Chapter 3
Food Industry Waste: A Panacea or Pollution Hazard?

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Abstract The food-processing industry produces large volumes of wastes, both solids and liquids, generated from the production, preparation, and consumption of food. These wastes pose increasing disposal and potentially severe pollution problems and represent a loss of valuable biomass and nutrients. Due consideration to proper utilization and disposal of solid waste is the need of the hour for sustainable industrial development. Industrial waste management techniques can be classified into three options: source reduction by processing plant modification, waste recovery, recycle or waste treatment for value-added products and eco-friendly detoxification or neutralization of the undesirable components. Efficient management of waste can bring down the cost of production of processed foods and minimize the pollution hazard.

Concept of 4-R, comprising Reduce, Reuse, Recycle, and Recover, is the ultimate goal to optimize utilization of solid waste while minimizing environmental problems. Extraction of pectin, essential oils from the citrus peels, and whey protein concentrate from whey are some of the examples of by-product utilization from food-processing industry. The by-products of fruits and vegetables are also found to be good sources of antioxidants and antimicrobial compounds. Microbial synthesis of single cell protein, amino acids, and vitamins is also possible by the use of whey, molasses, etc. The ultimate goal of green productivity could be achieved through zero discharge, zero emission, zero pollution, cost-effective processing, and application of clean production technology.

The waste from food-processing industry is not a waste in a real sense but can be converted and utilized as food, feed, and fodder. The regulatory agencies and the food-processing industries can work hand in hand to develop new processes for waste management and utilization which are commercially viable.

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1 Introduction

India's food-processing sector covers fruits and vegetables; meat and poultry; milk and milk products, alcoholic beverages, fisheries, plantation, grain processing, and other consumer product groups like confectionery, chocolates and cocoa products, soya-based products, mineral water, high protein foods, etc. The most promising sub-sectors include soft-drink bottling, confectionery manufacture, fishing, aquaculture, grain-milling and grain-based products, meat and poultry processing, alcoholic beverages, milk processing, tomato paste, fast food, ready-to-eat breakfast cereals, food additives, flavors, etc. Health food and health food supplement is another rapidly rising segment of this industry, which is gaining vast popularity amongst the health conscious.

India is ranked fifth in the world in terms of production, consumption, and export of processed food. It is a leading producer of quite a few agriculture-based and dairy-based items. It is ranked first in the world in production of rice, milk (fresh, whole, buffalo milk), pulses, ginger, chick pea, and fruits such as banana, guava, papaya, and mango. India also holds second position in the world in production of wheat, potato, garlic, cashew nut, ground nut, dry onion, green pea, pumpkin, guard, and cauliflower. A good agricultural and dairy produce enables India to expand its food-processing industry and meet the global demand easily after satisfying the domestic needs.

The food industry is now facing increasing pressure to ensure that their company's activities are environmentally sensitive, but there is also increased internal pressure to maintain or increase profitability in the face of fierce competition.

"Food waste" refers to food that is of good quality and fit for human consumption but that does not get consumed because it is discarded—either before or after it spoils. Food waste typically, but not exclusively, occurs at the retail and consumption stages in the food value chain and is the result of negligence or a conscious decision to throw food away (FAO 2013). Food loss and waste have many negative economic and environmental impacts. Economically, they represent a wasted investment that can reduce farmers' incomes and increase consumers' expenses. Environmentally, food loss and waste inflict a host of impacts, including unnecessary greenhouse gas emissions and inefficiently used water and land, which in turn can lead to diminished natural ecosystems and the services they provide.

Food loss and waste can occur at each stage of the food value chain. Some examples of how they can occur at each stage are:

- During production or harvest in the form of grain left behind by poor harvesting equipment, discarded fish, and fruit not harvested or discarded because they fail to meet quality standards or are uneconomical to harvest
- During handling and storage in the form of food degraded by pests, fungus, and disease

- During processing and packaging in the form of spilled milk, damaged fish, and fruit unsuitable for processing
- Processed foods may be lost or wasted because of poor order forecasting and inefficient factory processes
- During distribution and marketing in the form of edible food discarded because it is noncompliant with esthetic quality standards or is not sold before "best before" and "use-by" dates
- During consumption in the form of food purchased by consumers, restaurants, and caterers but not eaten

The food-processing industry has special concerns about the health and safety of the consumer. Key resources used by the food-processing industry include the water, raw materials, and energy. The key environmental issues for the food industry include the following:

Wastewater: Primary issues of concern are biochemical oxygen demand (BOD); total suspended solids (TSS); excessive nutrient loading, namely nitrogen and phosphorus compounds; pathogenic organisms, which are a result of animal processing; and residual chlorine and pesticide levels.

