OVERVIEW PAPER

Value-added Fruit Processing and Human Health – Global Perspectives

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ABSTRACT

Epidemiological studies suggest that regular or increased consumption of fruits and their products is associated with reduced risk of degenerative diseases such as various cancers, cardiovascular and neurodegenerative diseases. Scientific evidence also reveals that the disease prevention is mainly due to the presence of health promoting phytochemicals such as flavonoids, phenolic acids and carotenoids. Therefore, there is a global interest in developing value-added fruit processing methods to preserve the nutritional and non-nutrient bioactive constituents present in fruits and their products. This review discusses current global trends in processing fruits into value-added food products, functional food ingredients and natural health products. In addition, the fruit processing residues can be used in manufacturing of non-food bio-products such as animal feed, fiber, high value industrial chemicals, agro-chemicals, biofuels, and bio-plastic among many others. Biotechnological processes offer immense opportunities for better utilization of abundant fruit processing and postharvest wastes that can also resolve many environmental issues associated with disposal.

1. INTRODUCTION

Consumer self-awareness, ageing populations and escalating health-care costs have led to a rapid growth in the food industry with introduction of value-added food products with functional properties. Among them, fruit-derived ingredients and bioactives-enriched value-added foods continue to be cornerstones of the functional food market, due to their validated health benefits and consumer perceptions (Sun-waterhouse, 2011). Therefore, many novel food technologies have been introduced and being assessed for value-added processing to preserve the nutritional, constituents as well as bioactive phytochemicals present in fruits and their products. As a result, mild processing technologies such as high hydrostatic pressure (HHP), pulsed electric field (PEF), membrane filtration and UV exposure have been introduced in recent years. In addition to their beneficial effects on nutritional and bioactive content, many of these novel technologies are more cost-efficient and environment friendly. The first part of this review paper would present current trends in processing fruits into value-added products, functional food ingredients and natural health products, while the second part will throw light on the bio-processing of fruit based feedstock into various non-food bio-products.

2. Value-added fruit processing

Traditionally, value-added fruit processing could be fulfilled by canning, drying, freezing, preservation, fermentation, disinfection, among others. Accordingly, value-added fruit products generally include canned fruit products such as jam and jelly, dried fruit products such as fruit snacks, fermented fruit products such as wine and vinegar. Recently, non-thermal technologies and minimal processing concept have become popular in value-added fruit processing. Comprehensive reviews have been reported on novel non-thermal processed fruit product preservation including juices and beverages (Corbo *et al*. 2009; Rawson et al. 2011; Rupasinghe and Yu 2012a) and minimally processed fruit product preservation including fresh-cut fruit (Rojas-Graü et al. 2009; Oms-Oliu *et al*. 2010; Rupasinghe and Yu 2012b).

