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REVIEW ARTICLE

Microbial maceration: a sustainable approach for phytochemical extraction

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Abstract
A rapid change in the lifestyle has witnessed poor health with the increased incidences of numerous diseases in the recent years, and ultimately increasing the demand of nutritious foods containing phytochemicals. A wide range of phytochemicals (secondary metabolites) is being synthesized in plants, which influence the human health upon consumption as dietary component. Recently, a number of the technologies (conventional and non-conventional methods) have been standardized by the different researchers for the extraction of these phytochemicals depending upon the raw material. However, selection of extraction method for commercial use depends upon various factors such as extraction efficiency, time required, and cost of operation. Considering these factors, microbial maceration is one of the viable approaches which is easy to handle, cost-effective, energy efficient, less hazardous and having high extraction rate. Recently, researchers have utilized this technique for the maceration of different plant-based substrates (such as legumes, cereals, pulses, fruits and vegetables) and their respective wastes for the efficient extraction of numerous phytochemicals with increased efficiency. However, scale up studies and analysis of toxic compounds produced by microbes are still a lacking field and need to be explored further by the researchers and industrialists to bring it into reality. Therefore, the present review aims to document the recent findings related to microbial maceration in a crisp way to provide the complete information to the readers.

Keywords Microbial maceration · Phytochemical extraction · Bioactive compounds

Introduction

The history of utilizing plants for humankind (nutritional and medicinal purposes) is as old as the beginning of the human era. Plants synthesize a wide variety of secondary metabolites (phytochemicals) besides the primary metabolites. Phytochemicals are nonnutritive chemicals that are produced by the plant for protecting themselves from insect infestation and microbial attack and having the tendency to protect the humans from various diseases such as heart diseases, cancer, and many other chronic diseases. Phytochemicals are natural bioactive compounds found in fruits and vegetables that work together with many other components in promoting good health in many ways. In addition, they can be used as nutraceuticals having beneficial health effects for the treatment of various diseases (Bravo and Mateos 2008). Nowadays, researchers are looking towards the potential benefits of phytochemicals as an alternate to synthetic substances, which are mostly used in pharmaceutical, food and cosmetic industries (Joshi et al. 2012). Many functional foods produced with bioactive compounds are available in the market that provide health benefits beyond fulfilling the basic need of energy and nutrition (Šaponjac et al. 2016). In the early age, Maceration and fermentation technology was used to improve the nutritional properties (digestibility and bioactivity), shelf life, organoleptic quality characteristics of food and for extraction of the active compounds which can be used

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for the production of value-added food. With the base of these themes, research took a shift for the extraction of phytochemicals using microbial maceration from numerous agro-based raw materials (whole or waste).

Several classes of phytochemicals which include phenolics, antioxidants, pigments, alkaloids compounds have the ability to possess numerous health benefits such as antimicrobial, antidiarrhoeal (Cowan 1999), and anthelmintic (Mute et al. 2009; Sharma et al. 2009, 2010). A complete detail of the phytochemicals is given in Table 1 with their mode of actions.

Extraction of phytochemicals/bioactive compounds

With urbanization, globalization and economic development, a rapid change in the dietary lifestyle has been observed since last few years leading to increase in the incidence of poor health, which is being reflected by increased incidences of numerous diseases (obesity, diabetes, cardiovascular disease, stroke, hypertension, and some types of cancer) (Jnawali et al. 2016). Because of this, the demand of the health and nutraceutical foods

