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Abstract

The concentrations of phenolics and other phytochemicals present in the peels, pulp/pomace and seeds of many fruits and vegetables namely citrus, apples, peaches, pears, banana, pomegranate, berries mangoes, onions, potatoes, tomatoes and sugar beet are generally substantially higher than in their respective edible tissues, suggesting these wastes and residues to be the potential sources for isolating bio-active compounds. The antioxidants (polyphenolic and other phytochemicals) and other bio-active compounds from these sources exhibit anti-cancer, anti-microbial (pathogens), anti-oxidative and immune-modulatory effects. In addition they reduce incidence of cardiovascular diseases and capillary fragility, inhibit platelet aggregation and prevent thrombosis, oxidative stress, osteoporosis and diabetes in vertebrates. Specifically, the phenolics and flavonoids present in apple, date pit, rambutan (*Nephelium lappaceum*) peel, tomato peel extracts strongly inhibit tumour-cell proliferation. Penta-O-galloyl-glucoside (PGG) present in mango seed kernel extract and mango peel is used in pharmaceutical industries as it possesses anti-tumor, antioxidant, anti-cardiovascular and hepato-protective effects. The terpenoid and flavonoids in banana foliage exhibit anthelmintic properties. Pomace of apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, onion, raspberry, tomato and carrot, durian seeds (gelling and thickening agents), mango peels, date pits, cauliflower trimmings, empty pea pods and okara are used as dietary fibre supplements and as a functional ingredient in processed food products due to the presence of pectins and carotenoids and bound antioxidants. Some of the fruit and vegetable wastes are excellent source of biopigments; examples being betalains in beet root pulp and carotenoid in carrot pulp. Tomato seeds, banana peel, rambutan and mango seed kernel, passion fruit seed, black currant, date pits are good sources of edible oil rich in polyunsaturated fatty acids. Many fruit and vegetable wastes are used as a substrate for the production of organic acids (citric, lactic and ferulic acids), single cell protein, essential oils, exogenous enzymes, bio-ethanol/methanol, bio-pesticides, bio-sorbants, bio-degradable plastic, bio-fertilizers, bio-preservatives and edible mushrooms. Some have potential to decrease the emission of enteric methane.

Keywords: Vegetable waste, Fruit waste, Antioxidants, Bio-active compounds, Value added products, Bioeconomy

Introduction

Driven by increasing world population, economic development and income growth in developing countries the demand and production of fruits and vegetable have been increasing and this trend is likely to continue in the future [1]. This is resulting in the availability of increased amounts of their by-products and wastes for various applications. Our previous papers have discussed the nutritional value, conservation methods and feeding management of some fruit and vegetable wastes and their by-products; and provided guidance on the levels at which these unconventional feed resources can be used in feeds of different animal species [2, 3]. In this paper we present opportunities for obtaining an array of value added products having applications in food, pharmaceutical and allied industries. The main value added products that can be produced from fruit and vegetable wastes/residues include enzymes, reducing sugars, furfural, ethanol, proteins, amino acids, carbohydrates, lipids, organic acids, phenols, activated carbon, degradable plastic composites, cosmetics, biosorbent, resins, medicines, foods and feeds, methane, biopesticides, biopromoters, secondary metabolites, surfactants, fertilizer and other miscellaneous products [4–8]. These have been discussed under the following categories.

Nutraceuticals

A nutraceutical may be defined as a food (or part of food) that provides medical or health benefits, including the prevention and/or treatment of a disease [9]. Kalia [10] classified nutraceuticals into different groups, namely dietary fibre, polyunsaturated fatty acids, antioxidants, polyphenols, spices, probiotics and prebiotics. The health promoting effects of nutraceuticals are mainly mediated through biochemical and cellular interactions, which further prevent susceptibility to diseases or promote quality or quantity of livestock products. Important classes of nutraceuticals are discussed here.

Polyphenolic and other compounds

In the food industry, synthetic antioxidants, such as butylated hydroxyanizole (BHA) and butylated hydroxytoluene (BHT) have long been widely used as antioxidant additives to preserve and stabilize the freshness, nutritive value, flavour and colour of foods and animal feedstuffs. However, Schilderman *et al.* [11] revealed that BHT at high doses could be toxic. Nowadays, there is an increasing interest in the substitution of synthetic food antioxidants by natural ones. Different studies have shown that free radicals present in the human organism cause oxidative damage to various molecules, such as lipids, proteins and nucleic acids, and are thus involved in the initiation phase of the degenerative diseases. Beet root (*Beta vulgaris* L. family Chenopodiaceae) ranks among the ten most powerful vegetables with respect to its antioxidant capacity, ascribed to a total phenolic content of 50–60 μmol/g dry weight [12, 13]. The high content of folic acid (15.8 mg/g dry matter [DM]) is another nutritional feature of the beets [14]. The peel, pulp and seeds of most of the fruits are rich in polyphenolic compounds, other phytochemicals and vitamins are presented in Tables 1 and 2 [15–67]. The concentration of total phenolic compounds present in the peels, pulp/pomace and seeds of citrus fruits, apples, peaches, pears, yellow and white flesh nectarines, banana, pomegranate, mulberry, blackberry, mangoes, longans, avocados, jackfruits, tomatoes and sugar beet is substantially higher than in their respective edible tissues [32, 68, 69]. The polyphenolic and other phytochemical antioxidants exhibit anti-cancer [70–73], anti-microbial (pathogens), anti-oxidative and immune-modulatory effects; reduce incidence of cardiovascular diseases [74], the systolic pressure and the level of plasma cholesterol; reduce capillary fragility; and inhibit platelet aggregation and prevent thrombosis [75] in vertebrates. Best examples are citrus peel/pulp [76–78], citrus fruit seed oil (active components being D-limonene, a monoterpenoid) [79], Litchi (*Litchi chinensis* Sonn.) pericarp [41, 80], litchi seed [44, 81]; litchi bark [47, 48], persimmon peel [61, 82–84], *Carissa carandas* (Karonda fruit used in pickles) pomace, *Ananas comosus* L. Skin, *Artocarpus lachoocha* pomace, *Grewia asiatica* pomace, *B. vulgaris* pomace [81] and date pits [30, 85]. The phenolics and flavonoids present in apple extracts (both with and without skin) strongly inhibited tumour-cell proliferation in colon [86], date pit extract impaired the cytotoxicity of azoxymethane-induced cancer in colonic tissue in rats [87], the methanolic yellow rambutan (*Nephelium lappaceum*) peel extract had strong activity as anti-proliferative agent towards breast cancer cells and osteosarcoma cancer cells [88].

Mango seed kernel extract and mango peel are used in pharmaceutical industries [29, 89]. These contain ethyl gallate and penta-O-galloyl-glucoside (PGG) [90, 91]. PGG possesses potent hydroxyl radical, superoxide anion and singlet oxygen scavenging activity. Meanwhile, pharmaceutical studies have demonstrated that PGG show various bioactivities, including anti-tumour [92], antioxidant [93], anti-cardiovascular [94] and hepato-protective effects [95]. The potato peel extract (PPE) also exhibited very strong antioxidant activities, nearly equivalent to those of BHA and BHT [96]. For this reason, it has been used as antioxidant to prevent oxidation of vegetable oils [97]. PPE pretreatment was found to offset carbon tetra chloride-induced liver injury inrats [98], protect erythrocytes against oxidative damage *in vitro* [99], and strongly inhibit lipid peroxidation of rat liver homogenate [100]. The terpenoid and flavonoids in banana foliage exhibit anthelmintic properties [19].

