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Vegetable Waste Management: Techniques and Utilization

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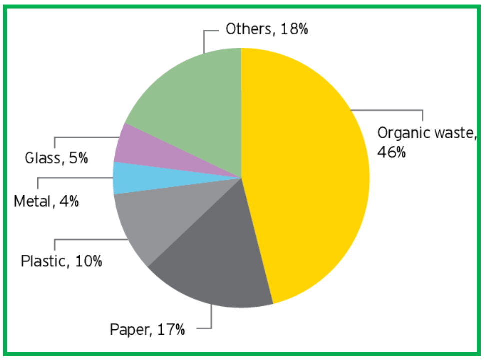
Abstract

Human population of the world is continuously rising and with the limited natural resources, it is difficult to supply food to the growing population. At the same time, due to the rising human population, there is a high demand for food production. Fruits and vegetables (FV) consumption is considerably increased with the increase in awareness of FV and their health benefits to humans. But most of the population do not consume raw FV in many cases and thusthis FV need to under go some kind of processing. During the processing,large amount of waste is generated. By using the 4R principle reduce, reuse, recycle and recover we can convert the waste into various value-added products like animal feed, bio-energy, briquetts, organic acids and enzymes, nutaceuicals etc. Here, we have discussed traditional and advance methods of vegetable waste management. Advance technologies like nutaceuticals, natural pigments, bioplastics, flavours and enzymes and single cell protein are more sustainable, valuable and environment friendly compare to traditional methods of managing waste.

Introduction

Fruits and vegetables are the most consumed commodities among all horticultural crops. It can either be consumed raw or as value-added products. But, with continuous increase in population and imbalances in supply chains from time to time, a growing concern has led to increase in food waste being generated globally. This food waste is generated after harvest at farmer level and as leftovers at households, restaurants and commercial establishments. Out of the different proportions of food materials wasted, fruits and vegetable waste constitute a significant proportion (42 %).

Depending on plant species and tissues, the waste generated from fruit and vegetable waste possesses a wide variety of properties. For instance, the waste peels and seeds are high in phytochemical compounds and therefore it can be utilized in food flavoring agents and preservation compounds. Similarly, the vegetable tissues are rich in carotenoids, vitamins and fibers possess antioxidant and anti-diabetic properties, which can prevent human diseases and disorders. Thus, effective utilization of waste products in different applications provide a valuable source in reducing environmental issues as well as solving the challenges in a sustainable manner.



Source: World Bank Report

Global solid waste scenario

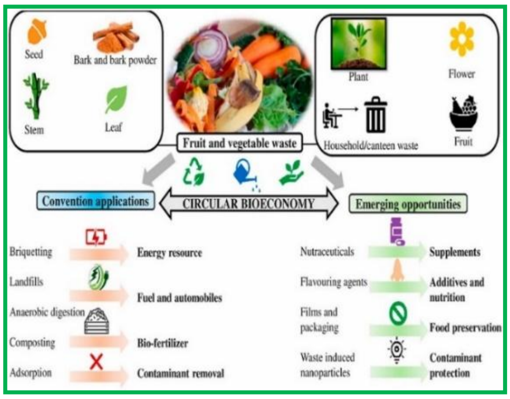
Globally, solid waste management (SWM) has been a major developmental concern because of its negative effects on health, social, environmental and economic system. According to the World Bank Report, solid waste consists of highest percentage of organic waste which accounts to approximately 46% globally, however the non-organic waste consists of paper, glass, metal, plastic and other materials. One of the major concerns emerged due to increased solid waste generation and unethical disposal mechanisms is greenhouse gas (GHG) emissions. As per the industry reports, methane released due to the irregular dump in landfill accounts for 12% of the GHG emissions.

What is Vegetable Waste?

Vegetable wastes include the rotten peels, shells, seed, pomace, stem and scraped portions of vegetables or slurries. The main forms of these organic waste are domestic/household, industrial and agricultural waste. Vegetable waste is a decomposable material generated in large amount, much of which is dumped on land to rot in the open, which not only emits a bad odor, but also creates a big nuisance by attracting birds, rats, and pigs—vectors of various diseases. Apart from post-harvest losses due to lack of storage capacity, processing and poor packaging of vegetables, customers' specifications also play a major role in waste generation.

