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Fruit Waste Utilization and Management for Clean and Healthy Ecosystem

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Fruit waste, which includes peels, seeds and pulp, constitutes a significant portion of food waste globally. Despite its high nutritional and biochemical potential, fruit waste is often discarded, contributing to environmental pollution. However, the utilization of fruit waste through various techniques offers promising opportunities for value-added products. This paper explores the diverse methods employed in fruit waste utilization, including bio-conversion, composting, fermentation and extraction of bioactive compounds. Specific techniques such as biogas production and the development of functional foods and natural pigments are discussed. Additionally, the potential for converting fruit waste into biodegradable packaging materials, animal feed and fertilizers is examined. The paper also highlights the environmental, economic, and health benefits of recycling fruit waste, while identifying challenges such as cost-effectiveness and scalability. Overall, the integration of these techniques can contribute to waste reduction, promote sustainability and create new market opportunities, ultimately reducing the ecological footprint of the fruit processing industry.

Keywords: Fruit waste, Biogas, Bioactive compound, Compost, Value added product

Introduction

Among the many factors that have caused the global environmental burden in recent years, the impact of fruit and vegetable waste has been identified as a major problem. The proportion of waste materials produced during handling and processing of the fruit and vegetable is usually high. Because of the characteristics of fruits and vegetables, it is natural to generate losses during the process of selection, washing, cleaning, peeling, and nucleating in the industrialized production and handling of fruits and vegetables. In addition, fruits and vegetables are rich in enzymes and subjected to enzymatic browning. The waste peels and seeds are high in phytochemical compounds and therefore can be used as food flavoring agents and preservation compounds. Similarly, the fruit tissues rich in carotenoids, vitamins and fibers possess antioxidant and antidiabetic properties, which can prevent human diseases and disorders.

IARI Director Dr. A. K. Singh in an interview to IANS said that almost 30 to 40 per cent of vegetables and fruits and almost 10 per cent of the total agricultural produce go to waste in the country. "If these products are been preserved properly then we will not only be able to increase the production while can also help the farmers in doubling their income," he said. Globally, the production of fruits and vegetables is about 675 million metric tons annually and out of which 1.3 billion ton wastage is produced. India alone produces 86.602 million metric tons of fruits and vegetables and constitute about 5.6 million ton of waste annually. Fruits and

vegetables account for the largest portion of that wastage. 18% of India's fruit and vegetable production valued at Rs 13,300 crore is wasted annually.