A daily intake of 5–7 mg lycopene (present in tomato peels) was found to be sufficient to counteract the effects of oxidative stress and cure cancer, cardiovascular diseases, osteoporosis and diabetes [101, 102]. It is also known that dissolving lycopene in fats allows a significant increase in bioavailability and hence its efficacy [103]. In the cosmetic field, the lycopene-enriched oil could be used, alone or in combination with sunscreen products, for skin photoprotection [104]. The lycopene-enriched oil and the tomato oleoresin could be used in the functional-food and cosmetic preparations.

Date pit extract could be used as a medicinal food in treating renal stone, bronchial asthma, cough, hyper

Table 1 Fruit and vegetable wastes as sources of bioactive compounds

Fruit and vegetable waste	Bioactive compounds	References
Acerola (*Malpighia glabra* L.) peels	Anthocyanins, phenolics, and vitamin C	Sancho *et al*. [15]
Apple pomace	Proanthocyanidins, flavonoids, flavan-3-ols (catechin, epicatechin, procyanidins), hydroxycinnamates, dihydrochalcones, quercetinglycosides, chlorogenic acid, and phloridzin, 3-hydroxyphloridzin.	Sudha *et al*.[16]; Lu and Foo [17]; Schieber *et al*. [18]
Banana leaves	Polyphenols (terpenoid and flavonoids)	Marie-Magdeleine *et al*. [19]
Banana	Catechin and gallocatechin	Babbar *et al*. [20]
Beet root pomace	Betalains and 1,1-Diphenyl-2-picryl-hydrazyl (DPPH)	Čanadanović-Brunet *et al*. [21]
Black currant (*Ribes nigrum*) pomace	Anthocyanins, linolenic acid and other fatty acids	Holtung *et al*. [22]
Broccoli by-products	Glucosinolates, phenolic acids, flavonoids and vitamin C	Domínguez-Perles *et al*. [23, 24]
Cabbage, watermelon rind and peach peels	As a carbon source for synthesis of carotenoids using *Blakeslea trispora*	Papaioannou and Liakopoulou-Kyriakides [25]
Carrot pomace	Hydroxycinnamic derivatives like chlorogenic acid and dicaff eoylquinic acids	Zhang and Hamauzu [26]
Cashew apple waste	Vitamin C, organic acids, antioxidants, unsaturated fatty acids, minerals	Sivagurunathan et al. [27]; Sancho *et al*. [15]
Cauliflower cull	Curcumin and phenethyl isothiocyanate	Anonymous [28]
Citrus juice, pulp and seed	Limonoids-highly oxygenated triterpenoid	Rudra *et al*. [29]
Date pits	High concentration of phenolic compounds (21.0–62.0 mg gallic acid equivalent (GAE)/100 g date pits) and antioxidants [580–929 ml Trolox equivalent antioxidant capacity (TEAC)/g]	Al–Farsi *et al*. [30]; Suresh *et al*. [31]
Grape and pomegranates peels, pomace and seeds	Flavonoids (catechin, epicatechin, procyanidins and anthocyanins), phenolic acids (gallic acid and ellagic acid) and stilbenes (resveratrol and piceid); dietary fibre	Shrikhande [32]; Jayaprakash et al. [33]; Yunfeng *et al*. [34]; Babbar *et al*. [20]
Gooseberry peels	Polyphenolic compounds e.g. ellagic and gallic acids and corilagin	Poltanov *et al*. [35];Chitturi *et al*. [36]
Guava peel and pulp	Polyphenolic compounds, melanin, dietary fibre	Jimenez-Escrig et al. [37]; Chitturi *et al*. [36]
Litchi pericarp	Phenolics (epicatechin, procyanidins, cyanidin-3-glucoside, and quercetin-3-rutinoside), flavonoids and anthocyanin (cyanidin-3-rutinoside)	Sarni *et al*. [38]; Duan *et al*. [39]; Liang *et al*. [40]; Jiang *et al*. [41]. Zangh *et al*. [42]
Litchi seed	Proanthocyanidins, flavonoids, steroids, and sesquiterpenes	Prasad *et al*. [43]; Xu *et al*. [44]; Singh *et al*. [45]; Queiroz *et al*. [46]
Litchi bark	Flavonoids, polyphenols, anthocyanins and vitamin C	Queiroz *et al*. [47, 48]
Longan seeds	A rich source of antioxidant polyphenolic compounds, mostly gallic acid and ellagic acid	Panyathep *et al*. [49]
Mango peel	Syringic acid, quercitin, mangiferin pentoside and ellagic acid,carotenoids, vitamins, enzymes and dietary fibres	Larrauri *et al*. [50]; Ajila *et al*. [51, 52]; Schieber et al. [18]; Berardini *et al*. [53]
Mango seed kernels	Gallic acid	Puravankara *et al*. [54]; Rudra *et al*. [30]
Mango pulp and ripe peel	Carotenoids (β-carotene)	Chen *et al*. [55]; Ajila *et al*. [51]; Varakumar *et al*. [56]
Onion waste	Quercetin	Hertog *et al*. [57]; Ly *et al*. [58]; Nuutila *et al*. [59]; Kim and Kim [60]
Persimmon peel	p-Coumaric, gallic acid, protocatechuic, proanthocyanidins, catechin, epicatechin, epigallocatechin, catechingallate gallocatechin, gallocatechin-gallate and ascorbic acid	Gorinstein *et al*. [61]; Matsuo and Ito [62]; Suzuki *et al*. [63]; Bubba *et al*. [64]
Rambutan (*Nephelium lappaceum*) peels	Ellagic acid, corilagin and geraniin	Palanisamy *et al*. [65]; Thitilertdecha *et al*. [66]
Tomato pomace	Sterols, tocopherols, carotenes (Lycopene), terpenes, flavonoids and ascorbic acid	Kalogeropoulos *et al*. [67]

Table 2 Bioactive moieties in fruits residues

Fruit	TPC (mg GAE/100 g)	Anthocyanins (mg/100 g)	Ascorbic acid (mg/100 g)
Acerola[1]	173.30	60.83	170.73
Cashew apple[1]	13.20	2.46	30.49
Guava[1]	2.80	1.55	39.63
Mango[1]	42.30	7.47	36.58
Papaya[1]	34.65	11.56	121.95
Pineapple[1]	15.18	10.91	51.83
Sapota[1]	4.35	4.09	36.58
Litchi pericarp[2]	93.9–301.6	1.77–20.94	–

TPC, total phenolic content; GAE, gallic acid equivalent.
[1]Sancho *et al*. [15].
[2]Liang *et al*. [40].

activity and weak memory [105]. Ishrud *et al.* [106] showed that date pits contain glucomannan, which helps to normalize blood sugar, relieves stress on the pancreas, and prevents blood sugar abnormalities such as hypoglycaemia.

Certain compounds in passion fruit peel have bronchodilator effect and can help relieve bronchospasm in asthma patients. Oral administration of the purple passion fruit peel extract is considered to reduce wheeze and cough and improve shortness of breath in adults with asthma [107].