Table 1 Activity and mode of action of phytochemical

Phytochemicals	Activity/ mode of action	References
Quinones	It shows antimicrobial activity that binds to the adhesions, form complex with the cell wall and enzymes get inactivated	Cowan (1999)
Flavanoids	It shows antimicrobial activity that forms complex with the cell wall and binds to the adhesions	Cowan (1999), Kumar et al. (2010)
	It has antidiarrheal activity that prevents the release of autacoids and prostaglandins, also prevent the contraction which is caused by the spasmogens, it also normalize the water transport across the mucosal cells, it prevent the release acetylcholine from gastrointestinal tract	
Polyphenols and tannins	It show the antimicrobial activity that binds to the adhesions, inhibit the enzymes, form complex with the cell wall, and disrupt the cell membrane	Cowan (1999) Mute et al. (2009)
	It also possess the antidiarrheal activity that makes mucosa present in the intestine more resistant and also reduce secretion, it normalize the water transport system across the mucosal cells and also reduce the intestinal transit, it also block the binding of enterotoxin to GM which results in enterotoxin-induced diarrhea and show astringent action	Sharma et al. (2009), Kumar et al. (2010)
	It also has anthelmintic activity that it forms protein complexes that help in increasing digestible protein in rumen, it decrease the gastro-intestinal metabolism	
Terpenoids and essential oils	It shows the antimicrobial activity that disrupts the membrane system	Cowan (1999)
	It also shows the antidiarrheal activity that prevents the release of prostaglandins and autacoids	
Alkaloids	It shows the antimicrobial activity that interchelates the cell wall of parasites	Cowan (1999), Mute et al. (2009)
	It also shows the antidiarrheal activity that prevents the release of prostaglandins and autacoids	Kumar et al. (2010)
	It shows the anthelmintic activity that helps in synthesis of protein by generating nitrate, it suppress the transfer of sugar to intestine, it also acts on central nervous system causing paralysis	Sharma et al. (2009)
Polypeptides and lectins	It shows the antiviral activity by forming the disulfide bridges it block the viral adsorption	Wang et al. (2010)
Glycosides	It shows the antidiarrheal activity that prevents the release of prostaglandins and autacoids	Kumar et al. (2010)
Steroids	It shows the antidiarrheal activity that increases the transport of sodium and water to the intestinal	Maniyar et al. (2010)
Saponins	It shows the antidiarrheal activity that prevents the histamine to release	Maniyar et al. (2010)
	It shows the anticancer activity that shows the membrane permeabilizing properties	Wang et al. (2010)
	It shows the anthelmintic activity teguments disintegrate	
Coumarins	It shows the antiviral activity that interacts with the DNA	Wang et al. (2010)

is increasing day by day as the consumer are becoming more health conscious. Many attempts have been made by researchers and industrialists to fulfill the demand of consumers by enriching or supplementing the foods with phytochemicals (in crude or pure form). For the extraction of these phytochemicals from different sources, a wide range of physical, chemical and biological techniques have been explored by various researchers depending upon the nature of raw material. Conventional extraction techniques include ecofriendly extraction, hydro-distillation, solvent maceration, soxhlet extraction (Azmir et al. 2013; Jansirani et al. 2014; Kushwaha et al. 2017), whereas non-conventional extraction techniques include microwave-assisted extraction, supercritical fluid extraction, pressurized liquid extraction, microbial maceration, enzymatic maceration, pulsed-electric field extraction, ultrasound-assisted extraction (Corrales et al. 2008; Azmir et al. 2013; Lenucci et al. 2015).

The efficiency of conventional techniques depends on the solvents, but it is also necessary to consider environmental safety and toxicity before selecting the solvent for the extraction process (Cowan 1999). Beside this, conventional methods have many disadvantages, i.e., time consuming, costly and less efficient as compared to non-conventional methods (Wang and Weller 2006). Whereas, numerous advantages are being possessed by the non-conventional methods including short time consumption, less hazardous, safe to use, energy efficient, lesser use of non-renewable resources, reduced derivatives production, prevention of the degradation of final product (Azmir et al. 2013). The extraction efficiency of these methods (conventional and non-conventional) may vary according to their capability and no doubt the substrate, especially for the waste management (Kushwaha et al. 2017). Cost of operation is one of the crucial factors influencing the extraction method selection. This situation is raising the demand of the low-cost technologies; and microbial maceration can be an acceptable option as it is very easy to handle, require low energy consumption, less hazardous, low-cost and having higher production (Singhania et al. 2009). A complete overview of the conventional and non-conventional extraction techniques is given in Fig. 1.

Microbial maceration

Maceration is the process of softening the tissue and breaking them into pieces using liquids. During maceration, the tissue gets soften and the compound present inside the tissue gets leached out into the liquid (extract). The extract