Solid Waste: Primary issues of concern include both organic and packaging waste. Organic waste, that is, the rinds, seeds, skin, and bones from raw materials, results from processing operations. Inorganic wastes typically include excessive packaging items that are plastic, glass, and metal. Organic wastes are finding ever-increasing markets for resale, and companies are slowly switching to more biodegradable and recyclable products for packaging. Excessive packaging has been reduced and recyclable products such as aluminum, glass, and high-density polyethylene (HDPE) are being used where applicable.

Some Glaring Facts

- India, the world's second largest fruit and vegetable producer, encounters a waste of close to 18% worth INR 44,000 crore ($7 billion) of produce (Anonymous 2012).
- The latest DIPP paper on Foreign Direct Investment (FDI) in retail estimated that against a production of 180 million metric tons a year of fruits, vegetables, and perishables. India has a capacity of storing only 23.6 million metric tons in 5386 cold storages across the country (Anonymous 2013).
- The Saumitra Chaudhuri Committee in 2012 indicated 61.3 million tonnes of cold storage requirement in the country against the present capacity of around 29 million tonnes.
- The country lost INR 45 crore ($7.2 million) worth of food grain in the past 5 years (Baweja 2013).
- A report by the Institution of Mechanical Engineers reveals that each year 21 million tonnes of wheat which is equivalent to Australia's annual grain production is wasted in India.
- Food Corporation of India (FCI) reports show that food grain worth Rs. 120.29 crore ($19.2 million) was lost in storage, while Rs. 106.18 crore ($17 million)

Table 3.1 Percentage of losses estimated for major produces

Crop	Cumulative wastage (per cent)
Cereals	4.65–5.99
Pulses	6.36–8.41
Oil seeds	3.08–9.96
Fruits and vegetables	4.58–15.88
Milk	0.92
Fisheries (Inland)	5.23
Fisheries (Marine)	10.52
Meat	2.71
Poultry	6.74

Source: CIPHET Study on post-harvest losses, 2016

worth of grain was lost in transit. The remaining Rs. 9.85 crore ($1.5 million) worth of food grains were not fit for human consumption (Thomas 2013).

As per a study conducted by the Central Institute of Post-Harvest Engineering & Technology (CIPHET), Ludhiana (published in 2016). Post-harvest losses of major agricultural commodities including fruits and vegetables at national level was estimated to the tune of about Rs. 92,651 crore per annum at 2014 wholesale prices. The cumulative wastage in fruits and vegetables is estimated in the range of 4.58–15.88% (Wastage of Agricultural Produce 2016) (Table 3.1).

2 Pollution from Food Processing

2.1 Fruit and Vegetable Food-Processing Sector

The primary steps in processing fruits and vegetables include:

1. General cleaning and dirt removal
2. Removal of leaves, skin, and seeds
3. Blanching
4. Washing and cooling
5. Packaging
6. Clean-up

Wastewater and solid wastes are the primary area of pollution control within the fruit and vegetable food-processing industry.

Wastewater is high in suspended solids, organic sugars, starches, and may contain residual pesticides.

Solid wastes include organic materials from mechanical preparation processes, i.e., rinds, seeds, and skins from raw materials.

2.2 Meat, Poultry, and Seafood Sector

The primary steps in processing livestock include:

1. Rendering and bleeding
2. Scalding and/or skin removal
3. Internal organ evisceration
4. Washing, chilling, and cooling
5. Packaging
6. Clean-up

Meat, poultry, and seafood facilities offer a more difficult waste stream to treat. The killing and rendering processes create blood by-products and waste streams, which are extremely high in BOD. These facilities are very prone to disease spread by pathogenic organisms carried and transmitted by livestock, poultry, and seafood.

Waste streams generalized into the following: process wastewaters; carcasses and skeleton waste; rejected or unsatisfactory animals; fats, oils, and greases (FOG); animal faeces; blood; and eviscerated organs.

2.3 Beverage and Fermentation Sector

The primary steps in processing beverages are

1. Raw material handling and processing
2. Mixing, fermentation, and/or cooking
3. Cooling
4. Bottling and packaging
5. Clean-up

Wastewater and solid waste are the primary waste streams for the beverage and fermentation sector. Solid wastes result from spent grains and materials used in the fermentation process. Wastewater volume of “soft-drink processes” is lower than in other food-processing sectors, but fermentation processes are higher in BOD and overall wastewater volume compared to other food-processing sectors.

