**Title**

**Fruits and Vegetable waste: A potential source of nutraceutical compounds for the mitigation of adverse effects of food insecurity.**

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Abstract:

Fruits and vegetables are enriched with essential nutrients that are required for proper functioning of the human body. To meet the increasing demand of rapidly growing population and changes in dietary preferences, the production of fruits and vegetables has increased. Lack of proper infrastructure and handling techniques, has led to deterioration of large amounts of fresh commodities, as well as their residues, by-products and parts. This loss in commodities impacts negatively on nutrition, the environment, and the economy. According to Food and Agriculture Organization of United Nations (FAO) fruits and vegetable losses are among the leading food losses and are expected to increase 60%. Up to 25-30 % of the waste is generated by fruits and vegetable processing industries, which includes mainly peels, seeds, rind and pomace. These by-products of food industry are enriched with bioactive compounds (dietary fibers, vitamins, polyphenols, enzymes, essential oils, carotenoids, etc.). The forthcoming food insecurity issues can be mitigated by utilization of nutrient-enriched waste products of the food industry. For promotion of good health exploration and utilization of plant-based Nutraceuticals has grown increasingly important keeping with the world’s paradigm shift towards an ecofriendly and sustainable solution to treat malnutrition. This chapter had highlighted the importance of food waste resources, the effective production of Nutraceuticals of by-products, their health benefits and to prevent pollution.

* 1. **Introduction**

Plants are important for well-being of mankind. The concept of the use of plants as medicine and their importance in Maintaining good health is a subject of increasing concern [1]. Thus plant-based foods are sources of essential macro and micronutrients required by the human body for proper functioning and thus prevent body from chronic ailments [2]. Fruits and vegetables (FVs) plants play an important role in the human diet. FVs are enriched with carbohydrates, proteins, amino acids, fatty acids, dietary fibers, vitamins, minerals, electrolytes and various bioactive components (figure 1) [3,4]. They exhibit health promoting properties, as, appropriate consumption has been linked epidemiologically with decrease risk of various non-communicable diseases. Nowadays, the essential function of antioxidants is mainly focused. Antioxidants acts as scavengers in eradicating free radicals before they have adverse effects on body [5].

In the present era, all people around the globe are dealing with various chronic health issues. In addition, developing countries are facing disorders related to nutritional deficiency. Dietary recommendations from several nations suggested a plant-based diet particularly fruits and vegetables as the foundation of healthy life for all age groups [6]. Around the globe, approximately 2 billion people suffer from nutrient deficiency (hidden hunger). Hidden hunger exhibits negative effects on productivity, immune system, cognition, economy, growth, and development [7]. United Nations anticipated that the world population on earth will increase up to 9.3 billion by 2050 [8], therefore, there is a need to increase the production of food by 70-100 % more than it is today [9]. Agricultural production and human population possess a complex relationship. Consumer demand fresh FVs for a healthy life. Agriculturists, farmers, and researchers have created ways for the production and maintenance of large amounts of crop varieties [10]. Due to changes in climate, poor infrastructure, lack of high-tech equipment, and industrial consequences increased demand for food production will impose a significant burden on the earth [11]. Indirect pathways link food access with climate change. Various factors viz, increase in population, consumerism trends and modernization of food industries have resulted in the production of large amounts of waste. Agro-food supply chain produces a significant amount of various types of waste, particularly organic waste that influence the environment negatively [12]. The increase in population growth confers a challenge in providing appropriate food for all the habitants at the right time. Food insecurity is among the major issues around the world, mainly in undeveloped countries. A large amount of food is wasted in production, processing, and consumption time. From an environmental and economic standpoint, agro-waste poses substantial management challenges. Among the food waste, 25-30% is made up of fruits and vegetables. FVs are perishable products, sensitive to mechanical damage and susceptible to microbial attack. To ensure food security, and reduce food loss there is a need to explore new ways for alternative uses of agro-food waste [9]. The present chapter explored the solutions to utilize the nutraceutical compounds present in agro-food waste.