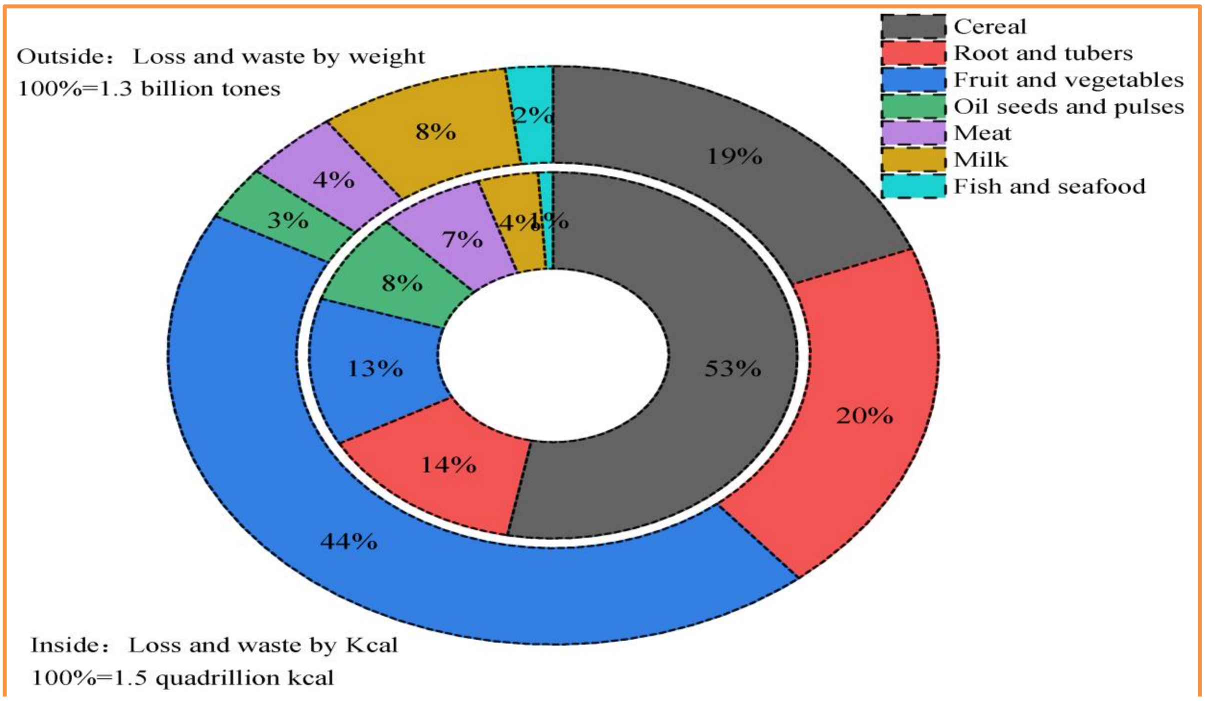
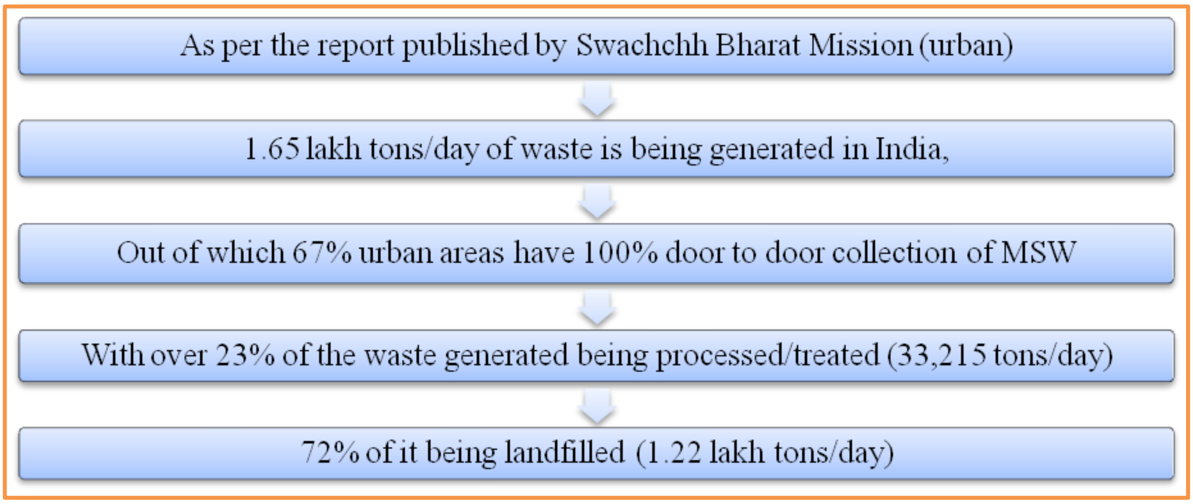


Fig. 1: Global food loss and waste by different calculations; Source: (ReFED – Rethink Food waste Through Economics and Data, 2020)

Solid waste scenario in India



Source: ASSOCHAM - EY report (2019)

Three most significant factors of post harvest loss of fruits

1. Lack of linkage between farmers and processing unit

- The effective linkage between farmers and processing units help to share valid information about the costs, stabilize fruit markets, maximize benefits, and minimize the risk of price fluctuations with farmers.

2. Lack of linkages between industry, government and institution

- The government can bridge the gap between industries (public and private) and the institutions.

3. Lack of usage of technology and advanced technique in food processing

- The knowledge regarding the latest trends in technology should be imparted to the supply chain members at various stages, through exhibitions or seminars.