3. Non-thermal methods

Traditionally, the application of heat is the most commonly used method for processing fruit due to its ability to inactivate microorganisms and spoilage enzymes. However, thermal pasteurization tends to reduce the product quality and freshness. Therefore, some non-thermal pasteurization methods have been proposed during the last couple of decades, including membrane filtration, ultra-violet light (UV) exposure, high hydrostatic pressure (HHP) and pulsed electric field (PEF) (Chen et al., 2013). PEF is one of the most promising non-thermal technologies and has already been adopted in the industry applications. It can inactivate microorganisms and enzymes with only a small increase in temperature and resulting in a minimal loss of nutrients and small changes in quality when treating liquid food. PEF can retain higher levels of bioactive and nutritional compounds in fruit juices and improve the stability of these compounds during the storage (Rawson *et al*. 2011). For example, Odriozola-Serrano *et al*. (2008) observed significantly less phenolic degradation by PEF (49%) than by thermal pasteurization (55%) after 56 days of storage. Similarly, Morales-de la Peña *et al*. (2010) noticed less degradation of vitamin C by PEF than by thermal pasteurization after 31 days of storage. Comprehensive reviews have been given by Soliva-Fortuny *et al*. (2009) on the effect of PEF processing in relation to the different bioactive compounds present in fruit and Rawson *et al*. (2011) on the effect of PEF as well as other non-thermal processing technologies on the bioactive content of exotic fruits and their products (Rupasinghe and Yu, 2012a,b). HHP processing uses pressures up to 1000 MPa to inactivate harmful microorganisms in food products. HHP is proven to meet the FDA requirement for pasteurization in fruit juices and beverages without sacrificing the sensory and nutritional attributes of fresh fruits. Due to these advantages, HHP has been widely used in fruit product preservation in the areas of microbial inactivation and shelf-life extension (Ramaswamy *et al*., 2005). Membrane filtration techniques have been widely used in fruit juice processing, especially in apple juice processing. Through this process, a cold pasteurized product could be produced with flavors better than thermally treated products (Cassano *et al.* 2003). Energy savings for membrane filtration are important compared with conventional thermal processing. Moreover, they are environmentally friendly avoiding waste generation. Due to these advantages, membrane filtration techniques have been widely used in fruit juice processing (Cassano *et al.* 2003). The effect of membrane filtration techniques on the quality degradation of fruit juice has been reviewed (Refer Chen et al., 2012). Ultra-violet light (UV) exposure is another non-thermal pasteurization technique which is used frequently in food preservation. Short wave UV light can be absorbed by the DNA of microorganisms and inhibits the replication processes of cells (Chen *et al.* 2012). Due to its limitation in penetration, UV exposure is normally used in combination with other non-thermal techniques for food preservation. For example, the combination of PEF and UV for apple juice preservation has been proven to be a very favorable method (Caminiti *et al.* 2011).

Apart from novel non-thermal technologies, consumer demand for natural origin, safe and environmental friendly food preservatives has been increasing (Muche and Rupasinghe, 2011). Natural antimicrobials such as bacteriocins, organic acids, essential oils and phenolic compounds with Generally Recognized As safe (GRAS) status have shown considerable promise for use in some food products (Corbo *et al.* 2009). Moreover, the combined application of non-thermal technologies and natural antimicrobials could provide synergistic effects on prolonging the shelf-life of fruit products and potentially could become replacements for traditional preservation methods (Rupasinghe and Yu 2012*a*).

4. Key factors in development of healthy snack products

Snack food product consumption has increased considerably in the North American market due to the changes in family demographics, eating habits, innovations in product delivery, taste and availability (Fernando 2012). The key factors in the development of health snacks include high in vitamins, minerals, fibers and natural antioxidants, low in sodium, calories and fat, no artificial food additives, as well as convenience and taste (Sun-Waterhouse, 2011). For examples, when compared to the deep-fried potato chips, apple snacks produced through dehydration had accepted sensory attributes, no fat and 20-fold higher antioxidant capacity (Joshi *et al.*, 2011a,b). In addition, vitamin, mineral and natural antioxidant content of apple snacks can be enhanced by application of food processing technologies such as vacuum impregnation (Joshi and Rupasinghe, 2010; Joshi *et al.*, 2010).

5. Trends in functional beverages

A functional beverage can be defined as a drink product that is non-alcoholic, ready-to-drink and has specific ingredients providing targeted health benefits beyond general nutrition. Popular examples include sports and performance drinks, energy drinks, ready to drink teas, enhanced fruit drinks, soy beverages and enhanced water (Busetto, 2008). Functional foods including functional beverages are among the top ten new food development trends for 2010 (Food Marketing and Technology, 2010). Health, indulgence and convenience continued to be the major new product development goals globally, with sleep improvement, weight management, beauty enhancement, cholesterol management, healthy energy drink, tooth friendly, and drink for elderly products still on the top list

(Anonymous 2012). Fruits contain a wide range of health-promoting components, including dietary fibre, vitamins and antioxidants. With the rise of "super-fruits" such as blueberry and pomegranate in the health and wellness market, fruit-based functional beverages are expected to possess a significant market share in the food sector (Sun-waterhouse, 2011).