Anti-microbial (-pathogens). Water and alcoholic extracts of date pits showed anti-microbial activity against *Klebsiella pneumoniae*, *Escherichia coli* [108], *Staphylococcus aurus, Proteus vulgaris* and *Bacillus subtilis* [109]. These extracts also have potential to be used as an antioxidant in nutraceutical, pharmaceutical and medicinal products [30]. Singh *et al.* [45] showed that litchi seed extracts in ethanol, acetone and distilled water have inhibitory effect against *E. coli, S. aureus, P. vulgaris, B. subtilis, K. pneumoniae* and *Pseudomonas aeruginosa.* Mango seed kernel extracts (MSKE) inhibit growth of both gram-negative and gram-positive bacteria. The most sensitive strain was gram-negative bacteria, *P. Aeruginosa* (ATCC 27853) [29]. Papaya contains sulphydroxyl protease which inhibits virus or microbial infections [110]. Jensen *et al.* [111] found passion fruit extracts effective against *B. subtilis* and some yeasts. Passion fruit peel; guava and guava leaf extracts (successively extracted with petroleum ether, chloroform and ethanol) showed anti-microbial activity against gram-positive (*S. aureus, B. subtilis, Bacillus cereus, Lactobacillus bulgaricus*) and gram-negative bacteria (*E. coli, Proteus vulgaricus, P. aeruginosa, Salmonelli typhi*), yeast (*Saccharomyces cerevisiae, Candida lypolytica*) and fungi (*Rhizopus* spp., *Aspergillus niger* and *Chlamydomucor* spp.). Rambutan peel too showed activity against the above tested bacteria except *P. aeruginosa* [112, 113]. Thanutchapisut *et al.* [114] suggested that phenolic compounds in durian peels may significantly contribute to anti-bacterial activity. Panthong [115] isolated two coumarins, scopoletin and fraxidin; and triterpenes, maslinic acid and arjunolic acid from acetone extract of twigs of durian plant. Most of the parts of durian fruit showed some anti-bacterial activity but poor activity against yeast or fungi. *S. aureus* and *B. cereus* showed higher susceptibility to the ethanol, acetone and water extracts of beet root pomace than *E. coli* and *P. aeruginosa* [21].

Extracts from banana, papaya, passion fruit and *Lansium domesticum* peels had activity against *C. lypolytica* (a pathogenic fungi) while extracts from guava had strong activity against *S. cerevisiae* [113]. Strong anti-fungal activity against pathogenic fungus such as *Rhizoctonia solani Kühn* and *Rhizoctonia cerealis vander Hoven* has been reported with ethyl acetate as well as ethanol crude extracts of mango peel [116]. However, in case of unripe mango peel, 95% methanol extract was more effective than 95% ethanol extract, and methylene chloride extract was more effective than ethyl acetate extract [117]. The major component for anti-fungal activity was 5-(12-heptadeconyl)-resorcinol [118].

Food-supplements

Dietary fibre

Fruit and vegetable by-products such as apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, onion and carrot pomace, mango peels and cauliflower trimmings are used as dietary fibre supplements (gelling and thickening agents) in the refined foods. These compounds increase the bulk of the food and help prevent constipation by reducing gastro-intestinal transit time [119]. They also bind to toxins in the food which helps to protect the gut mucus membrane and thus reduces colon cancer risk. Furthermore, dietary fibres bind to bile salts and decrease their re-absorption, thus helping to lower serum low density lipoproteins (LDL) cholesterol levels [120]. The typical inclusion levels of fruit and vegetable by-products vary between 2 and 15%. The vegetable materials were found to maintain antioxidant activity after extrusion.

The pea pod and okara contain more than 50% fibre and broad bean pods contain more than 40% fibre, which could be considered a source of dietary fibre [121]. Do Espírito Santo *et al.* [122] evaluated the effect of supplementing total dietary fibre from apple, banana or passion fruit processing by-products (peel, pulps and seeds) on the post-acidification, total treatable acidity, bacterial counts and fatty acid profiles in skim milk yoghurts, producing a new high nutritional value-added dairy product.

Dietary fibres and phytochemicals are gaining increased attention because of their antioxidant, anti-carcinogenic and other health benefiting properties [123]. Mango peel fibre, which has high hydration capacities, is considered to have potential in dietary fibre-rich foods preparation [124]. Ajila and Prasada Rao [125] indicated the presence of bound phenolics in dietary fibre, which adds additional antioxidant property; and its antioxidant capacity is greater than that of DL-α-tocopherol [50]. It is an important source of high quality antioxidant dietary fibre, pectin, polyphenols and carotenoids. Mango peel flour can be used as a functional ingredient in developing healthy food products such as noodles, bread, biscuits, sponge cakes and other bakery products [126]. Yogurt made with supplementation of 10% of mango peel powder showed a good texture, flavour and color characteristics and exhibited 1 month shelf life without adding preservatives [127]. The total dietary fibre content in macaroni increased from 8.6 to 17.8%, polyphenols increased from 0.46 to 1.80 mg/g and carotenoid content increased from 5 to 84 μg/g with 7.5% incorporation of mango peel powder [128]. It also possesses significant biotechnological potential since it has been found to be a suitable substrate for several bioprocesses including ethanol, biogas, lactic acid, enzymes and single cell production [129].

Date pits could be used as a source of dietary fibres and functional polysaccharides [130]. Date pit fibre is used for enhancing fibre content of foods such as bread, biscuits and cakes [131, 132]. It could be used as an alternative to wheat bran because it provides similar sensory properties [131].

Partial replacement of flour in cookies with the raspberry pomace is one of the possible ways to increase the amount of dietary fibre in the diet. The addition of raspberry pomace influences organoleptic qualities of short crust cookies. Cookies had different flavour depending on the quantity and form (crumbled or non-crumbled) of pomace used. The higher is the raspberry pomace addition, stronger is the fruit smell and the fruit sour taste. Cookies with 25 and 50% non-crumbled pomace were rated highest in terms of general desirability [133]. Pequi (*Caryocar brasiliense*) pulp contains edible oil and is rich in vitamin A and proteins, making it an important food supplement [134].

Onion industry produces wastes that amount to approximately 15% of the total production. Since onion (*Allium cepa* L.) wastes (residues, surplus and cull onion) are not suitable for fodder or landfill disposal due to the rapid growth of phytopathogens, e.g. *Sclerotium cepivorum* (white rot) [135]. Processing and stabilizing onion wastes could solve the problem of its disposal and getting stabilized onion by-products as natural anti-oxidant food ingredients [136]. Roldán *et al.* [135] showed that brown skin and top-bottom could be potentially used as a functional ingredient rich in dietary fibre, mainly in insoluble fraction, and in total phenolics and flavonoids, with high antioxidant activity. Moreover, brown skin contained a high concentration of quercetin aglycone and calcium, and top-bottom had high concentration of minerals. Outer scales could be used as source of flavonols, with good antioxidant activity and content of dietary fibre. Onion wastes adequately processed and stabilized could be useful in the food industry as functional ingredients to be added to processed foods [137]. Onion extracts could be used as natural food ingredients for the prevention of browning caused by enzyme polyphenol oxidase [138].

Polysaccharides

Durian seed, a waste of durian fruit, is a source of gum [139], which is highly hydrophilic [140]. It is preferred over animal and microbial gums due to its higher acceptance by consumers [141, 142] and can be used as thickeners, gelling agents, texture modifiers and stabilizers. Plant gums are widely used in commercial liquid and semisolid foods [143] and are viewed as biodegradable natural polymers, which are non-toxic and non-carcinogenic. These are also used in cosmetic and pharmaceutical products.

Pectins are widely distributed in fruits and vegetables (10–30%). They are found in pulps of tomato, pineapple, orange, apple and lemon; and in peels of turnips and citrus. Apple pomace and citrus peels contain 10–15 and 20–30% pectins [144], while mango peels contain 10–20% pectins [145, 146]. Papaya, muskmelon and pineapple peels contain around 5% extractable pectins. Mango peel pectins exhibited better gelling capacity than citrus pectins [147].

Xanthan is one of the major microbial polysaccharides, which is used in many industrial processes. Amongst the acid hydrolyzed waste of musk melon, water melon, cucumber and tomato, the best substrate for xanthan production was melon (*Cucumis melo*) waste [148].

