysteine agar	Riaz Rajoka et al. (2017)
Mango pulp	*Bacillus JHT3*, *DET6*	16S rRNA	Nutrient agar	Patel et al. (2009)
Dairy waste	*Siderophoregenic Bacillus DET9*	Partial 16S rRNA, biochemical characterization	MRS agar	Patel et al. (2010)
Fermented vegetable, silages, grass	*Lactococcus lactis* subsp. *lactis*	PCR	MRS agar	Kimoto et al. (2004)
Fish intestine	*Lactic acid bacteria KT1T*, *KT2W*, *KT1B*, *KA2*, *FS*, *Lactobacillus delbrueckii*	Gram's staining and biochemical tests	MRS agar plate	Rauta et al. (2013)
Fruit and vegetable waste	*Lysinibacillus JX416856*	Phenotypical and molecular method	MRS agar	Ahmad et al. (2014)
Fish intestine	Five strains of the *Lactococcus lactis* subsp. *lactics*, one *lactobacillus plantarum*, two *Enterococcus* spp., and one *Leuconostic mesenteroides*	PCR	MRS agar	Alonso et al. (2019)
Mango, barbodos cherry, soursop, pineapple, strawberry	*L. fermentum 139*, *L. fermentum 141*, *Lactobacillus plantarum 53*, *Lactobacillus fermentum 56*, *L. fermentum 60*, *Lactobacillus paracasei 106*, *L. fermentum 250*, *L. fermentum 263*, *L. fermentum 296*	Complete 16S rRNA	MRS agar	de Albuquerque et al. (2018)
The seed of pomegranate and grape	*Pichia kudriavzevii* and *Issatchenkia terricola*	18S rRNA	Yeast extract peptone dextrose (YEPD) agar supplemented with chloramphenicol	Prabina et al. (2019)
Traditional fermented dairy products	*Lactobacillus plantarum P-8*	16S rRNA, PCR	MRS agar	Wang et al. (2015)

(continued)

Table 1.1 (continued)

Source	Probiotic strain	Identification techniques	Medium	Reference
Laying hens	*Propionibacterium acidipropionici LET 105*	16S rRNA	Lactate agar	Argañaraz-Martínez et al. (2013)
Young calves	*Lactobacillus johnsonii*, *L. salivarius*, *L. murinus*, *L. mucosae*, *L. amylovorus*, *L. mucosae*	PCR, 16S rRNA	MRS and LAPT medium	Maldonado et al. (2012)
Chickens	*Lactobacillus salivarius 15K*	PCR,16S–23S rRNA	MRS agar	Bujnakova et al. (2014)
Date processing wastewater	*Lactobacillus rhamnous AW3*	Complete 16S rRNA	MRS agar	Al-Dhabi et al. (2020)
Soil	Bacillus strains 12, 17 S10, S3, 14, 13, 8	16S rRNA	Tryptic soy agar (TSA)	Mohkam et al. (2016)
Indigenous and broiler chickens	*Streptomyces* sp. *JD9 (KF878075)*	16S rRNA, PCR	MRS agar	Latha et al. (2016)
Indigenous poultry	*Lactobacillus plantarum TN8*	PCR, 16S rRNA	MRS medium	Ben Salah et al. (2012)
Broiler chickens	*Lactobacillus salivarius DSPV 001P*	PCR, 16S rRNA	MRS agar	Blajman et al. (2015)
Cows, pigs, chickens, and ducks.	*L. plantarum (strain P6)*, *L. paraplantarum (strain P25)*, *L. reuteri (strain P30)*	PCR,16S rRNA	MRS agar with 0.1% $CaCO_3$	Pringsulaka et al. (2015)
Weaned pig	*Bacillus subtilis KN-42*	PCR, gel electrophoresis, 16S rRNA	MRS agar	Hu et al. (2014)

1.5 Organic Waste for the Growth of Probiotics

The interest in probiotics has increased recently, but the cultivation of probiotics is expensive, especially the media used for growing it. The cost of the media has a negative effect on the economic aspect of growing probiotics. Technologies for the production of active probiotic strains require low-cost media for their growth. MRS media is a suitable media for the growth of probiotics, but it is costly; specific food waste can be used as a substitute for MRS media.