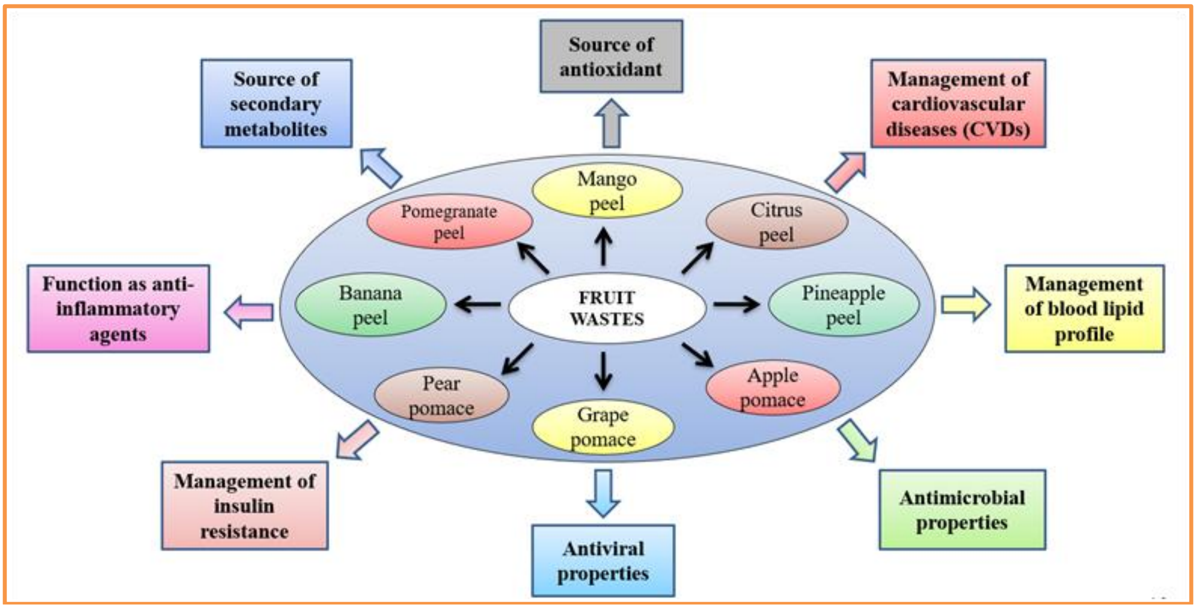


Fig. 2: Fruit waste and its bioactive compound

Food waste management hierarchy

Prevention → Prevent food waste generation throughout food supply chain

Re use → Reuse surplus food for people affected by food poverty, through redistribution network

Recycle → Recycle the waste to prepare value added products like animal feed, compost, functional food etc.

Recover → Treat food waste and recover energy via anaerobic digestion, gasification, briquetting

Disposal → Dispose waste into engineered landfill with landfill gas utilization system in place, only as the last option

Current technologies used for fruit wastes in food engineering

- Microwave-Assisted Extraction (MAE)
- Supercritical Fluid Extraction (SFE)
- High Hydrostatic Pressure Technique (HHP)
- Pulsed Electric Field (PEF)
- Ultrasonic-Assisted Extraction (UAE)
- Pressurized Liquid Extraction (PLE)
- Enzyme-Assisted Extraction (EAE)

Conventional applications

1) Waste to bioenergy conversion

Waste to energy (WTE) technology in India is based on build, operate and transfer model. As of 2022, A total of 14 waste to energy plants have been installed in India, out of which seven plants were closed. Andhra Pradesh has the largest installed capacity of WTE plants at 74 MW.

A. Animal feeding

Fruit wastes like apple pomace, banana peel, citrus peel and molasses, mango peel and pineapple wastes, etc. either fresh or dried serve as excellent alternative feed resources for livestock. 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.

B. Land filling

Landfills are considered as one of the traditional and easiest disposals for solid waste. As these fruit wastes have higher biodegradability than other wastes, they are disposed into landfill.

➢ **Disadvantages:**

- Landfill gases (LFG) are considered one of the largest anthropogenic sources of methane, responsible for 8 % of global greenhouse gas (GHG) emissions.
- With time, these landfills stabilize and form leachates that dramatically impact the soil quality and overall environment.

C. Anaerobic digestion

By anaerobic digestion, biomass waste is converted to biogas (by bacteria in the absence of oxygen) and compost. 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

❖ **Biogas:**

Biogas is a renewable energy source that's produced by breaking down organic matter in anaerobic conditions. Biogas is principally a mixture of methane (CH_4) and carbon dioxide (CO_2) along with other trace gases. The biogas typically has 60% methane and 35% carbon dioxide, there is also some percentage of hydrogen, nitrogen, oxygen, ammonia, moisture etc.

Table – 1: Biogas production using fruit wastes

Substrate	Total organic carbon (%)	Total Nitrogen (%)	Total Phosphorous (%)	C/N ratio	Total solids (%)	Average Biogas production (l/ kg)
Pulp	55.59	0.44	0.005	126.34	20.21	12.29
Pineapple peel	52.25	0.82	0.070	63.71	12.68	3.75
Mango peel	61.00	0.88	0.045	69.31	19.51	2.92
Papaya peel	45.76	2.89	0.182	15.81	16.96	6.42
Rotten wood apple	40.10	1.52	0.089	26.38	49.33	2.3
Mixed peel	49.17	1.76	0.096	27.93	18.30	8.5

❖ **Bioethanol:**

Bioethanol is a liquid biofuel produced from several different biomass feedstocks and conversion technologies. Fruit waste contains a lot of sugars and carbohydrates that can be collected and used to make bioethanol. The best conditions for ethanol production from fruit waste yields were pH 5.5, 32 °C, 0.865 specific gravity and a concentration of roughly 6.10 %, according to the findings.