6. Recovery of value-added products from fruits and their by-products

Fruit processing residues contain a number of valuable natural materials that can be extracted using appropriate consumer- and environment-friendly techniques. Pectins, phenolic compounds, fibers, sugars, oil are some of the valuables which can be obtained by bio-processing or conventional processing of fruit co-products. Use of multidirectional approach could be advantageous in terms of input costs and product yields (Figure 1).

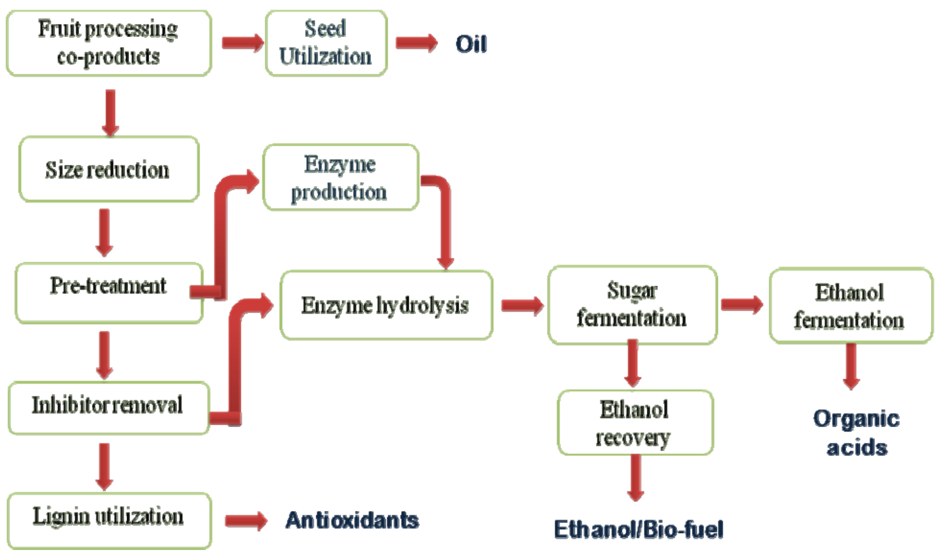


Figure 1. An example of multi-directional approach for utilization of fruit processing by-products

6.1 Antioxidant compounds

With the aim of maintaining health and preventing chronic disorders, natural antioxidants are widely used as food ingredients and dietary supplements. Fruit-residues are rich in phenolic compounds and carotenoids, which offer antioxidant and physiological properties against certain oxidative-stress-mediated chronic disorders both *in vivo* and *in vitro*. The health promoting properties of phenolic compounds include anti-allergic, anti-inflammatory, antimicrobial, antioxidant, antithrombotic, cardio-protective and vasodilatory effects. Application of appropriate extraction and purification techniques could offer a great potential for the recovery of these valuable compounds. For example, apple processing by-products are reported to contain significant amounts of flavonoids including quercetin glycosides, chlorogenic acid, epicatechin and phloridzin (Rupasinghe and Kean, 2008; Rupasinghe *et al.*, 2008;

Rupasinghe *et al.*, 2010). Also, apple peels have been shown to contain three- to six-fold more flavonoids than the flesh, thereby exhibiting greater antioxidant activities than flesh extracts (Tsao *et al.*, 2005). Grape pomace is rich in anthocyanins, flavonols and phenolic acids, especially gallic acid. A study by Ratanasooriya *et al*. (2010) showed that average concentrations of flavan-3-ols, flavonols, stilbenes and anthocyanins in grape pomace were 40, 90, 60 and 50% higher than that of the fresh fruits. Similarly, citrus waste contains high content of antioxidants and polyphenolic compounds. Ascorbic acid, carotenoids, flavonoids such as hesperidin are some of the major health enhancing compounds found in citrus waste (González-Molina *et al.*, 2010). Orange waste has been shown to contain flavonoids, with flavanones encompassing 50–80% of the total flavonoid content of oranges (Fernandez-Lopez *et al.*, 2007). Phenolic composition of mango waste has been analyzed as potential functional ingredients. It has been shown that ripe and unripe mango peels are a good source of polyphenols (Ajila *et al.*, (2007).