1.5.1 Agricultural Waste as a Probiotic Growth Media

1.5.1.1 Banana Peel Waste as a Probiotic Growth Media

India accounts for 29% of the total banana production globally (Panigrahi et al. 2021) and food industries produce a vast amount of banana peel waste. The banana peel waste can be used as an alternative medium for the MRS medium. The banana peel is chopped into small pieces and made into a paste. Twenty grams of this paste is mixed with 100 mL of distilled water. This mixture is autoclaved, and probiotic organisms like *L. sporogene* and *L. acidophilus* are inoculated. Submerged fermentation of the Banana peel medium is carried out. The maximum growth of these probiotic Lactobacilli strains was observed at pH 6.0 and 37 °C. On comparing the growth of these strains with the traditional MRS medium and the banana peel medium, the study indicated that there was no significant difference ($p > 0.05$) (Farees et al. n.d.).

1.5.1.2 Barley Spent Grain (BSG) as a Media for Probiotics

During Beer production, byproducts are generated and 85% of it is barley spent grain (Aliyu and Bala 2011). BGS consists of lignocellulosic biomass, mainly consisting of fiber (30–70%) and proteins (20–30%). *Lactobacillus* and *Bifidobacterium* sp. can use these byproducts for their growth. Hence, this can be a component of the growth media (Song et al. 2012). *Bifidobacterium adolescentis 94 BIM* and *Lactobacillus* sp. Firstly, the BGS is separated into coarse polysaccharide fraction (FF) and fine protein fraction (PF). Two grams of these fractions are added to 100 mL of distilled water. This mixture is autoclaved and the pH is adjusted to 7.2. The growth, acetic acid production, and morphology of *Bifidobacteria* and LAB were assessed by inoculating them in 11 different media compositions, including BHB (Brain heart broth) medium, media with FF and PF supplemented with additives like lactose, ascorbic acid, yeast extract, and mineral salts. The results indicated that the proteins and polysaccharide fractions of BSG supplemented with the right amount of additives can be used to cultivate probiotics (Novik et al. 2007).

1.5.2 Cheese Whey and Molasses: Media for Probiotic Bacteria to Produce Biosurfactant

Cheese whey is a byproduct of the cheese industry. Because of its high organic load, it is considered one of the most polluting byproducts of the food industry (Addai et al. 2020). However, it also contains high amounts of protein, lactose, organic acids, and vitamins, making it a suitable substrate for biosurfactant production. Molasses is an agricultural waste and byproduct of the sugarcane industry. It is composed of vitamins, organic compounds, and minerals, which are considered valuable for fermentation. The cheese whey is heated to denature proteins, and the precipitate is removed by centrifugation. The supernatant consists of 50 g/L lactose supplemented with peptone and yeast extract used as a culture media. Molasses is diluted such that the sucrose concentration is 20 g/L and supplemented with yeast extract and peptone used as a culture media. In order to check the sugar consumption, biomass yield, and biosurfactant production, 12 different media compositions were prepared with MRS broth being the control for *Lactococcus lactis 53* and M17 broth being control for *Streptococcus thermophilus A*. The best results were obtained with media supplemented with molasses. A 1.2–1.5 times increase in the mass of the produced biosurfactant per gram cell dry weight was also observed. This reduced 60–80% of the expense in preparation of media (Rodrigues et al. 2006).

1.5.3 Kitchen Waste as a Media for Probiotic Production

Kitchen waste is composed of organic fragments like carbohydrates, lipids, proteins, and fat. The conversion of this waste is challenging because of its low calorific value and high moisture content. It is also a valuable source that can be used as a medium for producing probiotic bacteria. Studies have been done in this arena. In one such study, five strains of microorganisms (*Lactobacillus*, *Bacillus licheniformis*, *Bacillus subtilis*, Yeast isolated from broiler chicken gut and another yeast isolated from an inoculum used to produce alcoholic food) were mixed in an equal ratio. Kitchen waste was added to a rotary drum bioreactor and the pH was adjusted to 7.2 using Na_2CO_3; this waste mixture was heated at 110 °C for 30 min, this is then cooled to 37 °C and 5% inoculum was added to it. The growth of Lactobacillus in kitchen waste was higher than the growth of Lactobacillus in pure culture media, which implies that kitchen waste can be used for probiotic production (Yin et al. 2013).