Proteins

Melon seeds can be used as an additive in pasta dishes [149]. Egusi, a wild member of the gourd family, looks almost identical to watermelon, but is filled with very dry, bitter flesh. Its seeds are the true delicacy. Seeds contain 50% edible oil and 30% protein. The seeds make an excellent dietary supplement in many parts of Africa, where farmers lack access to meat or dairy products. After soaking, fermenting, or boiling, the seeds take on different flavours and are frequently added to thicken soups and stews. On their own, the seeds can also be roasted and ground into a spread like peanut butter. Seeds are also often shelled and eaten as a snack. With further preparation, egusi-seed meal can be pressed into patties to be used like a meat substitute, and its oil can be used for cooking. The egusi can also be an important supplementary baby food, helping prevent malnutrition. Blending the seeds with water and honey produces a milky liquid that can be used for feeding babies if breast milk is unavailable [150, 151].

Bio-pigments and colourants

Colouring agents have wide applications in food, phar- AQ3 maceutical and textile industries. Biopigments produced from microbial sources have a number of advantages over synthetic pigments. *Monascus purpureus*, a fungus produces pigments, which possesses a number of therapeutic properties such as curing cancer, coronary heart disease and hypertension. Number of reports are available on the use of fruit and vegetable wastes as substrate for production of carotenoids e.g. kinnow peel powder and pea pod [152], apple pomace [153, 154], grape juice [155, 156], grape must [157, 158], date [159], sweet potato [160], tomato peel [161] and carrot pomace [26]. The quality of meat products can be improved by adding tomato peel containing lycopene and fibre. Beet root is a potential source of valuable water-soluble nitrogenous pigments, called betalains, which comprise two main groups, the red betacyanins and the yellow betaxanthins. The beet root pomace contains 11–23 mg β-xanthins/g of dry extract [21]. These are free radical scavengers and prevent active oxygen-induced and free radical-mediated oxidation of biological molecules [162]. Betalains have been extensively used in the modern food industry. They are one of the most important natural colorants and are also one of the earliest natural colorants developed for the use in food systems [163, 164].

The dried carrot pomace can be used in wheat bread at a level of 5% [165–167] to produce high fibre biscuits [168], cake, dressing and pickles [169] as a supplement of carotenoides, fibre and minerals and in functional drinks [170]. Onion pomace is used in snacks as a natural source of high-value functional ingredients like dietary fibre, mainly in insoluble fraction, and in total phenolics and flavonoids, with high antioxidant activity [171].

Emulsifiers

Protein fractions from defatted date pits are used to develop ingredients for use as emulsifiers, foaming agents and thickening or gelling agents in formulated foods [172].

Fermented edible products

A number of beverages such as cider, beer, wine and brandy, and vinegar can be obtained from the fermentation of fruit wastes. Apple pomace has been utilized for the production of cider. The possibility of making brandy from dried culled and surplus apples, grapes, oranges and other fruits has also been explored. Vinegar can also be prepared from fruit wastes. The fruit waste is initially subjected to alcoholic fermentation followed by acetic acid fermentation by *Acetobacter* bacteria, which produces acetic acid. Vinegar production by fermenting waste from pineapple juice and orange peel juice has been reported. Apple pomace extract can also be mixed with molasses for producing vinegar [173]. Fresh guavira (*Campomanesia pubescens*) is mostly used as a flavouring agent by the beverage industry due its high acidity and presence of ascorbic acid, minerals, dietary fibre and monoterpene hydrocarbons in substantial amounts [174].

Edible Oils

An important constituent in a fruit or vegetable powder extract is the lipid or oil [175]. Banana peel contains 2.2–10.9% lipids, which are rich in polyunsaturated fatty acids, particularly linoleic acid and α-linolenic acid [176]. These fatty acids contribute to the prevention of atherosclerosis, cancer, heart diseases and diabetes [177]. The lipid content in the residues is much higher (up to 10 times) than the amount in the edible portion of the fruit, and therefore the residues are a good source of lipids in comparison with the edible portion of the fruit [15]. Rambutan (*N. lappaceum*) seeds contain 14–41% fat [178], depending on the variety. Its fat contains 36.8–42.0% oleic acid and 34.3–36.4% arachidic acid [178–181]. The use of rambutan seed oil in food and cosmetic products may provide an economic advantage.

The oil in mango seed kernel is edible and its fatty acid and triglyceride profiles are similar to those of cocoa butter. Guava seeds, usually discarded during processing of juice and pulp making, contain 5–13% oil, rich in essential fatty acids [182]. The passion fruit seed oil is rich in unsaturated fatty acids (87.6%), mainly linoleic (73.1%) and oleic (13.8%) acids [183]. The oil has free radical scavenging activity.

Studies on seeds from five black currant (*Ribes nigrum* L.) cultivars revealed that Canadian black currant seed oil is a good source of essential fatty acids, tocopherols and phytosterols [184]. Dry tomato seeds contain about 17% oil, rich in linoleic and oleic acids, followed by linolenic and palmitoleic acids. The predominant saturated fatty acids are palmitic and stearic acids. The fatty acid composition is similar to that of sunflower and soybean oils [185]. Dry tomato peels contain 2.7% oleoresin, which in turn contains 7.2% lycopene. The oleoresin can be incorporated into the oil in amounts appropriate to achieve the desired lycopene enrichment levels. Grape seed oil is rich in unsaturated fatty acids, linoleic acid in particular.

The saturated fatty acids in the date pits oil are 0.11–38.81% lauric, 3.12–18.23% myrsitic, 0.42–15.09% palmitic and 1.66–6.05% stearic acid. The main monounsaturated fatty acids are 0.07–1.52% palmitoleic and 32.16–55.10% oleic acids. The major polyunsaturated fatty acids are 4.33–21.00% linoleic and 0.03–1.68% linolenic acid [186–192]. Oleic acid is beneficial for health due to its low saturation and *trans*-isomer levels; and it has potential to reduce LDL cholesterol in the blood [193]. Linolenic acid is vital for the healthy growth of human skin [194]. Date pits oil could protect the skin from ultraviolet sun light. Date pits oil was used for the preparation of mayonnaise [195], which was superior in sensory characteristics as compared with mayonnaise manufactured from corn oil. However, safety of date pits oil must be tested before its use for human consumption [189].

The passion fruit seed oil is edible and rich in unsaturated fatty acids (87.6%), mainly linoleic (73.1%) and oleic (13.8%) acids [183]. The oil has free radical scavenging activity. Peach seed oil can be used as an edible oil. It contains 8.0% palmitic acid, 0.3% stearic acid, 55.1% oleic acid and 36.5% linoleic acid. It can also be used for soap production. The peach seed oil is richer in oleic and linoleic acids than tomato seed oil.

Organic Acids

Organic acids are used in foods and pharmaceuticals. Recently these acids are being exploited as alternate hydrogen sink to mitigate enteric methane production. Dried apricot wastes are used as a substrate for production of citric acid by *A. niger* through fermentation. It was found that solid state fermentation (SSF) with *Aspergillus foetidus* ACM 3996 using dried apricot waste as a substrate produced higher amount of citric acid than from other waste sources such as apple pomace, rice or wheat brans. In another report, researchers have used four species of Aspergillus to compare the production of citric acid in a SSF. Under optimized conditions, a yield of 19.4 g citric acid/100 g dry fermented pineapple waste was obtained.

Most of the citric acid is manufactured mainly through solid-state fermentation (SSF) of starch/molasses exclusively by *A. niger* [196]. Molasses, fruit and vegetable pomace and cassava bagasse have been used as substrates for citric acid production [197]. Hang [198] used apple pomace as a substrate for citric acid production. Citric acid was also produced from date extract/molasses by using *A. niger* ATCC 6275 & 9642 [199] and from date wastes using *A. niger* ANSS-B5 [200].