Table – 2: Bioethanol production from fruit pulp and peel

Sample	Fruit Parts	Maximum ethanol content (% w/w)	Fermentation efficiency (%)	Ethanol Productivity (% w/w per hour)
Banana	Pulp	28.45	55.78	0.593
	Peel	13.84	27.13	0.330
Mango	Pulp	26.50	52.00	0.552
	Peel	9.68	18.96	0.230
Mixed fruit	Pulp	35.86	70.33	0.747
	Peel	11.94	23.40	0.284

D. Composting

Composting is defined as the biodegradation of organic matter that involves a reaction in which **aerobic microorganisms decompose** the substrate of waste to **produce carbon dioxide (CO_2) and heat**, and finally transformed into stable compost. Moisture levels, pH and temperature process control is required for better compost efficiency. Different types of composting techniques are used such as vermicomposting, NADEP, windrow and static composting.

- One of the most commonly used technique is **vermicomposting** in which compost is generated through **earthworms.**
- **NADEP composting method:**

The NADEP method of making miracle compost was first invented by a farmer named N.D. Pandharipande (also popularly known as "Nadepkaka") living in Maharashtra (India). Compost can be prepared from a wide range of organic materials including dead plant material such as crop residues, weeds, forest litter and kitchen waste. Compost making is an efficient way of converting all kinds biomass into high value fertilizer that serves as a good alternative to farmyard manure, especially for crop-growing households without livestock.

- **Windrow composting:**

It can treat large volumes of waste. Vegetable and fruit waste are placed in piles or windrows (triangular or trapezoidal form) and mixed manually. Produces high quality of compost at high temperatures.

- **Static composting involving active aeration:**

Fast and efficient composting method. It requires less time and space. Agents, air (or blowers) are passed into the pit to control aeration. Mature compost can be generated within 3 to 4 months.

2) Thermal process

- The main thermal processes are gasification, pyrolysis and combustion.

1. Gasification

It is thermal process which utilizes high temperature of 600 to 1300 °C and presence of limited amounts of oxygen to convert solid biomass into combustible synthetic gas (syngas) (mainly CO and H_2). The syngas produced can be used as energy source for electricity generation.

2. Pyrolysis

The pyrolysis of biomass is considered a thermochemical conversion process, where biomass is heated to temperature ranges from 400-800 °C, under the complete absence of oxygen, along with capturing the off gases.

3. 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 to 1000 °C.

3) Briquetting

The feasible alternative option to deal with the solid fruit waste is to convert it into high density briquettes, which give flexibility in storage, transportation as well as the use as per requirement. The lignin present in the waste provides high calorific value and aids the binding of particles leading to briquette or pellet formation.

Emerging opportunities

- **Bioactive Compounds**

Fruit 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 and in the health industry for nutraceuticals. It possesses beneficial health attributes: antioxidant, antibacterial, antitumor, antiviral, antimutagenic, and cardioprotective activities.

- **Natural pigments**

Fruit wastes/by products are a rich source of natural pigments such as: anthocyanins, betalains, carotenoids and chlorophylls. Utilization of fruit wastes and their byproducts can meet the demands of natural pigment production at the industrial levels for functional food, natural food dye, pharmaceuticals and cosmeceuticals applications.

- **Bioplastics**

Industrially processed wastes from edible cereals and fruits rich in cellulose can be transformed into bioplastics by simply aging them in Trifluoroacetic acid (TFA) solutions.

- **Advantage of bioplastics**

1. Environmental friendliness
2. In packaging materials like bags, bottles, and containers
3. Biodegradable mulch films from bioplastics
4. Medical devices
5. Automotive industries
6. Textiles

Conclusion

The foregoing discussion describes that using conventional and emerging application in fruit 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. High amount of TDF (total dietary fiber) was recorded from apple pomace and carotenoids, anthocyanin and betalain was extracted from different fruit waste. Various bioactive compounds derived from byproduct of fruit 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.