BIOCONVERSION OF FOOD WASTES AND BY-PRODUCTS TO VALUE-ADDED PRODUCTS: A COMPREHENSIVE REVIEW

Abstract

Food processing industries are considered to be rapidly expanding sectors due to the increase in the need for food to prevent hunger and the need for nourishing food to support the development of a healthy country. Nowadays, around one-third of the fresh crop is squandered during the food processing chain and is dumped in landfills and the ocean. According to an FAO report, 805 million people worldwide suffer from hunger, yet in 2020, the globe threw away 126 million tons of food waste. High amounts of waste and byproducts are produced during the manufacturing and processing of food in developing nations, which has a detrimental effect on the environment and is very expensive. It is crucial to turn these food wastes and byproducts into value-added goods for social, environmental, and economic reasons. The 3Rs—Reduce, Reuse, and Recycle—should be adhered to in order to address the problem of food waste in the food sector. Nonetheless, there is a good chance that these biomaterials will be used to create food additives, reducing poverty and malnutrition in the underdeveloped nations where they are generated. Beneficial substances including proteins, fats, carbohydrates, micronutrients, bioactive substances, and dietary fibers can be found in abundance in many of these biomaterials. First, this overview provides brief information on the production of different types of wastes from different processing sectors. Second, the several strategies for managing food waste sustainably as well as the difficulties in implementing these strategies are covered in length here. This review, , is an assortment of information pertaining to the recovery of several value-added byproducts, such as biofuel generation, dietary fibers, phytochemicals, bio-preservatives, colorants, and bioactive compounds.

Keywords: Bioconversion, By-product; nutritious phytoconstituents; Value added product

Introduction

Global food waste amounts are astounding because of factors such as population growth, post-harvest processing, edible leftovers, transportation, and storage of food products (Torres-Leon et al., 2018). "Based on the aforementioned behaviors, it is estimated that between one-third and half of the world's food output is wasted annually, or 1.3 billion tons of food. The processing of dairy products, meat, fish, vegetables, grains, legumes, and nuts releases a variety of wastes into the environment. According to reports, between 2005 and 2025, food waste in Asian countries may increase from 278 to 416 million tons annually.A significant amount of waste and byproducts are produced during agricultural production and agro-industrial processing. Greater than half of fresh fruit is made up of fruit byproducts such as bagasse, peels, trimmings, stems, shells, bran, and seeds; occasionally, these materials have greater nutritional or functional value than the fruit itself" (Ayala et al., 2011). "Damage sustained during processing, storage, and transportation also results in fruit and food waste. The creation of wastes and byproducts has recently increased due to the growing popularity of frozen, minimally processed, fruit juices, and nectars. Given that 805 million people worldwide suffer from hunger, social repercussions can be linked to an ethical and moral component of the idea of global food security" (FAO, 2014)."We need more diverse nutritional sources to address the dietary issues facing modern culture. Because there are enough amounts of proteins, lipids, carbohydrates, micronutrients, bioactive substances, and dietary fibers, food wastes and byproducts are quite important. One of the major issues in the majority of developing nations is protein inadequacy and the malnutrition that goes along with it" (Müller and Krawinkel, 2005). "In order to combat malnutrition, food fortification is essential, and significant efforts have been made in the USA and Europe to make use of leftovers and byproducts" (Mirabella *et al.*, 2014; Girotto *et al.*, 2015). "Because these biomaterials produce a lot of byproducts, there is a larger chance of exploitation in poorer countries where hunger and malnutrition are major issues. These nations' industries primarily use fruits, vegetables, dairy products, and fish as raw resources. Mango, pineapple, banana, grape, citrus, and other tropical and subtropical fruits are among the key fruits that are processed in developing nations" (Schieber et al., 2002).