Lactic acid has an important position in the family of carboxylic acids because of its application in both food and non-food industries. It is used as a preservative and acidulant in food industries. However, commercial production of lactic acid is costly due to high cost of the raw materials used. It can be economized by using biological wastes. By using pineapple waste, 19.3 and 14.7 g lactic acid/l of fermentation media can be produced as a substrate by SSF. AQ4

Karp *et al*. [201] developed a bioprocess to produce L(þ)-lactic acid, a product with various applications in food, cosmetic, pharmaceutical and chemical industries. It uses soybean vinasse as substrate, without supplementation with inorganic nitrogen sources and yeast extract. Potential of mango peel as a low cost substrate for the production of lactic acid has also been investigated [202]. In this study, mango peel was directly fermented using bacteria having both amylolytic and lactic acid producing capabilities. A maximum production of 17.48 g/l lactic acid was obtained through optimization of fermenting conditions. The mesophilic microbial system, which can operate at 35 °C was used in this study, and it seems to have practical advantage because of low cost. In another study, lactic acid concentration of 63.33 g/l of fermentation media was obtained from mango peel fermentation by *Lactobacillus casei* [203]. To reduce the cost of lactic acid production, inexpensive raw materials such as food waste (fruit and vegetable peel/waste) like sapota, banana, papaya, potato, corn cob and carboxymethyl cellulose were explored. All substrates tested supported growth and lactic acid production. Efficient lactic acid concentration (72 g/l) was obtained with sapota peel fermentation [204]. Nancib *et al*. [205] used date juice as a substrate for the production of lactic acid by using *L. casei* subsp. rhamnosus or by using *Lactobacillus delbrucki* [206].

Ferulic acid is the most abundant hydroxyl cinnamic acid found in plant cell walls. This phenolic antioxidant is widely used in the food and cosmetic industry. The peels of pineapple, orange and pomegranate have been used for extraction of ferulic acid [207–210]. Gallic acid (31.76 mg/100 g dry extracts), catechin (58.51 mg/100 g), epicatechin (50.00 mg/100 g), and ferulic acid (19.50 mg/100 g) were found to be the main polyphenolics in pineapple peels [209]. Ferulic acid is beneficial for sperm viability and motility in both fertile and infertile individuals; and the reduction of lipid peroxidative damage to sperm membranes and increase of intracellular cAMP and cGMP may be involved in these benefits. It is possible that ferulic acid may be used for curing asthenozoospermic infertility [211]. Acetic acid, another organic acid can be produced from carrots and white radish leafage. Carrot leafage has been used as the substrate in the hydrothermal two stage production of acetic acid which resulted in high yield [212]. Thus, organic acid production by utilizing vegetable waste serves two purposes: reduction in the cost of raw material and recycling of the waste, thus decreasing the pollution problem.

Organic Minerals

The amounts of minerals present in the residues for example seeds and peels of acerola (*Malpighia glabra* L.), guava (*Psidium guajava* L.), papaya (*Carica papaya* L.), sapota (*Achras sapota* L.), cashew apple bagasse (*Anacardiumoccidentale* L.), pineapple (*A. comosus* L.), and mango (*Mangifera indica*L.) were, in general, much higher than the amounts found in their respective edible portions of the fruit. The only exceptions were for iron in cashew apple and sodium in sapota. These results show that these fruit residues are good sources of minerals. Mango and cashew apple residues can also be considered good sources of manganese, because they could contribute to more than 10% of the recommended daily intake (RDI) of manganese (for a portion of 10 g of dried residue used as food supplement). Papaya residue could be used as a source for phosphorus, since a portion of 10 g of the dried residue could contribute more than 10% of the RDI. Pineapple residue may also be a remarkable source of manganese since only 10 g of the dried residue can contribute to more than 100% of the RDI for man and 92% of the RDI for woman [15].

Single Cell Protein

It is also called biomass, bioprotein or microbial protein and refers to proteins extracted from pure microbial cell culture. It is produced using bacteria, fungi algae or yeasts. Filamentous fungi (*Aspergillus, Fusarium, Rhizopus, etc.*), alga (*Spirullina, Chlorella,* etc.), many bacterial species (*Bacillus, Lactobacillus, Pseudomonas,* etc.) and yeasts (*S. cerevisiae*) are extensively used for single cell protein (SCP) production [213]. Besides high protein content (60–82% dry cell weight), SCP also contains fats, carbohydrates, nucleic acids, vitamins and minerals; and are rich in lysine and methionine which are limiting in most plant and animal foods. The fruit and vegetable processing wastes are useful substrates for the production of SCP. Their use besides solving waste disposal and controlling associated pollution problem is expected to cover, to some extent the global shortage of protein rich food and feed.

SCP can be produced from dried and pectin extracted apple pomace by using *Trichoderma viride* and *A. niger* [214–216]. Bhalla and Joshi [217] reported 200% increase in crude protein enrichment in apple pomace by using a combination of *Candida utilis* (Henneberg), syn. Pichia jadinii and *A. niger*. Five-fold increase in crude protein content with *Rhizopus oligosporus* [218], 100% increase in crude protein and 60% increase in mineral contents with *C. utilis* [219] have been observed. Pomegranate waste, orange waste, banana waste, watermelon waste were used as a sole carbon source for preparation of fermentation media on which strains of yeasts, *S. cerevisiae* have been used to produce SCP [220]. Citrus peel juice has also been used to generate SCP using *Fusarium*. Potato peels supplemented with ammonium chloride have also been used for the production of SCP by using a non-toxic fungi *Pleurotus ostreatus*. Similarly, waste from orange, sugarcane and grape processing industry have also been utilized for the production of SCP [173]. Papaya processing waste (PPW) served as substrate for *S. cerevisiae* growth. The product contained 45% crude protein. The commercial feed of shrimp could be replaced up to 50% by SCP obtained from papaya processing wastes. The 50% inclusion of PPW diets were comparable with commercial feed in weight, growth, feed conversion ratio and survival rate of shrimps [221].

Mango-peel extract has been used for SCP production using *Pichia pinus* yeast [222]. The *S. cerevisae* could be used to enhance the nutritive value and antioxidant properties of citrus peels; however, fermented shaddock and orange peels had the highest nutritive and antioxidant potentials, while grape fruit peel had the least potential [223]. The fermented peels could be a source for nutrients and nutraceuticals for livestock. Mondal *et al*. [224] found that higher crude protein (53.4%) was obtained from cucumber peels than from orange peels fermented with *S. cerevisiae*, because of higher available carbohydrates and minerals in the former, which might have favourably affected yeast biomass production. Stabnikova *et al*. [225] reported production of selenium enriched *S. cerevisae* biomass by growing the organism in extracts of cabbage, watermelon, a mixture of residual biomass of green salads and tropical fruits. The SCP production by yeast depends on the substrates or media composition. Gao *et al*. [226] achieved 53% CP in SCP from Jerusalem artichoke extract by using a marine yeast *Cryptococcus aureus* G7a.

Essential Oils

The essential oils extracted from lemon and lime peels are sometimes worth 20 times the value of their juice. Citrus terpenes, principally D-limonene, are extracted from the peel oil. D-limonene is used in the preparation of hand cleaners and thinner. The citrus peels are a potential source of essential oil and yield 0.5–3.0 kg essential oil/tonne of fruit [227]. Citrus essential oil is widely used in alcoholic beverages, confectioneries, soft drinks, perfumes, soaps, cosmetics and household products owing to its aromatic flavour. It is also used to mask bitter taste of drugs in pharmaceutical products [228]. It improves the shelf life and the safety of fresh fruits [229], skim milk and low-fat milk [230] and exhibits broad spectrum antibacterial activity [231]. Oils from both sweet and bitter oranges are used in tea formulations and as an ingredient in stomachic, carminative and laxative preparations. D-limonene isolated from lemon essential oil improves the immunity, counters occasional feelings of depression, promotes clarity of thought and purpose, energizes and stimulates the mind and body, opens and releases emotional blocks, supports skin health and reduces the appearance of wrinkles [232]. Dried bitter orange oil is used in treating prolapse of the uterus and rectum, diarrhea and piles.