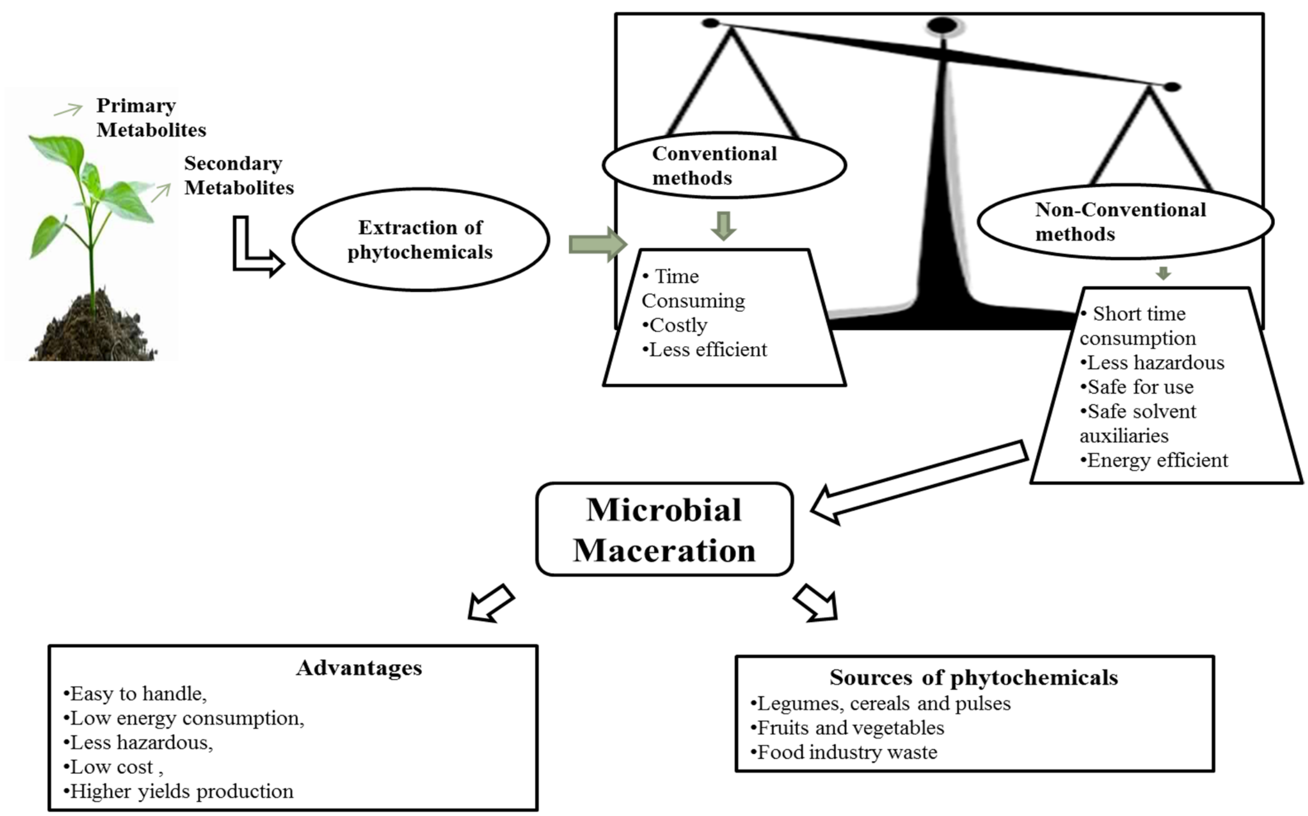

Fig. 1 An overview of the conventional and non-conventional extraction techniques

thus obtained contains many of the metabolites such as phenols, terpenes, flavonoids, and pigments (Azwanida 2015). This technique has been used by many of the researchers for making wine from the various fruits where the compounds are leached out into the must (Joshi et al. 2009). Recently, researchers have exploited the microbial maceration technique using different microbes for the extraction of various bioactive compounds such as phenolics, flavonoids, antioxidants, tannins, and saponins from the numerous substrates, i.e., fruits, vegetables, legumes, cereals and pulses as well as agro-industrial waste. The advantage of using microbes is to extract compound from different sources and its simplicity for getting high yields, very easy to handle, low-cost, and low energy consumption (Demain and Fang 2000).

In microbial maceration, different input factors (such as time, temperature, humidity, concentration of the inoculum and other conditions) are playing important role to determine the efficiency of the process. Moreover, maintaining microbial maceration conditions is necessary for the efficient growth of the microbes to macerate and ferment different sources and enhancing the extraction efficiency. Different microbes and their respective temperature required for the maceration of food materials are enlisted in Table 2.