Developing countries are somehow producing post-harvest losses that are competitively higher while maintaining supply chains and processing times that are similar to those of developed countries. Nevertheless, emerging economies are losing more money as consumers, and as a result, affluent countrieswaste more food per person. When consumers want their fruits and vegetables to be flawless and beautiful, they typically reject produce that could be used to prepare food [52,53]. This disposal has a detrimental impact on the ecosystem and increases the loss of phytoconstituents, which are crucial for human health. To get the necessary percentage of perfect produce, farmers must also grow more crops, which uses a lot of water and energy and increases the carbon footprint of food production.Approximately one-third of all food produced for human consumption is lost or wasted within the food supply chain, with the majority of this waste ending up in landfills and waterways, according to a 2011 FAO report. 1.3 billion metric tons of the 675 million metric tons of fruits and vegetables produced each year are wasted as pomace, seeds, peel, leaves, and other byproducts. These wastes can be recycled into biofuel, essential oils, phenolic compounds, high-value prebiotics, and carotenoids. They are also a rich source of energy, minerals, and dietary fiber. It has been documented that the residues from inferior mangoes can transform into 5-hydroxymethylfurfual, a highly valuable food ingredient.Because they are more sustainable and an enhanced agent for packaging, medicine distribution, and nutraceutical absorption, lists of nanocomposite and other bio-nano components rule higher quality living (Müller and Krawinkel, 2005). Furthermore, Memon (2010) proposed the 3Rs—Reduce, Reuse, and Recycle—as a solution to the global problem of food waste. The transportation, food processing, packaging, and infrastructure development sectors can all gain from the creation of value-added products. This reduces the amount of garbage that accumulates and has major economical advantages. In Africa, Asia, and America, tropical fruits, dairy products, and fish are major commercial food and crop enterprises that contribute significantly to the socioeconomic advancement of both rural and urban populations. Because of this, waste minimization is the first step in waste management systems. Four strategies were proposed by Riemer and Kristoffersen (1999) to attain perfect waste minimization in the industry:

1. Reducing waste by utilizing more productive production techniques
2. Production waste recycling internally
3. Improving waste quality with a focus on the source
4. Reusing merchandise. In the food business, a lot of by-products are also partially thrown away without much thought, despite the fact that they might be utilized to make worthwhile items. The approaches that are typically favored for transforming items into value-added products are examined in this analysis.

Efficient utilization of food waste and byproducts as raw materials or food additives could lead to financial benefits for the food business, mitigate nutritional issues, yield positive health outcomes, and lessen the environmental consequences associated with improper waste management. Industries are currently looking for technologies to achieve zero waste, where garbage is produced and used as a raw resource for new goods and applications. The Post 2015 Agenda, the Zero Hunger Challenge, the future Sustainable Development Goals, and the Millennium Development Goals can all be directly impacted by these measures. The primary objective of this review article is to highlight the potential of food waste and byproducts as a long-term substitute for reducing hunger and malnutrition in underdeveloped nations. The following items have been selected because they represent a contrast for which a wealth of information is available and where opportunities and improvements are clearly anticipated.

Given that food waste contains a variety of macro- and micronutrients, this analysis concentrates on the waste products produced by different food processing sectors and their importance from a nutritional, environmental, and financial standpoint. The next sections will focus on the physico-chemical and biological processes used to transform food wastes into products with added value. Furthermore, this review's compilation can provide guidance on how to technically use bulk spice wastes for extraction and ensuing uses in value-added products.

1. Food Waste and the Conversion of By-Products

1.1. Thermal Conversion

Food waste, especially solid waste, is thermally converted to produce fuel and chemicals, which are then utilized to run steam turbines to generate electricity or heat exchangers to warm process streams in industry. Compared to pyrolysis, hydrothermal carbonization is a wet process that uses autogenous pressures and a relatively low temperature (180-350 °C) to transform food wastes into a useful, energy-rich resource (Pham et al., 2015). In order to remove textile dyes from contaminated water, Parshetti et al. (2014) prepared hydrochars from urban food wastes using the hydrothermal carbonization process. Hydrothermal carbonization and pyrolysis are the two fundamental thermal conversion processes. During the pyrolysis process, food wastes burn at temperatures below 450°C and becoming gaseous at temperatures above 800°C.