6.2 Fibers

Dietary fibers are a combination of chemically heterogeneous substances, such as cellulose, hemicelluloses, pectin, gums, and lignin. The constituents of dietary fibers are divided into soluble (SDF, pectin, gums) and insoluble (IDF, cellulose, most hemicelluloses, lignin) fibres. Fruit processing by-products have been used since long time for the extraction of fiber using appropriate techniques (Table 1).

Table 1. Total dietary fiber content of some common fruit processing by-products

Fruit processing by-product	Total dietary fiber (% dry matter)	References
Citrus peel	30-65%	Grigelmo-Miguel and Martin-Belloso(1999)
Apple pomace	45%	Parmar and Rupasinghe (2012)
Grape pomace	77%	Llobera and Cañellas (2007)
Lemon peel	14%	Gorinstein *et al*. (2001)
Mango peel	51.2%	Ajila et al.(2008, 2009)
Orange peel	57%	Chau and Huang (2003)
Peach pomace	30-36%	Grigelmo-Miguel *et al*. (1999)

6.3 Pectin

Production of pectin from fruit processing co-products is considered to be the most reasonable utilization approach from both economical and ecological points of view. Pectin is mainly produced from apple pomace and citrus waste by acid extraction, dietary fibers by mechanical processing. Pectin produced from apple pomace is considered superior due to its better gelling properties than citrus pectin. However, pectin from apple pomace presents a brown hue that may limit its incorporation into light-colored foods.

6.4 Flavor compounds

Recently, there has been a growing interest in the production of flavor and other food additives from natural materials than conventional methods based on chemical synthesis. There are various categories of aroma compounds based on their chemical structure, physicochemical properties, and sensorial properties. Natural biosynthesis of aroma and flavors is based on bio-conversion of plant based bio-resources. Fruity aroma was produced by *Ceratocystis fimbriata* in solid-state cultures by using apple pomace and amaranth (Bramorski *et al*., 1998). Also, apple pomace has been used as substrates for the aroma production in solid state fermentation (Bramorski *et al*., 1998; Soares *et al*., 2000; Medeiros *et al*., 2001). The production of aroma compounds from fruit processing residues using microbial technology offers several advantages over traditional methods. Besides giving higher yields, the solid state fermentation of fruit processing-residues offers economical feasibility of the manufacturing process and application of aroma compounds.

6.5 Natural colorants

Owing to increasing public concern about the safety of synthetic colorants, natural pigment extracts are gaining greater importance. Fruit processing wastes are good sources for natural colorants being rich in pigments such as anthocyanin, carotenoids, chlorophylls and betalains. These pigments can be recovered and purified using appropriate techniques to be used as natural food colorants. Moreover, the natural pigments are known to exhibit numerous health benefits; therefore, their incorporation into food may enhance the functionality of foods and thus increase their consumer acceptance. Bio-resources such as grape pomace, citrus waste, mango, pineapple, berries or banana bracts etc. can be used for extracting these natural pigments (Mazza, 1995; Aravantinos-Zafiris *et al*., 1992; Pazmino-Duran *et al*., 2001). Carotenoids can be extracted mainly from orange peel using organic solvents and acetone has been proven to give higher yields (Aravantinos-Zafiris *et al*., 1992). Similarly, other by-products such as grape pomace and banana bracts have been utilized for carotenoid extraction owing to their anthocyanin content (Pazmino-Duran *et al*., 2001). Nevertheless, there is a growing need for the development of cost efficient technologies for the industrial scale manufacture of these natural pigments. Therefore, using fruit processing by-products as substrates for microbial production of natural pigments would be a step towards adding value to the industry concerned.