Exogenous Enzymes

Fruit and vegetable wastes/residues used as substrate for microbial fermentation for enzymes production, having a wide range of applications are presented in Table 3 [233–254]. Proteolytic enzyme bromelain may be extracted from the mature pineapple, and papain from latex of papaya fruit. Using SSF, banana waste can be used for the production of α-amylase [235]. Pequi (*C. brasiliense*) a Brazilian fruit can also be used as substrate for production of amylase [255], hemicellulase [238] and cellulase [239]. Highest filter paper cellulase (FPase) activity of 13.4 IU/g dried substrate (gds) was observed when dried kinnow pulp supplemented with wheat bran in the ratio of 4 : 1 was used as a substrate and SSF was done using *Trichoderma reesei* Rut C-30; while the endo-1,4-β-glucanase (CMCase) activity was found to be the highest when kinnow pulp was supplemented with wheat bran in the ratio 3 : 2 using Mandel Weber (MW) medium [245]. Agha *et al.* [256] investigated the use of a crude peroxidase preparation from onion solid by-products. Gassara *et al.* [233] used apple pomace for lignin and manganese peroxidase and laccase production by *Phanerocheate chrysosporium*. Sapota peels and citrus peels can be used as a substrate for the production of pectinase [246]. Mango peel has been used for CMCase production using *Paenibacillus polymyxa* [252] and cellulase using *T. reesei* [253]. Verma *et al.* [257] used pea peel waste to produce cellulase in SSF.

Pectins in pulps of tomato, pineapple, orange, apple, lemon and turnips and in peels of oranges and other citrus fruits form important natural substrates for production of pectinase [258–260]. Totapuri mango peel was used to produce polygalacturonase and pectinase, using *A. foetidus* [252]. Potato peels were used for the production of polygalacturanase, using *Bacillus licheniformis* [261]. Amongst 16 agro-industrial wastes, high yield of pectinase (39.836 U/gds) was obtained using *A. niger* (NCIM 548) when grown using jack fruit waste as a substrate [251]. The SSF based production of exo-pectinase (573 IU/ml) and endo-pectinase (52 IU/ml) using orange peel [262], lemon peel [263], orange peel [264] and apple pomace [265] as substrates has been demonstrated.

Protease activity was found in peels of Jujube, pineapple and papaya. Highest specific activity of protease was observed in pumpkin waste, comparable with that in cauliflower and cabbage wastes when used as substrates fermentation using *A. niger* [266].

An extracellular lipase was produced by *Bacillus coagulans* [267] and *Rhizopus nigricans* by SSF using melon peels.

Botella *et al*. [268] have used grape pomace as a solid substrate to produce xylanase and pectinase. Furthermore, grape pomace could induce the production of laccase by *Trametes versicolor* [269]. Some species of microorganisms belonging to the *Aspergillus* genus can produce tannase [270], naringinase [271], β-glucosidase [272], feruloyl esterase [273] and flavonol 2, 4-dioxygenase [274], having wide industrial applications.

Bio-ethanol/Methanol

Several reports are available on bioethanol production from various food and vegetable wastes [275] by using *S. cerevisiae*. Fruit and vegetable wastes can either be used directly as an untreated material for microbial growth or after appropriate treatments with enzymes for bioenergy production. The products generated from perishable wastes can be in liquid or gaseous forms of biofuels. The fruit and vegetable wastes, which have high pectin, cellulose and hemicellulose serve as a suitable substrate for fermentation. Amongst various wastes used for bioethanol production, potato peels [276], apple pomace and waste apples [277], banana peel and banana waste [278–280], beet waste and beet pomace [281], kinnow mandarin *(Citrus reticulata)* waste [282]and peels [283] and peach wastes have shown encouraging results. Pineapple pulp contains substantial amounts of sucrose, starch and hemicellulose. These may therefore be used for bioethanol production [284]. Bioethanol production from fruit peels of pineapple, orange and sweet lime [285–290] and powdered avocado seed wastes [291] have also been reported. Shilpa *et al*. [292] reported that after 7 days of fermentation, the bioethanol yield was 8.34, 7.45, 3.98 and 2.58% for pineapple, banana, orange and pea peels, respectively. Amongst the 4 peel extracts, highest production of bioethanol was obtained from papaya peel extract followed by banana and apple peel extracts (5.90–4.94%), and lowest yield was from turnip peel extract (1.5%) [293]. On an average 20% of the watermelon crop is culled, which can be used for bioethanol production. Approximately 174 kg/ha or 220 l/ha of ethanol would be produced from these culled watermelons [294]. The peach waste is used for brandy production, 6 litre brandi with 43% alcohol can be obtained from 100 kg peach waste.

Date extract was used as a substrate for the production of ethanol by using *S. cerevisae* ATCC 36858 and *S. cerevisae* STAR brand [295], from date wastes by using *S cerevisiae* SDB [200]. Spoiled date fruit was used as a substrate for the production of methanol by using *Clostridium acetobutylicum* ATCC824 and *B. subtilis* DSM 4451 [296].

Bio-degradable Plastic

Bacterial cellulose (BC) is biologically produced from several species of *Acetobacter* because of its unique properties, and it has advantages over plant cellulose. *Acetobacter xylinum* produces BC from various substrates including sugars, fruits and vegetable wastes. Bacterial cellulose produced by *A. xylinum* is a new type

Table 3 Fruits and vegetables used as substrates for microbial fermentation for enzyme production

Substrate	Microbe	Enzyme	References
Apple pomace	*Phanerocheate chrysosporium*	Lignin peroxidase, manganese peroxidase and laccase	Gassara *et al*. [233]
		α-Amylase	Nigam and Singh [234]
Banana waste (peel and stalk)	*Bacillus subtilis*	α-Amylase	Krishna and Chandrasekaran [235]; Kokab *et al*. [236]
	Aspergillus niger	α-Amylase	Francis *et al*. [237]
		Hemicellulase	Medeiros *et al*. [238]
		Cellulase	Krishna [239]
Banana peel	*Aspergillus fumigatus* VkJ2.4.5	Laccase	Vivekanand *et al*. [240]
Citrus peels	*Aspergillus niger*	Pectinase	Patil and Dayanand [241]; Dhillon *et al*. [242]
Citrus waste	*Eupencillium javanicum*	Xylanase, pectinase	Tao *et al*. [243]
Citrus pulp	*Aspergillus niger*	Phytase	Spier *et al*. [244]
Kinnow pulp wheat bran (4 : 1)		Cellulase (filter paper activity)	Oberoi *et al*. [245]
		Pectinase	Sabika and Gyana Prasuna [246]
Corn cob	*Phaenerochate chrysosporium*	Cellulase, xylanase	El-Nassar *et al*. [247]
Corn stalk	*Fsarium oxysporum*	Endoglucanase, β-glucosidase	Panagiotou *et al*. [248]
Date syrup	*Bacillus subtilis* EFRL 01	Pectinase	Qureshi *et al*. [249]
Date pomace	*Aspergillus niger* PC5	Endopectinase	Bari *et al*. [250]
Date wastes	*Candida guilliermondii* CGL-A10	Alpha amylase	Acourene and Ammouche [200]
Jack fruit waste	*Aspergillus niger* (NCIM 548)	Pectinase	Rao *et al*. [251]
Mango peel	*Paenibacillus polymyxa*	Carboxymethyl cellulase (CMCase)	Kumar *et al*. [252] Saravanan *et al*. [253]
	Aspergillus foetidus	Pectinases	Kumar *et al*. [252]
Potato peels	*Bacillus licheniformis Bacillus subtilis*	α-Amylase	Shukla and Kar [254]

of biopolymer. Nowadays, biopolymers have numerous applications in industrial sector; being biodegradable and nontoxic in nature. The residues left after extraction of coconut water, papaya juice and muskmelon juice were used as a substrate (carbon source) in the production of BC. Without additional sugars incorporated into the residues, the yields of BC were 2.43, 4.52 and 1.68 g/100 g for coconut, papaya and muskmelon residues, respectively [297]. In recent years, vegetable and food wastes have been used for production of polyhydroxybutyrate (PHB)[298, 299], a biopolymer that can be used as a biodegradable thermoplastic [300]. It has wide applications in different areas such as packaging, pharmaceuticals, chemical and cosmetic industries. Omar *et al*. [301] used date syrup as substrate for the production of PHB by using *Bacillus megaterium*. Rusendi and Sheppard, [302] reported the use of potato processing waste from the potato chip manufacturing plant for the production of PHB.