2.4 Dairy Sector

A majority of the waste milk in dairy wastewaters comes from start-up and shut-down operations performed in the high-temperature, short time (HTST) pasteurization process. This waste is pure milk raw material mixed with water.

Another waste stream of the dairy sector is from equipment and tank-cleaning wastewaters. These waste streams contain waste milk and sanitary cleaners and are one of the principal waste constituents of dairy wastewater.

Over time, milk waste degrades to form corrosive lactic and formic acids. Approximately 90% of a dairy's wastewater load is milk.

2.5 Can Cooker Products

Water plays a role in most of the problems associated with metal food containers after processing. Whether steam, hot water or cold water, each can serve as the vehicle to transport undesirable substances.

2.6 Food Packaging Waste

The role of packaging is to protect the food between processing and usage by the consumer. After the usage, packaging needs to be dealt with in an environmentally responsible manner (Marsh and Bugusu 2007). Packaging contributes significantly to the waste. Food packaging accounts for two-thirds of total packaging waste by volume (Hunt et al. 1990).

3 Techniques to Protect Environment

Concept of 4-R, comprising Reduce, Reuse, Recycle, and Recover, is the ultimate goal to optimize utilization of solid and liquid waste while minimizing environmental problems.

- Since food is such an incredibly valuable resource that can be used to protect our soil and water or grow our next generation of crops, there are so many better uses for it to consider before putting in a landfill or incinerator.
- If food is anaerobically digested for renewable energy production, then the residuals (digestate) can, and should, be put to beneficial use to then feed the soilnot landfills.

Various methods to protect environment from food industry waste can be:

3.1 Source Reduction

Source reduction is the most effective method of environmental protection to decrease the volume of waste material and by-products generated in the production process. Source reduction should be the most logical starting point for reducing disposal. Examples of source reduction include:

(a) Use brooms and scrapers to clean floors and equipment while they are dry before washing them down with water.
(b) Use high-pressure spray washes during clean-up to conserve water.
(c) Dedicate mixing lines to certain products to reduce changeover clean-ups.
(d) Minimize spills and leaks on the production line to prevent raw materials from becoming wastes.

3.2 *Food Waste Management Alternatives*

Many alternatives exist for managing the food waste. They include:

3.2.1 Using the Food By-Product as an Animal Feed

Feeding food by-products directly to livestock allows for former wastes to be useful again. In addition, the quantity of liquid and solid waste is reduced when by-products are fed to livestock rather than being disposed of in landfills or wastewater treatment plants.

3.2.2 Composting or Land Spreading the Food By-Product

With proper management, food by-products can be kept out of the landfill and instead be composted and added to the soil at appropriate rates.

Benefits of compost to the food industry are:

(a) Reduces solid waste disposal fees
(b) Ends wasting large quantities of recyclable raw ingredients
(c) Educates consumers on the benefits of food waste composting
(d) Markets your establishment as environmentally conscious
(e) Markets your establishment as one that assists local farmers and the community
(f) Helps close the food waste loop by returning it back to agriculture
(g) Reduces the need for more landfill space

3.2.3 Food Packaging Waste Management

The integrated waste management approach involves source reduction, recycling, composting, combustion, and landfilling. By altering the design, manufacture, purchase, or use of the packaging materials, the reduction of impact of solid waste on environment can be achieved. It involves less packaging, designing long lasting products, and reusing the packaging materials. Recycling involves reprocessing the materials to new product. Plastic waste is used for plastic foot ware, box strapping.

PET is used in rugs, carpets, blankets, luggage, pillows, etc. Composting is a valuable alternative to organic waste disposal. Where the waste cannot be recycled or composted, combustion is an alternative.

3.2.4 Clean Technology Developments

Clean technologies are defined as "manufacturing processes or product technologies that reduce pollution or waste, energy use, or material use in comparison to the technologies that they replace."

Common source reduction methods employed at most plants include improving good housekeeping practices, making process modifications, substituting more environmentally friendly raw materials, and segregating waste streams. Some simple cost-effective means of achieving source reduction include installing automatic shut-off valves, using low-flow or air-injected faucets/spray cleaners, switching from chemical caustic peeling processes to mechanical peeling, and converting from water to mechanical conveyance of raw materials through a production line.