Crop-specific extraction of phytochemicals using microbial maceration

Legumes, cereals, and pulses

Legumes, cereals, and pulses are playing very important role in human diet and possess many health benefits (Saleh et al. 2013). Moreover, recent studies reported that the microbial maceration of legumes, cereals, and pulses resulted in extraction of higher amount of phytochemicals, which possess numerous biological functions such as antioxidant activity and anticancer effects (Azmir et al. 2013). Recently, different researchers have reported that microbial maceration significantly enhanced the soluble total phenolic content of cheonggukjang soybean, soybean, black soybean, chickpea, cowpea, bran, black soybean, pea, common bean, kidney beans, wheat koji, buckwheat, barley, wheat, rye, *Avena sativa* and lotus seeds (Zheng and Shetty 2000; Duenas et al. 2005; Katina et al. 2007; Bhanja et al. 2008, 2009; Dordevic et al. 2010; Hu et al. 2010; Cho et al. 2011; Xiao et al. 2015; Starzyńska et al. 2014; Wang et al. 2014; Limon et al. 2015). Many microbes are able to produce enzymes, which can degrade the cell wall matrix and can release the bound phenolics (Huynh et al. 2014). Both the bound and free phenolics contribute for the increased yields of the total phenolic content. However, many studies show that microbial maceration not only increase the yield of the phenolic content but also reduce the yield in some sources such as soybean (Lee et al. 2008), which is due to the degradation of some phenols during the maceration process.

Recent studies have witnessed an increase in the antioxidant activity (free radical-scavenging, reducing and metal-chelating effects), flavonoids and anthocyanin content of legumes, pulses and cereals extract because of the microbial maceration as compared to the control samples (Table 3). It has been reported that black soybean, small runner bean, small rice bean, lentil, speckled kidney bean, mottled cowpea, black cow gram, cowpeas, black bean koji, rye, wheat, barley, buckwheat, cheonggukjang soybean, brown soybean, *Moringa oleifera* seeds, black soybeans, and black soybean show high antioxidant activity, flavonoids and anthocyanin as compared to the control (Lee et al. 2008; Dordevic et al. 2010; Juan and Chou 2010; Hu et al. 2010; Cho et al. 2011; Shin et al. 2014; Gan et al.

Table 2 Different microbes and temperature required for the maceration

Microorganism	Species	Temperature (°C)	References
Bacteria	*Lactobacillus acidophilus, Lactobacillus brevis, Lactobacillus bulgaricus, Lactobacillus johnsonii, Lactobacillus casei, Lactobacillus fermentum, Lactobacillus lactis, Lactobacillus plantarum, Lactobacillus johnsonii, Lactobacillus paracasei, Lactobacillus reuteri, Lactobacillus rossiae, Lactobacillus zeae, Lactococcus lactis, Bifidobacterium animalis, Bifidobacterium infantis, Streptococcus thermophilus, and Weissella paramesenteroides*	22–37	Frias et al. (2005), Othman et al. (2009), Hur et al. (2014), Gan et al. (2017)
Fungi	*Bacillus subtilis, Bacillus cereus, Bacillus thuringiensis, Aspergillus oryzae, Aspergillus niger, Aspergillus awamori, Aspergillus sojae, Agrocybe cylindracea, Cordyceps militaris, Coprinus cinereus, Grifola frondosa, Ganoderma austral, Ganoderma lucidum, Lentinus edodes, Monascus ruber, Rhizopus microsporus, Rhizopus oligosporus, Rhizopus oryzae, Thamnidium elegans*	22–30	Fernandez-Orozco et al. (2007), Bhanja et al. (2009), Cai et al. (2011)
Yeast	*Cryptococcus flavus, Issatchenkia orientalis, Saccharomyces cerevisiae, Saccharomyces boulardii, Cryptococcus sp.S-2, Rhodotorula glutinis*	20–30	Hur et al. (2014), Escuder et al. (2013) Kumar et al. (2015), Gan al. (2017)

Table 3 Effect of microbial maceration on extraction of phytochemicals from legumes, cereals and pulses