1.6 Fermentation of Organic Waste and Production of Value-Added Products

Value-added products or compounds are generally produced by fermenting fruit and vegetable wastes. Generally, hydrogen and alcohol are produced by fermenting soluble sugars which are a result of the hydrolysis of food and vegetable waste. Acidogenic fermentation produces lactic acid and solid-state fermentation of wastes is hydrolyzed by making use of mixtures of crude enzymes for the production of succinic acid. Food waste can produce several high-end products through the fermentation process.

1.6.1 Probiotic Drinks

They are produced by fermenting a substrate with probiotic microbes. These drinks can be produced at significantly lower costs and with more valuable properties by using wastes as a substrate. Such manufactured drinks possess high antioxidant properties, good taste, and aid in improving health as they contain probiotics.

1.6.1.1 Production of Probiotic Drinks from Fruit and Vegetable Waste

The food processing industries, namely fruit and vegetable industries produce waste that can be valorized due to their bioactive potential. Around 15–30% of the raw material is wasted (Calinoiub et al. 2019). Beetroot is rich in betalains which can be utilized for making functional beverages using probiotics. Nondairy probiotic drink was developed using beetroot, rich in *Lactobacillus plantarum*, *Lactobacillus rhamnnosus*, and *Lactobacillus delbrueckii* sp. This drink can be used as an alternative to dairy drinks for people with Lactose intolerance (Panghal et al. 2017).

An inexpensive drink rich in antioxidant and probiotic properties is produced using pomegranate peel extract (POPE) and pasteurized cow milk. *Lactobacillus Plantarum* and *Bifidobacterium longum* are probiotic strains. *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *Bulgaricus* were the starter culture strains. Both were grown in sterile skim milk and inoculated into pasteurized cow milk before use. Antioxidant activity of fermented milk beverages supplemented with pomegranate peel (FMPO) has been identified as better than regular milk. Phenol contents were high in POPE and decreased after fermentation (Al-Hindi and Abd El Ghani 2020).

Kefir grains were cultured in milk (Lactic acid bacteria) and the biomass obtained was used as a pre-inoculum for fermentation. Mango peels were freeze-dried and ground into powder. This powder mixed milk acts as culture media to which kefir grains were added for fermentation under static submerged conditions. Tests conclude that mango peel milk fermented with kefir grains have high antioxidant properties because of the release of phenolic compounds from the peel. Also, the bacterial count and growth in medium containing mango peel have shown significant results. Hence, a potential probiotic drink can be produced inexpensively using mango peels (Vicenssuto and de Castro 2020).

1.6.1.2 Production of Probiotic Drinks from Dairy Waste

Cheese whey, a byproduct of the cheese industry, has many nutrients that can harbor probiotics and can be used for producing probiotic drinks. Whey was directly used and sometimes with supplements like buttermilk powder or skim milk powder with different ratios to develop a probiotic beverage. The whey was fermented with common probiotic strain *Lactobacillus acidophilus La-5* and *Bifidobacterium animalis Bb-12*. It was stored for 21 days and throughout this period the viable cells of La-5 and Bb-12 were above 8 log CFU/mL. The whey and buttermilk powder formulation had better sensory scores than the other formulations (Skryplonek and Jasińska 2015).

1.6.2 Polyhydroxybutyrate

Polyhydroxyalkanoates are carbon and energy storage compounds present in gram-negative bacteria. As they resemble properties of synthetic plastic, PHAs especially polyhydroxybutyrate (PHB) can be used as biological plastic of lower cost and good biodegradability. PHB can be extracted from strains capable of producing it fermented in a food waste medium (Tsang et al. 2019).

1.6.2.1 Polyhydroxybutyrate Production from Dairy Waste Using Probiotics

A possible probiotic strain *SRKP-3* capable of producing polyhydroxyalkanoates (PHA) similar to *Bacillus megaterium* was isolated from brackish water. The fed-batch process is carried out and dairy waste was fed at the 12th and 24th h of fermentation. Dairy waste was given as a substrate, and PHAs were isolated from dried cells. Production of PHB was maximum at 36th h of fermentation with a yield of 11.32 g/L. Hence, using a cheap medium highly useful polymer, PHB, was produced (RamKumar Pandian et al. 2010).