6.6. Use for production of non-food bio-products

6.6.1 Enzymes:

The possibility of fruit-based residues for the commercial production of enzymes has been well explored. Besides fermentable sugars, most of these fruit by-products are rich in natural polymers, such as cellulose, lignin, pectin, starch etc, microorganisms produce large amount of different types of enzymes to degrade these substrates during fermentation. Several bacterial and fungal strains are used for the production of variety of enzymes from fruit-based biomass (Table 1). For instance, apple pomace has been used to produce lignolytic enzymes by solid-state cultures of *Phanerochaetechrysosporium* BKM-F-1767 (Fatma *et al*., 2010), cellulase using *Trichoderma harzianum, Aspergillus ustus, Bortrytes* spp, pectinase using *Aspergillus niger* (Joshi *et al*., 2006) and polygalacturonase using *Lentinusedodes* (Zheng and Shetty, 2000). Similarly, citrus waste has been widely used to produce pectinase, cellulase using *Penicilliumatrovenetum, Aspergillus flavus, Aspergillus niger and Aspergillus oryzae* (Adeleke *et al*., 2012; Dhillon *et al*., 2004; Mrudula and Anitharaj, 2011). α-L-Rhamnopyranosidase is an enzyme used for de-bittering citrus-juice by hydrolyzing naringin and hesperidin, apart from being used as aroma enhancer in juices and alcoholic beverages. Very recently, Abbatea *et al*. (2012) reported that the purification and characterization of α-L-rhamnopyranosidase from citrus solid waste. Palm fruit bunch fiber has been recently shown to produce cellulase by solid state fermentation using *Penicillium verruculosum* COKE4E (Kim and Kim, 2012). Banana waste has been recently investigated for its use in the production of alpha-amylase using *Bacillus subtilis* under solid state fermentation (Unakal *et al*., 2012). Reduction in the cost of enzyme production and improvement in the efficiency of production are major goals for future research. Agro-industrial by-products can be successfully utilized for solid state fermentation to produce the microbial production of enzymes. Currently, these residues are under-utilized, therefore, abundant and freely available as a low-cost raw material.

6.6.2 Organic acids

Organic acids are heavily used in foods, beverages, pharmaceuticals, cosmetics, detergents, plastics, resins, and other chemical manufacturing. In this context, fruit processing by-products offer ideal substrates for the bio-production of organic acids such as citric, acetic, tartaric, malic, gluconic and lactic acids. The production of organic acids from processing by-products involves three types of fermentation: surface/stationary fermentation, submerged fermentation and solid state culture based fermentation. Apple pomace, grape pomace, and orange waste have been reported for the production of citric acid by solid state fermentation using *Aspergillus niger* (Dhillon *et al*., 2011; Hang and Woodams, 1985, 1987; Rivas *et al*., 2008; Soccol *et al*., 2004; Shojaosadati and Babaeipour, 2002; Tran *et al*., 1998). Apple pomace, mango peel waste and banana waste have been studied to produce lactic acid (Jawad *et al*.,2012; Chan-Blanco *et al*., 2003; Gullón *et al*., 2008).

6.6.3 Animal feed components

During the last decades, the scientific research has been focused on many aspects of fruit processing by-products as animal feed, mainly optimizing their nutritive value, characterization of phenolic compounds, fatty acids etc. Other factors such as type and amount of by-products generated, their moisture and nutrient content, storage facility, presence of contaminants and toxins and handling practices need to be explored for investigating the suitability of fruit by-products as animal feed (Crickenberge and Carawan, 1996).

Citrus by-products, including fresh and dried citrus pulp, silage, meal, molasses, peel and activated sludge have been utilized as alternative feed components for cattle (Bampidis and Robinson 2006; Caparra *et al*., 2006). Similarly, olive by-products have also been evaluated as animal feed with respect to their composition, digestion, degradation, ruminal fermentation and their impact on animal performance and product quality (Molina-Alcaide and Yáñez-Ruiz 2008). The effluent from biogas production from mango processing waste has been utilized for the production of fresh water fishes, such as carp, rohu etc. (Mahadevaswamy and Venkataraman, 1990). On the other hand, apple pomace finds limited use as animal feed due to the presence of anti-nutritional factors such as pectin, tannins and low protein content. However, efforts have been made to biodegrade the anti-nutritional factors and to improve the nutritional value in apple pomace by microorganisms such as *Candida utilis*, *Aspergillus niger*, *Aspergillus oryzae, Fusarium moniliforme* and *Pleurotus ostreatus* (Joshi *et al.* 2000; Shojaosadati and Babaeipour, 2002; Niture and Pant, 2007; Tao *et al*., 2009). The production of animal feed from agro- residues represents one of the highest cash return due to the fact that the demand for animal feed is always stable and significant. Therefore, animal feed production from fruit processing residues can be a sustainable technology for profiting the fruit industry and for the better management of environment related challenges.