Advanced Wastewater Treatment Practices: The following is a listing of some technologies being used in advanced wastewater treatment:

(a) Membrane applications
(b) Disinfection
(c) Charge separation, e.g., electro-coagulation
(d) Other separation practices, e.g., air flotation system

4 Utilization of Waste Produced by Food Industry

4.1 Fruit and Vegetable Processing Waste

Waste generated from the organized sector of fruit and vegetable processing, packaging, distribution, and consumption in India, Philippines, China, and the United States is about 55 million tonnes. Most of the waste is dumped in landfills or in rivers, creating environmental hazards. Alternative to these methods could be to use the waste as manure, as livestock feed, as an alternative energy source, or for development of value-added products.

4.1.1 Utilization as Livestock Feed

Dried ripe banana peels and citrus peels can be incorporated along with wheat straw or broiler litter in the feed of lactating animals. Dried pineapple juice waste and pomace of bottle gourd juice can replace the roughage portion in the diets of ruminants. Fresh cauliflower and cabbage leaves with stems, empty pea pods being a rich source of proteins, sugars, and micronutrients can be used as such or after drying or ensiling with cereal straws in the diets of livestock. Cull carrots fed to dairy cows improves their reproductive system. Carrot flakes or dehydrated carrots are given to horses. Cull potatoes are used for lactating cows whereas dried tomato pomace can be fed to adult buffaloes (Wadhwa and Bakshi 2013).

4.1.2 Utilization for Extraction of Value-Added Products

Peels, pomace, and seeds are rich sources of sugars, minerals, organic acids, dietary fiber, and bioactive compounds. Pectin, a soluble dietary fiber, is extracted from citrus peels, apple pomace, and guava. It is used in processed foods and beverages. Essential oil extracted from citrus peels finds wide use in beverages, cosmetics, and pharmaceutical industry. The bioactive compounds from fruits and vegetables include phenolic compounds such as simple phenolics, phenolic acids, flavonoids, lignans, lignins, and tannins. Many of these compounds show antioxidant, antibacterial, anticancer, and antimutagenic activities. Apple pomace is a rich source of dietary fiber, polyphenols, and minerals. Major compounds isolated are catechins, hydroxycinnamates, phloretin glycosides, and quercetin glycosides. Wine making from grapes generate huge amount of waste. This waste can be used for production of grape seed oil, ethanol, citric acid, tartrates, hydrocolloids and dietary fiber, anthocyanins, etc. Anthocyanins, catechins, flavonol glycosides, phenolic acids, alcohols, and stilbenes are the principal phenolic constituents of grape pomace (Djilas et al. 2009).

4.2 Utilization of Cereal Processing Waste

The cereals like wheat, rice, barley, oat, and maize are milled in order to meet sensory expectations of consumers. The by-products of cereal processing pose a threat to the environment since the BOD and COD levels can reach 3.5×10^4–5×10^4 and 10^5–1.5×10^5 mg/L, respectively (ElMekawy et al. 2013). The processing of cereals generates by-products such as bran, germ, endosperm, husk, and broken kernels. The bran is a source of vitamins and minerals and is also used as dietary fiber in many refined foods. Oil extracted from rice bran is cardio protective. Starch is extracted from endosperm and is used as thickener in sauces and desserts. The husk has many uses from fuel and abrasive to packaging material (The Rice Association 2015). Corn undergoes either wet or dry milling. After removing germ and starch, the main by-product remaining is protein used as corn gluten.

The cereal by-products have been used in microbial fermentation to produce organic acids such as lactic and citric acid. Brewer's spent grain (BSG) was used in *Aspergillus niger* fermentation to produce citric acid. Corn steep liquor (CSL) and BSG have been tried in production of lactic acid.

Biopolymers are gaining attraction as petroleum-based polymers affect the environment negatively. Biopolymers like polyhydroxyalkonates (PHA), polyalcohols (e.g., xylitol), and polysaccharides (e.g., pullulan) are produced using biotechnological methods. BSG, CSL, and rice bran have been used in the production of xylitol, pullulan, and PHA, respectively.

Hydrogen gas is an eco-friendly fuel having high energy content. Biomass containing starch and cellulose are raw materials for bio-hydrogen production. Wheat starch and barley malt by-product have been used in the bio-hydrogen refinery.

Bioethanol is a substitute for fossil fuels. The main biomass for bioethanol production is starch-rich agro-industrial by-products such as wheat bran, rice hull, CSL, and other corn milling by-products.