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Figure 1 Nutrient content of fruits and vegetables

1. **Fruits and vegetable waste production**

The unused and unconsumed parts of horticultural products (mainly fruits and vegetables) are known as Fruits and Vegetable losses and waste (FWL).  It is generated as a result of a lack of proper handling techniques, poor infrastructure, morphological quality or simply discarded for diverse reasons. A significant amount of FWL is also generated by FVs processing industries [12, 13]. Panouille *et al.*[13] documented that the type and quantity of FWL depend upon commodity and morphological parts (seeds, roots, stems, leaves, skin, tubers, stones, pomace, etc.). Some fruits and vegetables produce 25-30% waste that cannot be used further, mainly including peels (90-92 %), followed by pomace, core, rag, skin, shell, pods, stones, vine, and other materials [14, 15].  Among all the horticultural crops, FVs are most frequently consumed, because of the presence of bioactive compounds. Mostly processed, minimally processed, or raw FVs are consumed. With a rapid increase in population and change in dietary habits, the production and processing of FVs has been significantly enhanced.  Nutritional, environmental, and economic issues are emerging as a result of losses and waste of processing industries [16]. It is reported that in industrial countries FLW waste is primarily generated at the consumer and retail level, whereas, at the postharvest and processing level by developing countries [17]. The production of FLW is significantly higher in developed countries of the world. Approximately 198.9 kg of FLW is generated by developed countries annually by a person. It is estimated that FLW accounts for 40% of the whole food chain in the US [18]. 32% of the world FLW is produced in North Africa, Central and West Asia [19]. Whereas, 20 % (a third) of the world’s FLW is generated by the European continent, and 6 % by Latin America [20]. Hence the production of FLW imposes a significant effect on the environment and biodiversity [21]. FLW negatively influences food security and also causes a 60 % increase in greenhouse gas emissions [22]. Some FVs cannot be consumed raw, therefore they are processed to get the desired products [23] (Ayala-Zavala and others 2010,) like coffee and macadamia [24]. Slicing of apples generates 10.91% of seed and pulp upon 89.09% finished product. Papaya dicing generates 32% of the pulp (unusable), 8.5% of the peel, and 6.5% of seeds as a waste production of 53% final product. 16% of waste is generated by the peeling of Mandarins and 84% of the final product [23, 25]. 5.5 MMT (million metric tons) of waste (including pomace) is generated during FVs juice production. Annually, approximately 5-9 MMT of solid waste are generated by grapes and wine processing industries [26,27]. Each year canning and freezing industries of FVs produced 6 MMT of solid waste comprising of leaves, stems and stalks [13].





Figure 2. Fruit and vegetable waste and losses nature (a) and percentage (b)

1. **Effect of FLW on environment and economy**

According to FAO [45] FLW can be determined quantitatively and qualitatively. A reduction in the amount of consumable food is known as quantitative FLW. whereas FLW signified before the food item is wasted is qualitative FLW. Qualitative FLW can be identified as the decrease in consumer acceptability, nutritional and economic value. In spite of the beneficial role of qualitative FLW, it is hard to quantify and assess. A wide range of manufacturing operations are included in the agricultural food supply chain, which generates a large amount of various waste, mainly organic waste that can negatively influence the environment [15]. Agricultural food waste management is among the leading challenges around the globe. Moreover, FLW cause a significant loss of valuable of resources (food, fuel, bioactive compounds, etc.). In the field of waste management environmental sustainability is one of the most frequently discussed topics. Zero-emission systems, greener production, waste prevention and minimization are some eco-friendly approaches for waste management [45]. Agri-food productions require land preparation, application of fertilizers and many other costs. Hence FLW is also a huge economic loss [46-48]. FLW can increase the rate of poverty in developing nations. FLW can reduce the farmer’s income and enhance the price, as the decrease in quality, causes a reduction in the quantity of commodities that can be sold [48;49]. Food and Agriculture Organization [50] reported that the direct economic cost of FLW is 1.3 billion tonnes which are approximately USD 1 trillion/year excluding environmental damage which is projected to be almost USD 700 billion and externalities which cost around USD 900 billion.  It is documented that every year production of FLW consume 173-250 km3 of water [51;52] and 198 million hectares of fertile land [47]. Decrease in FLW production will ultimately cause decrease in environmental pollution, less use of resources (water, land and fertilizers) [48]. Various environmental issues can be upraised by organic waste as a result of climate change, susceptibility to microbial damage and due to high biological and chemical oxygen demand. Generation of greenhouse gases (CO2), variation in pH and chemical composition. Increase in accumulation rate that reduces the amount of available fertile land for disposal are among the leading environmental pollution raised by organic waste [53]. In 2009, Worldwide FLW produces almost 3,300-5600 million tonnes of CO2. Cereals waste generated approximately 34% of greenhouse gases, around the globe [52, 54].

* 1. **Fruits and Vegetable waste: A sustainable source of nutraceutical compounds**

Over the coming decades, the world will face significant issues regarding food security, economic growth, and environmental externalities. The rapid increase in world population will increase the risk of food insecurity. To feed the entire world’s population, there is a need to assure food security in a sustainable manner. Although various global organizations had worked on food security, but they have not yet succeeded in eradicating hunger. Using the best alternative approaches and reducing FLW are the two sustainable methods to enhance global food security. For sustenance of global community improvement in the supply chain, inclusive agriculture and a compromise among government industries, and consumers are required. To ensure food security, there is a need to reduce and reutilize the waste generated by food industries [9]. Global report on food crises (GRFC) for the year 2023 highlighted an increase in the number of people facing food insecurity. It is also documented that because of economic shock and the Ukraine war, a quarter of a billion people are facing malnutrition. The report also indicated that approximately 258 million people in 58 territories are affected by food insecurity. In the GRFC’s seven years of history, this is the highest number [55].