Potato or cornstarch waste is hydrolyzed to glucose by high-temperature α-amylase and glucoamylase. The glucose is fermented to lactic acid by *Lactobacillus*. Lactic acid with equal amounts of hydroxyl and carboxyl groups can self-condense to form linear thermoplastic polyester poly-lactic acid (PLA), a biodegradable plastic. It can be used as timed release coatings for fertilizers, pesticides, and as agricultural mulch films, which degrade in the soil [303–306]. Another useful application of polysaccharides extracted from tomato processing industrial wastes and from granadilla peels is the formation of biodegradable films [307, 308].

Bio-fertilizers

Vegetable and fruit wastes can be composted and used to replace a significant part of the nitrogen fertilizer with nitrogen recovery of 6–22%. The plots fertilized according to the nitrogen recommendations had comparable yields, whether it was provided (fully or partially) through vegetable and fruit compost (VFC) or not. Long-term VFC applications resulted in carbon accumulation on the top soil, mainly due to increase of the more resistant carbon fractions. The long-term compost applications improved the nitrogen status of the soil over the years [309]. Sarkar *et al*. [310] used two amylolytic and three cellulolytic thermophilic bacteria (***Geobacillus* strains**) for composting of vegetable wastes. They reported a significant reduction in C/N ratio after 10 days of incubation.

The vermicompost is a rich source of beneficial microorganisms and nutrients and is used as a soil conditioner/fertilizer. It involves the bio-oxidation and stabilization of organic matter through the joint action of earthworms and microorganisms under aerobic and mesophilic conditions. Jadia and Fulekar [311] procured cabbage, French bean, cauliflower, lady finger, spinach and carrot wastes from dumping site and used as raw material for the development of compost. Suther [312] reported vermicomposting of vegetable-market solid wastes decreased organic carbon (12.7–28%) and C:N ratio (42.4–57.8%); increased total N (50.6–75.8%), available P (42.5–110.4%) and exchangeable K (36.0–78.4%) contents in vermicompost. Aerobic treatment can successfully be integrated into the vegetable waste management with the enforcement of legislative measures, and technical and managerial support.

Biofuel

Anaerobic digestion results in generation of biogas and effluent which serve as a natural fertilizer. Fruit and vegetable wastes can be used for biogas production by anaerobic fermentation [313, 314]. Pineapple peels have been anaerobically digested to yield biogas in the form of methane [315]. Processing of custard apple peel sugars for biogas production has been reported by Narayani and Priya [316]. Mixture of fruit wastes (700 g each of apple, orange, pineapple, sapota, grape, mango and banana) used for solid-state biomethanation revealed that the biogas generation increased with increase in total solids, and 4% initial total solids content were ideal for solid-state biomethanation [314].

Amongst 13 fruit and vegetable wastes, the highest methane production was observed from carrot waste (417 ml/g volatile solids [VS] with an organic loading rate [OLR] of 0.8–0.9 g VS/l/day) [317], followed by from French bean waste (343 ml/g VS with an OLR of 0.96–1.15 g VS/l/day), pineapple pressings (335 ml/g VS with an OLR of 3.87 g VS/l/day) and asparagus peels (219 ml/g VS with an OLR of 0.74–1.06 g VS/l/day) [318]. Sagagi *et al*. [319] studied the co-digestion of fruits and vegetables waste materials and their effect on plants for determining its manural value. The highest weekly individual production rate was recorded for the cow dung slurry (1554 cm^3 biogas), followed by pineapple waste (965 cm^3), orange waste (612 cm^3), lastly, 373 and 269 cm^3 biogas yield was associated with pumpkin and spinach wastes, respectively. Gunaseelan [320] studied the biochemical methane potential (BMP) of 54 fruits and vegetable wastes samples and eight standard biomass samples for determining the methane yield. The ultimate methane yields of fruit wastes ranged from 0.18 to 0.732 l/g VS added and that of vegetable wastes ranged from 0.19 to 0.4 l/gVS added. The biogas yield in the range of 0.18–0.732 l/gVS and 0.19–0.4 l/g VS was reported for fruit and vegetable wastes, respectively [320]. The production of biogas to a large extent depends on the nature of the substrate. Co-digesting organic fraction of municipal solid waste (OFMSW) and vegetable oil (83 : 17 on DM basis), OFMSW and animal fat (83 : 17 on DM basis), and cow manure with fruit and vegetable waste (50 : 50 on DM basis) gave methane yields of 686, 508 [321] and 450 Nm^3/tonne VS [322], respectively.

Beatriz *et al.* [323] evaluated co-digestion of animal wastes – swine manure (SM), poultry litter (PL) and vegetable processing wastes (VPW) mixtures to determine its biomethanation potential. In SM-VPW co-digestions, CH_4 yield increased from 111 to 244 ml CH_4/g VS added. Islam *et al.* [324] studied the effect of co-digestion of vegetable waste and cow-dung in various proportions using 4 litre capacity laboratory scale digesters. The maximum amount of biogas yield was 1200 ml/kg of wastes at the vegetable waste and cow dung ratio 1 : 1. Biogas yield and efficiency of volatile solids removal in co-digestion of vegetable waste with other organic wastes is higher than the anaerobic digestion of vegetable waste alone. Vegetable waste and animal waste combination is found to be better since it yields high amount of biogas. Thus co-digestion appears to be a potential economically viable option for the generation of renewable source of energy. It also controls environmental pollution by treating the waste in an eco-friendly manner [241].

Ensiling mango peel for 6 months resulted in 58% higher gas production as compared with control [325]. Earlier, Devi and Nand [326] revealed that pretreatment of mango peel for 6 days resulted in 8-fold increase in total gas production. Higher gas production was observed for mango peel, when co-digested with cow dung in 1 : 10 ratio and at 8% total solids compared with control [327].

The proportion of stem, peel and fruit portion of banana represented 0.84, 17.71 and 81.46% with specific methane yield of 0.256, 0.322 and 0.367 m^3/kg VS, respectively. Hence, anaerobic digestion of banana waste could generate substantial amounts of energy.

The biohydrogen production through anaerobic fermentation of jackfruit peel waste has also been reported [328]. Abd-Alla *et al.* [329] reported that biohydrogen could be produced from rotten date by using *E. coli* EGY, *C. acetobutylicum* ATCC 824 and *Rhodobacter capsulatus* DSM 1710.

Bio-adsorption

Bio-adsorption is considered to be an efficient and a low cost technique because it uses low-cost and abundant biomaterials, usually wastes, for removing heavy metals and dyes from water. It also minimizes release of chemical or biological sludge in the environment and gives possibility of regenerating biosorbents that could recover metals.