1.6.2.2 Polyhydroxybutyrate Production from Agricultural Waste Using Probiotics

Probiotics such as *Bacillus megaterium* and *Pseudomonas aeruginosa* were grown in mineral salt medium (MSM) with different carbon sources such as sucrose, fructose, cane molasses, orange peel powder, and also with amino acids and vitamins supplementation. PHB analysis was done. PHB yield (1.73 g/L) and the samples inoculated in a medium containing cane molasses showed better results than the rest of the carbon sources. PHB yield was enhanced due to amino acid and vitamin supplementation and obtained polymer can be used in food packaging applications (Tripathi et al. 2019).

1.6.3 Production of Biosurfactant from Food and Agricultural Waste Using Probiotics

Biosurfactants are surface-active agents that are produced extracellularly or as a part of the cell membrane. The biochemical and the 16S rRNA analysis identified the most efficient surfactant product by *Azorhizobium* strain (Pendse et al. 2018). Non-septic production of biosurfactant from molasses by a mixed culture was investigated in the stirred-Batch reactor (Ghurye et al. 1994). The production was directly correlated with biomass production and was improved by pH control on the addition of yeast (Bakshi et al. 2016).

Nutritional requirements of the microorganism producing biosurfactant play a vital role in developing a suitable growth media. Food waste like maize powder, potato peel powder, and sugarcane bagasse can be used as a carbon source. Rhamnolipid is a type of biosurfactant produced by *Pseudomonas aeruginosa*. Paneer whey is another byproduct of the dairy industry and is used to produce rhamnolipid using *Pseudomonas aeruginosa*. Oil waste can be used for the production of rhamnolipid (Nitschke et al. 2005). The carbon source in the feed produced a low dry cell weight concentration (g/L), but the rhamnolipid concentration was very high. So, optimizing carbon and nitrogen sources available for utilization is vital for higher productivity of biosurfactants. Four different Pseudomonas species were taken. *Pseudomonas cepacia*, *Pseudomonas pickettii*, *Pseudomonas fluorescens*, and *Pseudomonas acidovorans* in low-cost substrates, which were different. *Pseudomonas cepacia* showed the best result (Lee et al. 2004). The results show that low-cost agricultural waste can be used as a renewable source for producing biosurfactants. Peanut oil cake is a byproduct of oil industries and it is a suitable substrate for lipopeptide production by *Bacillus cereus SNAU01* (Nalini et al. 2016). Fish waste has also been shown to produce lipopeptide using *Bacillus subtilis N3-1P* (Zhu et al. 2020).

1.6.4 Production of Cosmetics

Bacterial fermentation, especially probiotic fermentation, is one of the emerging fields in the cosmetic industry. Fermented probiotic products reduce the cosmetic resources' toxicities and improve absorption into the skin by altering the molecular structures and improving certain pharmacological activities. The fermented products used in beauty products are rich in antioxidants, nutrients, omega-3 fatty acids, and enzymes. Conventional skincare products incorporate probiotics in them. The tropical probiotic products are now rising to trend wellness in the beauty industry (Tkachenko et al. 2017).

S. thermophilus is a probiotic bacteria that has many benefits to the skin. *S. thermophilus YIT 2001* and *S. thermophilus YIT 2084* has a skin hydration effect and seems to show antioxidative effects (Yamada 1982). The latter one also can produce hyaluronic acid, which is a conventional cosmetic ingredient (Izawa and Sone 2014).

1.6.5 Production of Biofuels

Biofuels is a renewable source produced by the transesterification and fermentation of vegetable oils or animal fat with alcohol (methanol or ethanol) which has recently sustained interest due to its contribution to petroleum-based diesel global dependence production. Three probiotic strains of Lactobacillus, such as *Lactobacillus acidophilus*, *Lactobacillus delbrueckii*, and *Lactobacillus plantarum* was tested to check their capability to acquire and metabolize glycerol. Biodiesel-derived glycerol is used as a major carbon and energy source in microaerobic growth. These strains were able to acquire glycerol, consuming between 38% and 48% in approximately 24 h. *L. acidophilus* and *L. delbrueckii* showed similar growth, higher than