Phyto-active constituents of the FWL can be a source of nutraceuticals and an ingredient for the preparation of functional food [56; 57]. The word nutraceutical coined by Dr. Stephen DeFelice, derived from the combination of two words “nutrition” and “pharmaceutical” in 1989 [58]. Zeisel [59] defined nutraceutical as a dietary supplement that delivers a concentration form of bioactive food component in a nonfood matrix and maintains a good health. Nutraceutical can also be defined as any substance whose nutritional content is known [60], usually sold in medical form (capsules or pills). A dietary substance that provides nutrition, energy, regulates various physiological processes and lowers the risk of diseases is known as functional food. [61]. Functional food differs from nutraceuticals in that it supplies one or more active substances inside the food matrix. The waste generated by food industries is enriched with various functional food ingredients like dietary fibers, fatty acids, amino acids, phenolic compounds, probiotics, minerals, carotenoids, minerals and various other bioactive components. These functional food ingredients can prevent serious ailments. The popularity of functional foods (functional beverages) is increasing rapidly nowadays. The by-products and waste of food industries can be economically good source of functional food ingredient. Moreover, it results in generation of new jobs and reduces environmental pollution caused by food industrial waste [62]. Researchers around the world are working in utilization of dietary fibers present in the fruits and vegetables. These dietary fibers improve sugar absorption, intestinal motility and bulking mediators [63]. Nutraceutical industries uses polyphenols (diverse bioactive compounds) [64]. Polyphenols mainly flavonoids, phenolic acids, phenyl paranoids, tannins quinones and lignin plays an active role in scavenging free radicals, reduction of cardiovascular and chronic degenerative ailments. Sir Elkhatim et al. [65] docuemted that waste products of fruits and vegetables can be a rich source of phenolic compounds and hence can be used as a supplements.

Ajikumar *et al.* [66] documented that the bioactive compounds can treat and prevent various chronic ailments, by interacting with DNA, proteins and various biomolecules. Currently, as per consumer demands for healthy and nutritional food items food industries are working on the formation of nutraceutical products. Total phenolic compounds (TPC) and dietary fibers exhibit cardio-protective, anticancer and antimicrobial potential. FWL is enriched with these valuable bioactive compounds. Pulp or juice of citrus fruits (oranges, lime, lemon and grapefruit) are usually consumed. Citrus fruits processing, generates 50% of the waste consisting of pulp, peels and seeds [67]. Citrus fruits seeds and peels are enriched with antioxidant compounds mainly pectins, flavonoids, fibers, naringin, hesperidin, narirutin, eriocitrin and limonene [68]. Dijlas et al., [69] documented that limonoids (Limonin, nomilinic and nimolin) present in the citrus fruit peels exhibit antimicrobial potential.

*Mangifera indica* L. (Mango) is a common seasonal fruit usually processed for products pickles, purees, juices and canned products. By-products (unused) of mango comprises of kernels (9-40 %) and peels (7-24 %) are enriched with various bioactive compounds. Amino acids (leucine, valine and lysine) and phenolic compounds are present in mango kernels. Functional compounds viz; polyphenolic, hydrolysable tannis, xanthanoids, catechins, flavonoiods, carotenoids, dietary fibers, vitamins C and E are present in mango seeds [70-72]. BenOthman et al., [72] reported that mango peel and seeds are enriched with Mangiferin (a bioactive compound that showed antioxidant, antimicrobial and immunomodulatory potential). Bananas are characterized as second largest tropical fruit. Banana peels (a waste product) make up 40% of the overall fruit weight. Various antioxidant bioactive compounds, proteins and dietary fibers are present in banana peels. Banana peels are used in animal feed, in formation of banana powder and chips [73; 74]. In spite of this, a large amount of banana peels is discarded which is hazardous for the environment. Therefore, there is a need of formation of valuable food products. Apple juice yields pomace which constitutes 30 % of the fruit. Apple pomace contains 2-4 % seeds, 1 % stem and 95% peels. It is an essential source of phenolic compounds (naringenin, epicatechin, quercetin, phloridzin, catechin, etc.) and antioxidants [75-76]. Grape wine industry produced pomace (by product), which constitutes 15-20 % of the total weight of the grapes. Grape pomace consists of stems, seeds, pulp and skins. Grape by-products are an essential source of anthocyanins, flavonols (kaempferol-3-O-glucoside, quercetin-3-O-glucoside, quercetin, myricetin), flavanols (proanthocyanidins), stilbenes (resveratrol, piceid, astringin), phenolic acids (ferulic, gallic, p-coumaric, vanillic, caffeic and p-hydroxybenzoic) [77]. Liu et al., [78] documented that cabbage external leaves are principle waste product which are removed before processing. For the extraction and utilization of essential phyto-active constituents from cabbage waste products efforts are being made. Flesh, crown, and peels are the waste products of beet root (*Beta vulgaris*). Strong antioxidant compounds Betalains (red betacyanins yellow beta-xanthins) are the main valuable compound present in flesh (14%), crown (32%) and peels (54%) of beet root [79]. Onion skin is enriched with quercetin, flavonoids, phenolics, aglycone, fructans, dieatary fibers, and alkenyl cysteine sulfoxides. These bioactive compounds observed to have antidiabetic, antispasmodic, antimicrobial activities [80]. Kallel et al., [81] reported that garlic husk is a rich source for polyphenolic compounds, cellulose, hemicellulose and lignin.