1.2. Transformation of Chemicals

Hydrolysis and oxidation processes are the most common chemical conversion techniques employed in the food processing industry to deal with food wastes and by-products. By using green extraction techniques, which primarily favor the use of water as an extraction medium over organic solvent extraction, valuable components of food wastes and byproducts can also be retrieved. In order to recover antioxidant bioactive compounds from winery wastes and by-products, Barba et al. (2016) thoroughly reviewed alternative extraction techniques such as pulsed electric fields, high voltage electrical discharges, pulsed ohmic heating, ultrasounds, microwave-assisted extractions, sub- and supercritical fluid extractions, as well as pressurized liquid extraction. Water was also utilized by Zungur et al. (2016) to extract the milk from melon seeds, which are typically referred to as waste. In 2014, Amado et al. attempted to use ethanol to extract antioxidant from potato peel waste. They looked into how the temperature, duration, and ethanol concentration of the extraction procedure affected the extraction of antioxidants from potato peels. Goula and Lazarides (2015) provided information on how to valorize pomegranate and olive mill refuse. Their recommendations for fully utilizing pomegranate seeds and peels included converting olive mill waste into live paste spread, olive powder, and encapsulated polyphenols, as well as using ultrasound assistance to extract oil and phenolics from the seeds and peels.

1.3. Biological Conversion

"Worldwide interest in the biological treatment of food wastes and by-products to recover energy and bioactive substances is currently growing. Food waste is a perfect substrate for anaerobic digestion since it contains a lot of moisture and organic stuff. The four stages of anaerobic digestion are methanogenesis, acetogenesis, hydrolysis, and acidogenesis. The acidogenesis of food waste is influenced by pH, temperature, and the rate of organic loading" (Jiang et al., 2013). Anaerobic digestion produced biogas, which is mainly composed of methane and carbon dioxide, according to Chandrasekaran (2012). Biogas has the potential to be employed as a natural gas substitute. Composting food scraps and byproducts is another biological conversion technique in addition to anaerobic digestion. The biological process of composting releases nutrients and minerals while breaking down organic materials.

2. Fruit Processing Wastes and By-Products

2.1 Mango

The mango, or *Mangifera indica* L., is a member of the Anacardiaceae family and is primarily grown in tropical and subtropical countries, either naturally or by cultivation. The mango, often known as "the king of fruits," is regarded as one of the most significant fruits in the world because of its mouthwatering flavor, alluring scent, stunning color, and high nutritious content (Ibarra et al., 2015). The top producing nations in the world are Pakistan, India, China, Thailand, Mexico, Indonesia, and Indonesia. According to FAOSTAT (2017), Asia accounts for 75.6% of global mango output, with America and Africa following at 13.3% and 11%, respectively.It's also a good idea to read the entire review study by Serna-Cock et al. (2016) to learn more about the chemical characterisation of mango peel. Some fundamental information about the primary nutritional components and their potential uses will be included in this review document. There is a lot of soluble dietary fiber in mango peels (Serna-Cock et al., 2016). A crucial ingredient in the creation of functional foods is dietary fiber. Mango peel has a dietary fiber content that ranges from 51.2 to 78.4%. Dietary fibers, which are indigestible carbohydrates found in plants, are thought to be a crucial part of a balanced diet for humans (Juarez Garcia et al., 2006).

2.2. Banana

The banana is a fruit that is widely farmed worldwide, primarily in regions with tropical or subtropical climates. This fruit is a member of the family Musaceae. Originating in Southeast Asia, bananas are grown in more than 130 nations (Mohapatra et al., 2010). Merely 12% of the fruit's weight is edible, resulting in a significant amount of agro-industrial waste, such as peel, which is primarily utilized in industrial processes to create new goods (chips, dried pulps, jams, wine, beer, and sauces). Thirty to forty percent of the fruit's weight is made up of banana peels (Bankar et al., 2010; Babbar et al., 2011). After bananas are processed, a lot of peel is gathered and disposed of as waste because it is regarded as fruit waste. Since these leftovers are burned or scattered throughout the growing area, they pose a significant pollution risk.