Bioelectricity is produced by transformation of lignocellulosic biomass residues to electricity in a microbial fuel cell (MFC) (ElMekawy et al. 2013).

4.3 Utilization of Dairy Waste

Dairy industry is one of the major industries generating large volumes of wastewater. Wastewater is generated in milk-processing unit and in the production of butter, cheese, skim milk powder, ghee, etc. The major by-products of these processes are skim milk, butter milk, and whey. Edible casein is manufactured from skim milk. It has wide applications in dairy and food products. Casein is also used in glue textile fibers, rubber, paints, sizing, and in the production of caseinates and casein hydrolysates. Whey is the largest by-product of dairy industry. It is produced during the manufacture of cheese, chhana, paneer, and casein (Gupta 2008). Discharging of whey as waste creates severe pollution problems due to its high BOD (35–40 g/L). This high BOD is due mainly to the lactose, which is present at concentrations between 4.5 and 5%.

Whey proteins and lactose have gained a lot of importance. Whey is used in different ways and can be classified in three categories:

- Fermentation: production of ethyl alcohol, lactic acids, vitamins, SCP, Baker's yeast, xanthan gum
- Concentration: whey protein, dried whey, production of lactose
- Pasteurization: whey cream and pasteurized sweet whey

Whey derivatives with different functional and nutritional properties are produced using modern industrial membrane processing techniques such as ultrafiltration, reverse osmosis, electrodialysis. Ultra-filtration (UF) is generally used for whey utilization to separate the proteins from the permeate containing mostly lactose. Applications of UF and RO for concentrating the whey solids have gained an importance. Whey protein concentrate is an item of worldwide commerce due to its nutritious composition.

Whey has also been widely used for the production of single cell protein (SCP). It has advantages since the process is simple, the BOD is considerably reduced and lactose is converted into yeast biomass.

Recovery of sugars, proteins, and minerals in the waste effluents by crystallization, evaporation, and spray drying are practiced in many dairy plants (Gupta 2008).

4.4 Utilization of Meat, Fish, and Poultry Waste

India ranks first in the livestock wealth. The contribution of livestock industry is >12% GDP. Efficient utilization of by-products can have direct impact on economy and environmental pollution. Non-utilization of animal by-products can create major health problems.

In the meat industry, most of the waste comes from slaughter houses. Hides and skin are the valuable by-products of animals. It finds use in leather industry, athletic equipment, cosmetics, edible gelatin, and glue. Animal organs and glands are used either as food or has medicinal applications. Organs and bones are also used in the production of meat meal and bone meal. Bones are also used in the manufacture of gelatin. Brain, nervous system, and spinal cord are source of cholesterol which is a raw material for vitamin D3. Liver extract from pigs and cattle is a source of vitamin B12 and is used in nutritional supplements. Insulin is extracted from pancreas and is used in the treatment of diabetes.

Fish waste is a source of proteins, minerals, and fats. Fish protein hydrolysate and fish oil apart from the chemicals like chitosan are valuable products obtained from fish waste.

Feathers are produced in large quantities as the by-products of poultry industry. If not treated, they become a source of pollution hazard. They find multiple uses in animal feed, erosion control, thermal insulation, filtration units, biodegradable composites, and fabrics. Hydrolyzed poultry feathers also find use in the production of biofuel (Jayathilakan et al. 2012).

5 Future Trends

The exploitation of by-products of fruit and vegetable processing as a source of functional compounds and their application in food is a promising field, which requires interdisciplinary research of food technologists, food chemists, nutritionists, and toxicologists. In the near future, we are challenged to respond to the following research needs:

- Food-processing technology should be optimized in order to minimize the amounts of waste arising.

- Methods for complete utilization of by-products resulting from food processing on a large scale and at affordable levels should be developed. Active participation of the food and allied industries with respect to sustainable production and waste management is required.
- Natural and anthropogenic toxins such as solanin, patulin, ochratoxin, dioxins, and polycyclic aromatic hydrocarbons need to be excluded by efficient quality control systems. Minimization of potentially hazardous constituents, e.g., solanin, amygdalin, and optimization of valuable compounds such as carotenoids and betalains may also be achieved by plant breeding.
- There is a need for specific analytical methods for the characterization and quantification of organic micronutrients and other functional compounds.
- The bioactivity, bioavailability, and toxicology of photochemical need to be carefully assessed by in vitro and in vivo studies.

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