Characterization of vegetable waste: evaluation for reusability

Vegetable and fruit wastes needs to be characterized to understand its nature of application as raw material and to propose the best methodology for its proper utilization. Characterization of waste can be done physically, chemically, or biologically. Bioconversion of vegetable residues to valuable products is highly dependent upon the biochemical composition of the left-over material. Therefore, the characterization of the waste generated through the systems is an essential step. The next step focuses on identifying, analyzing and designing for potential recovery and reuse of it. Together all these steps, form a systematic methodology that develops a circular bio economy model for waste management.



Circular Bioeconomy

Importance of vegetable waste management

It helps in solving the problem of food scarcity. We can relocate unused food to those people who are suffering from food insecurity. It is a good source of nutrients and can increase soil fertility- bio-compost, vermicompost. It acts as a good supplement for the nutrition of human population- nutraceuticals, bioactive compounds. Different types of value-added products can be prepared- animal feed, bio-energy, compost. It prevents environmental pollution by reducing the green-house gas (methane) emissions. It increases the economic returns of the industry.

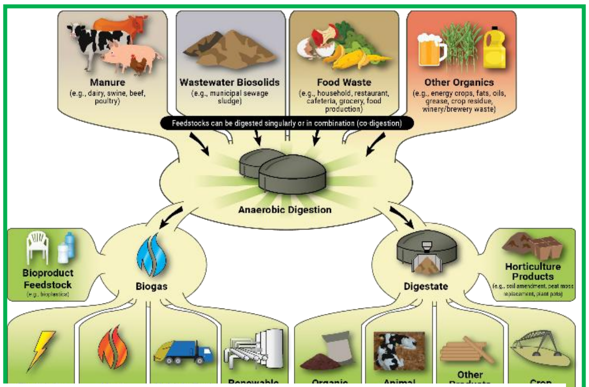
Traditional methods of vegetable waste management

Land Filling: Landfills are considered as one of the traditional and easiest disposals for solid waste. As these vegetable/fruit wastes have higher decomposability than other wastes, they are dumped into landfill. But the major concern about landfilling is that it produces landfill gases and this landfill gases (LFG) are considered as one of the largest sources of methane which is responsible for 8 % of global green-house gas (GHG) emissions. With time, these landfills stabilize and form leachates that dramatically impact the soil quality and overall environment.

Animal Feeding: Fruit and vegetable wastes like tomato pomace, bottle gourd pomace, citrus pulp, carrot pulp, cabbage and cauliflower leaves, sarson saag waste and pea pods, pineapple waste etc. are highly fermentable and perishable, because of high moisture (80−90 percent) content. Suitable methods should be adopted to conserve such waste resources so that it can be fed to the livestock throughout the year or specifically during the lean period of green fodder production. The most commonly used methods of making animal feed is drying or silage making (anaerobic fermentation of waste material.

Composting: Composting is defined as the biodegradation of organic matter that involves a reaction in which aerobic micro-organisms decomposes the substrate of waste to produce carbon dioxide (CO_2) and heat, and finally transformed into stable compost. Different types of composting techniques are used such as vermicomposting, windrow and static composting. One of the most commonly used processes is vermicomposting. In which compost is generated through earthworms. Moisture levels, pH and temperature process control is required for better compost efficiency.

Anaerobic digestion: By anaerobic digestion, biomass waste is converted to biogas (by bacteria in the absence of oxygen) and compost. The biogas is mainly a mixture of CO_2 and CH_4. Anaerobic digestion is carried out in specifically designed bioreactors (digesters) that allow controlling the main operating parameters. The technique can be carried out at different temperatures, namely psychrophilic (10-20 °C), mesophilic (25-35 °C), and thermophilic (55- 65 °C). Biological degradation is a complex process that involves several steps such as i) Hydrolysis ii) Acidogenesis iii) Acetogenesis iv) Methanogenesis.



Anaerobic digestion system

Waste to Bioenergy: Waste to bioenergy model reduces the amount of waste to end up in landfill and in turn generates clean and reliable energy from a renewable fuel source reducing GHG (Green-house gas) emissions. As of November 2016, 33 waste-to-energy (WtE) plants were operational in the country. Andhra Pradesh has the largest installed capacity of WtE plants at 74 MW (27%). The top five states in terms of potential for energy recovery from MSW (Municipal Solid waste) are Maharashtra, Uttar Pradesh, Tamil Nadu, West Bengal and Delhi.