Nawirska and Kwasniewska [330] proposed chokeberry and apple pomace as biosorbents for heavy metals. Mango peel was used as biosorbent for the removal of Cd and Pb from aqueous solution [331]. A fast biosorption rates i.e. reaching equilibrium in 60 min, for both metals were observed. In a similar study, effective removal of Cu^{++}, Ni^{++} and Zn^{++} from constituted metal solutions and genuine electroplating industry waste water have been reported using mango peel waste [332]. Ahmad *et al.* [333] reviewed the potential of activated carbon developed from date pits to remove pollutants like heavy metals, dyes, phenolic compounds, pesticides etc. Date pits ash had remarkably higher efficiency of boron (71%) and phenol removal from drinking water when compared with power plant ash, pine tree fly ash and ferric chloride [334, 335]. Date pits powder and activated carbon from date pits were effective in purifying water because these removed different types of pollutants, such as heavy metals, boron, dyes, phenolic compounds and pesticides [130].

Peach stone particles have ability for biosorption of mycotoxins under *in vitro* conditions because of their rather high cellulose content (58.5%). The presence of biological polymers (cellulose, lignin and hemicellulose) in peach shells give them richness in hydroxyl and phenol groups which can be further chemically modified to produce adsorbent materials with improved adsorbing properties [336].

Pineapple stem and leaf powder has been used as low-cost adsorbents to remove basic dye (methylene blue) from aqueous solution. Pineapple fruit residue has been used as an effective biosorbent to remove toxic metals like mercury, lead, cadmium, copper, zinc and nickel [30]. These authors have reported that the addition of phosphate groups in the fruit residues increased the adsorbent capacities at lower pH. Heavy metals (Cr, Pb, Ni) could be removed from contaminated sewage sludge using citric acid (obtained from pineapple wastes fermented with *A. niger*), before their disposal in land fills. Pineapple waste water has also been used as a low-cost substitute of nutrients for *Acinetobacter haemolyticus*, which was used to reduce the contamination of chromium VI [30].

The orange peels can be used as low-cost and eco-friendly adsorbents for removing dyes from waste water [337]. Citrus fruit oil (D-limonene) shows detoxification and antioxidant properties by increasing the level of glutathione S-transferase in liver [338]. Dhanapal *et al.* [339] suggested that citrus fruit oil can be used as a feed additive to partially ameliorate aflatoxicosis.

Bio-pesticides

Absence of large-scale production of bio-pesticides is one of the major constraints in the wider application of many biopesticides. Carob pulp aqueous extracts were used as carbon source in the production of the biocontrol agent *Pantoea agglomerans* PBC-1, used as a bio-pesticide [340]. A 78% reduction of the pathogen incidence was achieved with PBC-1 at 1×10^8 cfu/ml of fermentation media. The extracts of cucumber plant waste (leaves, stem and roots excluding flowers and fruits) have been reported to inhibit the germination and growth of barnyard grass (*Echinochloa crus-galli*) under laboratory and greenhouse conditions [341]. It is a potent weed in rice fields causing huge losses to rice production. Two potent growth inhibitory substances, 9-hydroxy-4,7-megastigmadien-9-one (HMO) and (6S,7E,9S)-6,9,10-trihydroxy-4,7-megastigmadien-3-one (THMO) were isolated from an aqueous methanol extract of cucumber plants [342].

A novel antifungal protein with an approximate molecular mass of 40 kDa was isolated from pumpkin rind and designated as Pr-1. It inhibited growth of several fungi including *Botrytis cinerea, Fusarium oxysporum, Fusarium solani and R. solani*, as well as yeast, *Candida albicans*. Pr-1 is potentially a useful and effective antifungal agent for crop protection [343].

Bio-preservatives

The mango seed kernel (MSK) acts as a natural antioxidant in foods. The methanol extract of MSKE or MSK oil increased the oxidative stability of sunflower oil at ambient temperature as well as during frying. These also improved the stability and quality characteristics of fresh and stored potato chips, and shelf life of ghee.

Antimicrobial substrates are potentially useful as food additives to extend the shelf life of foods, in particular unheated products such as beverages where heat treatment may impair their delicate flavour profile. Number of fruit and vegetable wastes have better efficacy compared with other natural anti-microbials. Best examples are methanol extract of MSK, methanolic, ethanolic and aqueous extracts of pomegranate peels [344, 345], papaya seed waste [346]. Roy and Lingampeta [347] revealed that acetone extracts has antimicrobial activity, in the order of pomegranate peels > jackfruit peels > custard apple peels, which is attributed to the presence of furanone, furfural (along with imidazole) and phenolic compounds (mainly benezenetriol).

Mushroom Cultivation

Pequi (*C. brasiliense*) and guavira (*C. pubescens)* fruit wastes were successfully utilized as substrates for *Pleurotus sajor-caju* production during a solid state bioprocess. The protein enriched spent biomass can be used in livestock feeding [255]. Banana leaves can be used for the cultivation of *Volvariella volvacea*, an edible mushroom [348]. The winery and apple wastes can be recycled as useful raw materials for mushroom compost preparation, giving 20–28 kg mushroom/100 kg of composts [349, 350]. Petre and Teodorescu [351] cultivated medicinal mushrooms *Ganoderma lucidum* and *Lentinula edodes* and recorded 1.5–2.8 kg mushroom production/10 kg of solid composts made from winery wastes. Behera and Gupta [352] used 11 fruit and vegetable peels for the substrate production for growing some wild edible mushrooms and revealed that papaya peel, drumstick peel, carrot peel and bottle gourd peel in the media enhance growth of *P. sajor-caju, Lentinus tuberregium* and *Calocybe indica.*

Enteric Methane Mitigation

Mangosteen (*Garcinia mangostan*) peel containing 16% condensed tannins and 10% crude saponins on DM basis were supplemented at the rate of 100 g DM/day with 3% sunflower oil and 3% coconut oil in a rice straw and ruzi grass (*Brachiaria ruziziensis*) based diet fed to dairy cattle. It improved rumen ecology, especially increased bacterial population and reduced protozoa number without any significant effect on fungal zoospores population. This also reduced enteric methane production. The milk yield and milk composition were unaffected [353]. *In vitro* methane production was reduced by 51% after 21 h incubation on using mangosteen peels in a substrate containing molasses and cassava leaf meal [354]. Rambutan fruit peel contains saponin [355], addition of 0.2% saponins from rambutan peel decreased methan production, without any adverse effect on the rumen fermentation.

Conclusion

The fruit and vegetable wastes are rich sources of energy, protein, minerals and vitamins; and therefore, have great potential as feed for livestock, poultry and fish [2, 3]. Besides conventional nutrients, these are excellent sources of bio-active compounds, which can be utilized extensively in pharmaceutical, food processing and other allied industries. The bio-active compounds present in these wastes (Tables 1 and 2) exhibit anti-cancer, anti-microbial (-pathogens), anti-oxidative and immune-modulatory effects. They reduce incidence of cardio-vascular diseases and capillary fragility, inhibit platelet aggregation and prevent thrombosis, oxidative stress, osteoporosis and diabetes in vertebrates. AQ5

Pomace/pulps, peels, seeds of many fruits and vegetables are used as dietary fibre supplements and as a functional ingredient in developing processed food products having health benefitting effects. Some fruit and vegetable wastes are excellent sources of bio-pigments and edible oil rich in poly unsaturated fatty acids. Many fruit and vegetable wastes are used as a substrate for the production of organic acids (citric, lactic and ferulic acids), single cell protein, essential oils, exogenous enzymes (Table 3), bio-ethanol/methanol, bio-fuel, bio-pesticides, biosorbants, bio-degradable plastic, bio-fertilizers, bio-preservatives and edible mushroom cultivation. The utilization of fruit and vegetable wastes for generation of value added products will promote bioeconomy projects in addition to help reducing environmental pollution. AQ6

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AQ1: Please check the inserted expansion of 'DM'.
AQ2: Please check if it is appropriate to replace the phrase 'On their own,' with 'Besides,' in the sentence 'On their own, the seeds ... like peanut butter'.
AQ3: Please check the changes made to the sentence 'Colouring agents have ... textile industries' else the sentence seems incomplete.
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