Banana peels have a wide range of uses that are documented in the literature (Bankar et al., 2010). They can be used as fertilizer, cattle and poultry feed, ethanol and biogas generation, and banana oil extraction (Mohapatra et al., 2010). because of its antioxidant qualities, as an adsorbent for the removal of heavy metals from water purification systems, for the synthesis of proteins, for the generation of biomass for energy conversion (Bankar et al., 2010; González Montelongo et al., 2010), and for the development of neutraceuticals. Banana peels' possible uses are mostly determined by their chemical makeup (Pelissari et al., 2014). Since it has been noted that the fruit's starch and hemicellulose content decreases as it ripens, ripening in bananas is a significant factor that affects the substances found in the peel. This is thought to be caused by the action of endogenous enzymes, which raise the concentration of proteins, lipids, and soluble carbohydrates like glucose, fructose, and sucrose (Happi Emaga *et al*., 2007; Mohapatra *et al*., 2010).

2.3. Grape

Nutritious grapes have an effect on the economic standing of the nations that produce them. These fruits are used to make wine as well as table grapes, raisins, and juices. Because table grapes and wine contain antioxidant polyphenols like resveratrol, consuming them provides several nutritional and physiological benefits for people. The FAO (2013) reports that more than 21.9 million tons of grapes are produced worldwide each year. Grape's great economic value stems from its varied usage; at the moment, 31% of global production is destined for the fresh market, 67% is used to make wine and other alcoholic beverages, and 2% is processed into dry fruit.

Due of its various health benefits, grapes have been the subject of intensive research. According to Kammerer et al. (2004) and Corrales et al. (2009), grapes are a rich source of potassium, vitamin C, thiamine (vitamin B1), and manganese. They are also an excellent source of vitamin B6. Furthermore, grapes are among the best providers of bioactive substances such proanthocyanidins, flavonoids, anthocyanins, and phenolic acids. These substances, which are mostly present in the grape's skin, give grapes their color and scent. Another byproduct produced by the majority of the wine businesses is grape seed, which makes up no more than 5 to 6% of the grape bunch's weight. Rich in tocopherols, which prevent oxidation of linoleic acid, and linoleic acid (60–70%), grape seed oil is distinctive. Important nutritional qualities of grape seed oil include lowering cholesterol and lipidemia, avoiding the development of atheromatous lesions, and improving human health (Cao and Ito, 2003; Maier et al., 2009). It is frequently utilized in non-food industries, such as the cosmetics industry to make soaps and even in lipoquimia to produce fatty acids. Proanthocyanidins, also known as catechin polymers or procyanidolic oligomers (OPC), are abundant in seeds and have the ability to partially scavenge cholesterol and provide a certain level of vascular protection (Cao and Ito, 2003; Maier et al., 2009).

2.4. Citrus Fruits

Worldwide, citrus fruits are a popular fruit family to eat. Their current distribution is primarily in warm, temperate regions with temperatures between 23 and 34°C; they originated in Southwest Asia (Amaro et al., 2015; Micheloud et al., 2016). Among the top producers are tropical and subtropical nations like Mexico (4.6%), Brazil (18%), China (21%), and India (6%). Another distinguishing feature of this fruit family is vitamin C. Citrus has a lot of this vitamin, which is a common antioxidant. We also found a lot of fiber and minerals like magnesium, calcium, and potassium in addition to these main ingredients (Rezzadori et al., 2012). Since the middle of the 1980s, citrus fruit production and consumption have grown significantly worldwide. Citrus residues have demonstrated a notable presence of polyphenols, primarily flavonoids, polymethoxyflavones, and glycosylated flavanones, as well as phenolic acids, in recent years (Domínguez, 2016; Sormoli and Langrish, 2016). Despite the fact that flavonoids are typically regarded as non-nutritive substances, research on flavonoids has been linked to a rise in interest in medications intended to treat a number of severe chronic illnesses (Roussos, 2011; Chen et al., 2017). Tomato residues are also a good source of bioactive compounds, particularly carotenoids like lycopene and β-carotene, which have a high antioxidant content and impart both favorable health qualities and high nutritional value. According to Colle et al. (2010), they also contain proteins, carbohydrates, waxes, ois, lycopene, β-carotene fiber, and seed oil.