Biogas: Biogas, collected during anaerobic digestion by the microbial bacteria, is a cheap form of renewable energy that is environmentally friendly. Normally, biogas is composed of 45–70 % methane, 30–45 % carbon dioxide, 0.5–1.0 % hydrogen sulfide, 1–5 % water vapor, and a smaller number of other gases (hydrogen ammonia, nitrogen, etc.). Use of vegetable waste for biogas production not only solves the problem of landfilling of waste and pollution, but also reduces the dependency on fuel wood.

Bioethanol and Biobutanol: The wastes from fruit and vegetable processing industries being rich in polysaccharides (cellulose, hemi-cellulose and lignin) can be subjected to solid state fermentation for the production of ethanol and butanol, which has several uses such as a solvent in many industries and alsoas a liquid fuel supplement. Vegetable waste to biofuel production consists of biomass pretreatment, saccharification, and fermentation. Ethanol has been a key industrial chemical for many years. Fuel ethanol, in particular, is considered more environment friendly than fossil fuels. It has been seen as a replacement for gasoline. The potential microorganisms for ethanol fermentation include *Saccharomyces cerevisiae*, *Zymomonas mobilis* and recombinant *Escherichia coli*, *S. cerevisiae*.is widely used for industrial ethanol production.

Table 1: Different value-added product developed from vegetable waste

Vegetable waste	Value added products	References
Asparagus waste	Mushroom production	Wang *et al*., 2010
Tomato waste	Biomethane, Biogas, single cell protein	Fernandez-gomez *et al*., 2010; Trujillo *et al*., 1993; Viswanath
Onion waste	Vinegar, Biomethane	Horiuchi *et al*., 1999; Romano and Zhang 2008
Carrot waste	Biohydrogen, Mass production of entomopathogenic fungi	Sahayaraj and Namasivayam, 2008; Vrije *et al*., 2010
Cabbage waste	Briquetts, single cell protein	Sahayaraj and Namasivayam, 2008; Vrije *et al*., 2010

Thermal processes

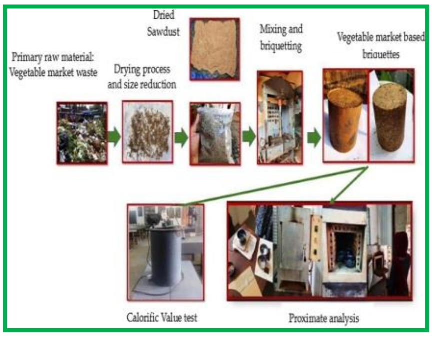
The main thermal processes are gasification, combustion and pyrolysis.

Gasification: It is a thermal process which utilizes high temperature of above 8000°C and an oxygen-deficient environment to convert solid biomass into combustible synthetic gas or syngas (mainly CO and H_2). The syngas produced can be used as energy source for electricity generation. Solid by-product biochar has great applications in agriculture to improve soil quality by enhancing the nutrient content, remediate pollution by adsorbing aromatic contaminants and heavy metals, for soil rehabilitation purposes biochar can be applied to the nutrient-poor, acidic soil.

Pyrolysis: The pyrolysis of biomass is considered a thermochemical conversion process, where biomass is heated to temperatures greater than 400 °C, under the partial presence of/or the complete absence of oxygen, along with capturing the off gases.

Combustion/Incineration: Combustion is a process in which biomass is directly burnt in the presence of oxygen/air, and consequently the stored chemical energy in biomass gets converted into thermal energy (*i.e.* heat). This process takes place within a temperature range of about 800–1000 °C.

Briquetting: The feasible alternative option to deal with the solid vegetable waste is to convert it into high density briquettes, which give flexibility in storage, transportation as well as the use as per requirement. Briquetting of dried vegetable waste biomass can be done by bringing its moisture content to the specific level, drying and mixing it with some kind of binder or by direct compacting. The raw green vegetable market waste gave about 15 to 20% dry matter after open sun drying. The lignin present in the waste provides high calorific value and aids the binding of particles leading to briquette or pellet formation.