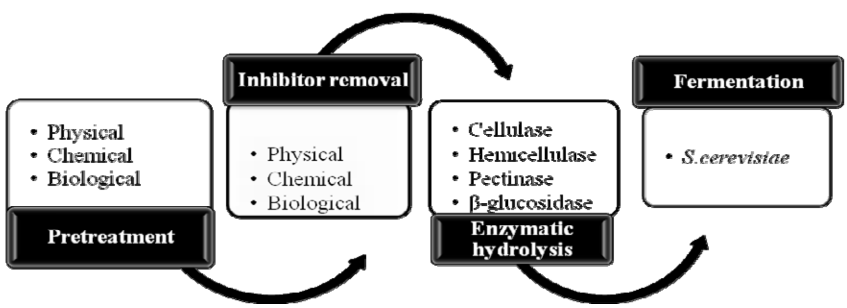
6.6.4 Use as organic fertilizer and bio-herbicidal agents

Owing to their suitable moisture content, biological oxygen demand (BOD), C:N ratio, pH and soluble salts, fruit processing by-products can be beneficially used as a soil conditioner, fertilizer and/or weed control agents. During the last decades, composting technology has been arising as a sustainable tool for the efficient utilization of the fruit-processing wastes and to convert them into value-added products. This process is a controlled bio-conversion of waste material into hygienic humus rich and bio-stable product that conditions soils and nourishes plants. Certain fruit processing co-products such as peels, pulps, outer skins, pomace, cores, leaves, fruit twigs and sludge can be used as soil fertilizers. For instance, previous studies have reported the use of olive processing waste being used for weed control in a dose-dependent manner (Cayuela et al., 2008; Boz et al., 2009). Cranberry pomace has also been used as soil fertilizer (Zheng and Shetty, 1998). Bioconversion of cranberry pomace can be carried out by solid state fermentation by some commonly used fungi such as *Trichoderma, Penicillium* and *Rhizopus* (Zheng and Shetty 1998). It has been demonstrated that soil application of cranberry pomace waste augmented with *Trichoderma harzianum* inoculant can be used for pest control.

Since the commencement of agriculture, weed management has been a critical issue to be addressed. This is for the reason that unmanaged weeds cause excessive decrement in crop yields than the existence of any other agricultural pest. In the modern agriculture, more than half of the volume of all agricultural pesticides applied is herbicides. Environmental and health concerns related to the use of synthetic herbicides for weed control in crops have lead to a rise in public alertness to find new ways in order to fight these issues in environmental friendly way. Plant-derived compounds as natural herbicides have become replacement for synthetic compounds and the products lost due to registration requirements (Coppings and Duke, 2007). Canadian provinces are thinking to take similar actions to ban the use of synthetic herbicides by replacing them with natural products (Block, 2006; Canadian Press, 2008). Natural products such as vinegar might have potential for use as broadcast applications in agricultural crops. Vinegar or acetic acid has emerged as a natural non-selective weed control agent in organic agriculture. These days, 20% acetic acid is marketed as "horticultural vinegar" for weed control in gardens, lawns, roadsides, railway right of ways, golf courses, driveways and industrial sites. Horticultural vinegar is commercially produced by acetous fermentation of grain based ethyl alcohol. Now, efforts are being made to utilize other biomass such as agro-industrial waste for the production of natural vinegar for its use in horticulture.