* 1. **Extraction of value-added compounds from Phytowaste**

Proliferation in diet related health issues enhances the need of dietary supplements. Fruits and vegetables are enriched with bioactive active compounds and essential oils. Nutraceutics serve as dietary supplements that prevents or treat human ailments and are formulated from food items. Fruits and vegetable waste can be a source for the creation of nutraceutics [82]. Extraction of bioactive compounds without affecting their chemical and structural properties is challenging. Various conventional extraction techniques including have been evaluated solvent extraction, maceration, enzyme assistance, as well as non-thermal methods, including microwave-assisted extraction, electric pulse field, ultrasound assisted extraction, high voltage electric discharge, and subcritical fluid extraction have been evaluated [83;84].

Extraction of bioactive compounds plays an important role in increasing the economy of the developing nations. For the successful scale-up cost effective and viable techniques plays an important role in extraction and identification of these beneficial compounds. The countries like Africa and Sub-Saharan region lacks the technology to recover the maximum amount of nutrients and development of beneficial products. There is a need to explore the appropriate solvent and collaboration of international agro-industries for the generation of maximum amount of nutrients from the fruits and vegetables waste products [85]. Fruits and vegetable waste can enhance the flavor of food products. Pineapple cannery waste enriched with ferulic acid, is known as the precursor of vanillic acid and vanillin [86]. 4-hydroxy-3-methoxy benzaldehyde (vanillin) is the main constituent present in vanilla beans. *Aspergillus niger* I-1472 is reported in transformation of ferulic acid into vanillic acid, whereas *Pycnoporus* *cinnabarinus* MUCL 39533 converts vanillic acid to vanillin [87]. Lalou and Mantzouridou [88], extracted flavoring compounds like ethyl octanoate, isoamyl acetate, phenyl ethyl acetate, ethyl do decanoate, ethyl decanoate and ethyl decanoate by cultivation of yeast VitilevureMT (S.cerevisiae) on orange peel waste using solid state fermentation. Whereas, pectin, L-ascorbic acid, and carotenoids were the by-products produced through this process. Biotransformation of apple pomace by fungus *Tyromyces chioneus* results in formation of flavoring compounds viz; acetic acid, benzyl alcohol, 3-phenyl-1-1propanol, benzaldehyde and 3-phenulpropanal [89]. Cinnamic acid enhances 10 times the production of 3-phenylpropanal and 3-phenul-2-propanol. Extraction of bioactive compounds using micro-organisms and enzymes enhance valorization of waste. However, enzymatic extraction and solid state-fermentation significantly enhances a variety of bioactive compounds if challenges like volatility and environmental sensitivity should be addressed properly. Optimization of fermentation process can reduce the loss of volatile compounds from the reactor. The efficacy of extraction can be improving by the use of hybrid technologies [90].

 **Conclusion**

Fruits and vegetables enriched with essential nutrients that are required for healthy life. A diet high in fruit has been linked to a lower risk of chronic diseases. World population is increasing rapidly and is expected to reach 9.6 billion in 2050. Food production has been increased to meet the increasing demand of food. A large amount of fruits and vegetable waste and loss is generated because of poor infrastructure, mishandling, and processing. The affinity of plants to replace chemicals and nutraceuticals is of interest of food industries. To ensure more sustainable productivity and global food security, waste from the cultivation, harvesting, and processing of fruits and vegetables from biomass is currently considered as the best alternative source of nutraceuticals.

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