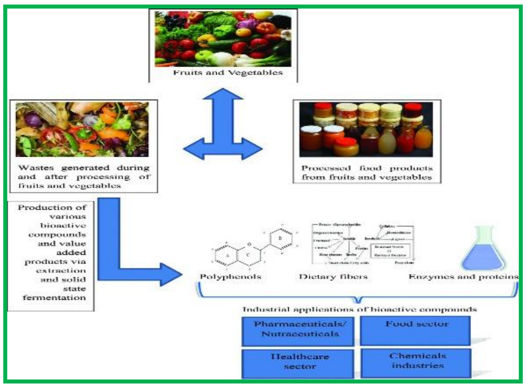


Briquetting process

Emerging opportunities of vegetable waste management

Bio-active Compounds: Fruits and vegetables waste contains good sources of potentially valuable bioactive compounds, such as carotenoids, polyphenols, dietary fibers, vitamins, enzymes, organic acids and oils. These phytochemicals can be utilized in different industries including the food industry, for the development of functional or enriched foods and in the health industry for nutraceuticals. It possesses beneficial health attributes: antioxidant, antibacterial, antitumor, antiviral, antimutagenic, and cardioprotective activities.

Nutraceuticals: Nowadays there is an increase in diet-related health problems therefore need for the supplement diet becomes essential. These fruits and vegetables contain essential compounds and oils present in small amounts. Nutraceuticals are compounds derived from a food or a part of it (byproducts like potato peels, tomato pomace, onion skin etc.) to provide health benefits for human beings by treating or preventing diseases. Bioactive compounds from vegetable and fruit waste act as a pool for the production of nutraceuticals.



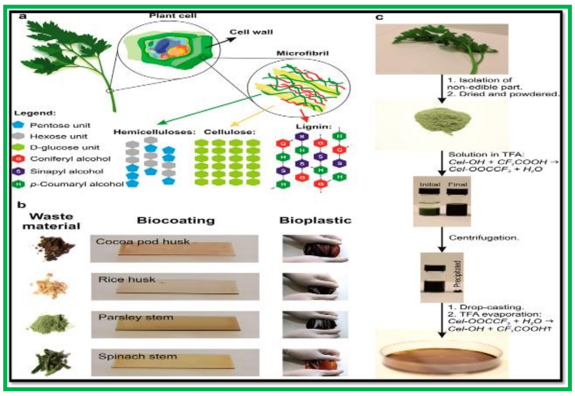
Fate of fruits and vegetables after & during processing

Table2: Total (TDF), insoluble (IDF), and soluble (SDF) dietary fiber contents in the waste of different fruits and vegetables

Commodity	Type of waste	TDF (%)	IDF (%)	SDF (%)	Reference
Pea	Hulls	91.5	87.5	4.1	Ralet and others (1993)
Green chilli	Peel and seeds	80.41	-	-	Matsuda (1997), Mckee and latner (2000)
Pumpkin	Pomace	76.94	-	-	Turskoy and ozkaya 92011)
Onion	Skin	68.3	-	-	Jaime and others (2002)

Natural Pigments: Synthetic pigments from petrochemicals have been extensively used in a wide range of food products. However, these pigments have adverse effects on human health. Hence, there is a need for sustainable production of pigments from renewable bioresources. Vegetable wastes/by-products are a rich source of natural pigments such as: anthocyanins, betalains, carotenoids, and chlorophylls. Utilization of vegetable wastes and their by-products can meet the demands of natural pigment production at the industrial levels for functional food, natural food dye, pharmaceuticals and cosmeceuticals applications.

Bio-Plastics: Combining different fruit/vegetable-derived materials as possible films for bio-packaging has attracted various researchers to produce sustainable materials as an alternative for plastics. Various attempts were made using starch/cellulose as the primary material. Cellulose is a natural polymer with an abundant resource. Bioplastic production from vegetable or fruit waste can be considered a sustainable process due to its biodegradability and carbon-neutral nature. Industrially processed wastes from edible cereals and vegetables rich in cellulose can be transformed into bioplastics by simply aging them in trifluoroacetic acid (TFA) solutions.



Bio-plastic production process

Summary

The foregoing discussion describes that using conventional and emerging application in vegetable waste management, we can prepare various value-added products like biogas, bioethanol, vermicompost, livestock feed, phenolic compounds, organic acids, enzymes, biopolymers, dietary fiber and natural pigments. Various bioactive compounds derived from by-product of vegetable waste can be used in preparation of functional/nutraceutical food. Compared to conventional methods where high volumes of fruit and vegetable wastes are required to produce value-added products, emerging approaches in terms of low volume, high value with improved sustainability is forecasted as a possible road forward. Greener technologies to extract value-added products from vegetable waste (micro or nanoencapsulation) could enhance the bioavailability providing healthier benefits than the conventional practices. However, strict considerations must be given considering safety, feasibility, cost-effectiveness, and sustainability for a better scale-up of waste management systems.