Fruit processing waste can be used in energy production

Global increasing energy demand has stirred recent interest to explore alternative sources for petroleum-based fuels. Biofuel production from agro-industrial wastes especially fruit processing waste and even waste of postharvest loses is one of the interesting approaches from the economic and environment protection point of view. Rich in soluble as well as insoluble carbohydrates, fruit by-products offer a great potential for their use in bio-ethanol production by fermentation. Ethanol production from fruit processing waste mainly includes pretreatment, hydrolysis and fermentation as represented in Figure 2. *Saccharomyces cerevisiae* is the main yeast strain use for fermentation of sugars into ethanol. Use of fruit processing waste as a source of bio-ethanol manufacturing has been investigated by many countries. For instance, efforts have been made on the utilization of sugars, starch, cellulose, pectin and hemicelluoses present in fruit processing waste such as pineapple juice residue (Tanaka *et al.*, 1999), banana waste (Tewari *et al.*, 1986), apple pomace (Parmar and Rupasinghe, 2012; 2013), citrus waste (Oberoi *et al.*, 2010) and mango waste (Arumugam and Manikandan, 2011). Despite their large potential to produce bio-ethanol, the feasibility of using fruit processing by-products is limited by the costs involved in each step. Although new biotechnologies such as commercial enzymes i.e. Novazyme™ products have increased the efficiency of the process, cost of manufacturing must be addressed before the large-scale use of these feedstock for bio-ethanol manufacturing. It has been shown that consolidated bio-processing (CBP) has the potential to provide a cost effective channel for bioconversion of fruit-based feedstock to ethanol by combining enzyme production, cellulose hydrolysis and fermentation in one step (Lynd *et al.*, 2005). CBP offers the potential to reduce the need for pre-treatments, reduce energy inputs and increase conversion efficiencies (Carere *et al.*, 2008). CBP can be carried out either through strain selection to enhance ethanol yield of native cellulolytic micro-organisms (thermophiles such as *Clostridium*) or by genetically engineering cellulose-utilization pathways into an organism with high ethanol yield such as yeast (Lynd *et al.*, 2005).



7. Bio-plastics from agro-industry waste

Due to decreasing natural resources and increasing environmental issues, there is a growing trend towards efficient utilization of agro-industry wastes for sustainable solutions. Therefore, fruit processing waste being rich in carbohydrates has been investigated as a reliable source for the production of bio-plastics. Jiang and coworkers (2008) developed processes to convert agro-industrial residues containing starch, oil and sugars into value-added bio-plastics, polyhydroxyalkanoates (PHA). The process begins with fermentation of organic waste into organic acid followed by bacterial conversion into PHA. This research group showed that the development of a microbial community with a PHA content of 90% of cell dry weight from lactate, which is comparable to or even better than the current industrial processes based on genetically modified organisms. PHA-derived plastics are truly biodegradable and are regarded as the best candidates to replace the current petroleum-based plastics due to their durability and properties. The family of PHA polymers seems to be one of the most promising biodegradable materials emerging in biodegradable plastic, therefore, agro-industrial by-products has potential to be use in bio-plastic production.

CONCLUSIONS

Global perception of fruit processing residues is changing in response to need for sustainable agricultural productivity, food security and environmental conservation. There is a need for appropriate technologies for the value-addition of fruit-based biomass. Biotechnological processes offer immense opportunities for better utilization of abundant fruit processing wastes for the production of valuable compounds. These technologies possess several advantages of low cost substrates, high product specificity and low energy consumption. In addition, consumers are increasingly interested in the health benefits of foods such as diseases prevention, health enhancing and antioxidant properties beyond their general nutritional benefits. The functional foods and nutraceuticals have an important role in reducing health care costs and supporting economic development globally. Recently, research on the production of nutraceuticals from fruit processing residues has gained interest world-wide. Also, the use of fruit processing waste for the development of bio-products such as animal feed, fiber, biofuels, organic acids and antioxidants will lead to better management of these residues which is one of the main causes of environmental pollution especially in developing countries.

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