2.5. Tomato

Given that a sizable portion of the economically active population is either directly or indirectly involved in tomato agriculture, tomatoes have a significant social significance. A low calorie value of 17 kcal/100 g, its high water content (90–94%), significant amounts of soluble sugars (fructose, glucose, and sucrose), a low percentage of proteins, fiber, and organic acids (citric and malic), and a notable amount of vitamins A and C, carotenoids, and mineral elements are its defining characteristics. This plant bears berries that are round, oval, or periphery in shape. The tomato can be categorized in three different ways based on its color, ripeness, and shape.There are five varieties based on shape, ranging from little to large: cherry, saladette, pear type, standard ball, and giant ball. According to Borel et al. (2015), lycopene is the main pigment that gives tomatoes their red color. It makes up about 80–90% of the pigments in the mixture (Basuny, 2012). Compared to carotene, it differs structurally (Campos et al., 2017). Zing et al. (2015) state that lycopene is not a precursor of vitamin A, in contrast to β-carotene. High levels of free radical scavenging and antioxidant capacity against singlet oxygen (1O2) are attributes of lycopene (Boyacioglu et al., 2016).

3. Food and waste product factors those are anti-nutritional

A good supply of protein, carbs, vitamins, and minerals are the waste byproducts. However, the presence of anti-nutritional factors (ANF) including condensed tannins, saponins, trypsin inhibitors, phytates, and isoflavonoids, among others, limits the use of these products in the food sector (Ee and Yates, 2013; Tresina et al., 2017). Plants produce ANF as a means of defense against predators during their secondary metabolism. Because ANFs bind to proteins, carbs, and minerals and interfere with their digestion and bioavailability, they lower the nutritional value of diets containing them. The two categories of ANF are thermostable and thermolabile. Among the thermolabile are protease inhibitors, amylases inhibitors, D, E and B_{12} antivitamins; and among the thermostable are the saponins, cyanogens, phytates, alkaloids, oligosaccharides, and tannins (Elizalde *et al*., 2009). Because fermentation reduces the amount of ANF and significantly increases the protein's digestibility, it has been determined to be one of the biological therapies with higher efficiency. Aspergillus and Rhizopus filamentous fungus, as well as lactic acid bacteria (LAB), are the most commonly used microorganisms in this context. Because these bacteria do not create mycotoxins, one of their unique qualities is that they are classified as safe (GRAS). Because lactic acid bacteria can create enzymes during fermentation, they are crucial to the decrease of ANFs. Filamentous fungus are used in certain research conducted under solid state fermentation conditions (SSF). A reduction of approximately 86% of condensed tannins was achieved by Londoño et al. (2016) using the strain Rhizopus oryzae (MUCL 28168) in an SSF process with sorghum as the substrate. The optimal conditions were temperature 32.97° C, air velocity 84.11 mm 3 min-1, wheat bran 1.16%, and particle size 0.82 mm. Although soybeans have the highest protein concentration of any legume, they also have a very high FAN content. Reducing these chemicals has been the subject of numerous scientific projects. In order to lower the amount of phytic acid in soy meal, Chen et al. (2014) employed the strain Aspergillus oryzae (ATCC, 9362) in an SSF. With an inoculum size of 1.7 mL and 41% moisture at 50°C, 57% of the phytic acid was decomposed. Similarly, there was a 9.5% rise in protein content.

Conclusion

One concerning issue for both individuals and the environment is food waste. Food wastes and byproducts should, therefore, be valued for social, economic, and environmental reasons. It is possible to turn food wastes and byproducts into useful goods via thermal, chemical, and biological processes. The goal of the recovery process and the makeup of food wastes and byproducts are taken into consideration while choosing the right conversion procedure. Food waste utilization for human consumption has to be a top priority given the nutritional issues that modern civilization faces (such as hunger indices and an expanding global population). In addition to having significant nutritional and functional value in its formulation, wastes and byproducts generated in underdeveloped nations can effectively reduce hunger. Furthermore, the diversification of production chains can offer added value by opening up job opportunities for locals, so yielding additional social benefits.

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