Source/product	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Phenolic						
Cheonggukjang Soybean	*B. subtilis CS90*	60 h at 37 °C	Gallic acid	306.40 (mg/kg)	1062.5 (mg/kg)	Cho et al. (2011)
		48 h at 37 °C	Protocatechuic acid	4.42 (mg/kg)	4.56 (mg/kg)	
		36 h at 37 °C	p-Coumaric acid	0.16 (mg/kg)	0.17 (mg/kg)	
Red beans	*B. subtilis*	120 h 30 °C	Total phenolic	ND	22.58 (mg/g)	Chung et al. (2002)
Jatropha curcas	*Rhizopus oryzae*	8 h at 37 °C	Total phenolic	ND	1.17%	Oseni and Akindahunsi (2011)
			Tannins	ND	0.76%	
Soybean	*Monascus* (*MFS-31499*)	24 h at 25 °C	Total phenol	5.82 ± 0.04 (mg/g)	0.35 ± 0.05 (mg/g)	Lee et al. (2008)
	Monascus (*MFS-31527*)		Total phenol	5.82 ± 0.04 (mg/g)	6.05 ± 0.02 (mg/g)	
Wheat koji	*Aspergillus oryzae*	96 h at 30 °C	Phenolic	7.226 (μmol/g)	158.912 (μmol/g)	Bhanja et al. (2009)
Wheat koji	*Aspergillus awamori*	120 h at 30 °C	Phenolic	7.226 (μmol/g)	124.176 (μmol/g)	Bhanja et al. (2009)
Moringa oleifera seeds	Natural fermentation	72 h at 25 °C	Tannins	ND	146.67 (mg/100 g)	Ijarotimi et al. (2013)
			Phenolics	ND	23.00 (mg/100 g)	
			Saponins	ND	7.5 (mg/100 g)	
			Terpenoids	ND	25.0 (mg/100 g)	
Soybeans	*Aspergillus oryzae*	120 h at 30 °C	Phenolics	ND	56.2 (mg/g)	Wardhani et al. (2010)
Buckwheat	*Lactobacillus rhamnosus*	24 h at 37 °C	Total phenolic	50.7 ± 0.04 (mg/g)	59.4 ± 0.06 (mg/g)	Dordevic et al. (2010)
	Saccharomyces cerevisiae	24 h at 30 °C	Total phenolic	50.7 ± 0.04 (mg/g)	53.2 ± 0.02 (mg/g)	
Barley	*Lactobacillus rhamnosus*	24 h at 37 °C	Total phenolic	16.4 ± 0.04 (mg/g)	20.1 ± 0.08 (mg/g)	
	Saccharomyces cerevisiae	24 h at 30 °C	Total phenolic	16.4 ± 0.04 (mg/g)	18.5 ± 0.09 (mg/g)	
Wheat	*Lactobacillus rhamnosus*	24 h at 37 °C	Total phenolic	16.2 ± 0.07 (mg/g)	20.7 ± 0.06b (mg/g)	Dordevic et al. (2010)
	Saccharomyces cerevisiae	24 h at 30 °C	Total phenolic	16.2 ± 0.07 (mg/g)	18.4 ± 0.08 (mg/g)	
Rye	*Lactobacillus rhamnosus*	24 h at 37 °C	Total phenolic	13.2 ± 0.06 (mg/g)	18.4 ± 0.06 (mg/g)	Dordevic et al. (2010)
	Saccharomyces cerevisiae	24 h at 30 °C	Total phenolic	13.2 ± 0.06 (mg/g)	16.2 ± 0.04 (mg/g)	
Black soybeans	*B. subtilis*	18 h at 40 °C	Total phenolic	6.04 0.33 (mg/g)	12.44 0.41 (mg/g)	Juan and Chou (2010)
Avena sativa L.	*A. oryzae var. effuses*	3 days at 25 °C	Chlorogenic acid	63.9 ± 5.34 (mg/100 g)	163.8 ± 2.72 (mg/100 g)	Cai et al. (2011)
			Caffeic acid	116.6 ± 2.34 (mg/100 g)	385.7 ± 4.57 (mg/100 g)	
			p-Coumaric acid	55.1 ± 1.23 (mg/100 g)	119.0 ± 5.69 (mg/100 g)	
			Ferulic acid	89.0 ± 0.84 (mg/100 g)	793.8 ± 6.85 (mg/100 g)	
Avena sativa L.	*A. oryzae*	3 days at 25 °C	Chlorogenic acid	63.9 ± 5.34 (mg/100 g)	138.4 ± 0.76 (mg/100 g)	Cai et al. (2011)
			Caffeic acid	116.6 ± 2.34 (mg/100 g)	319.6 ± 0.72 (mg/100 g)	
			p-Coumaric acid	55.1 ± 1.23 (mg/100 g)	98.5 ± 3.35 (mg/100 g)	
			Ferulic acid	89.0 ± 0.84 (mg/100 g)	493.1 ± 5.36 (mg/100 g)	
Avena sativa L.	*A. niger*	3 days at 25 °C	Caffeic acid	116.6 ± 2.34 (mg/100 g)	160.6 ± 3.21 (mg/100 g)	Cai et al. (2011)
			p-Coumaric acid	55.1 ± 1.23 (mg/100 g)	104.9 ± 4.78 (mg/100 g)	
			Ferulic acid	89.0 ± 0.84 (mg/100 g)	87.2 ± 4.12 (mg/100 g)	
Chickpea	*Cordyceps militaris SN-18*	8 days at 25 °C	Total phenolic contents	6.07 ± 0.19 (mg/g)	10.53 ± 0.02 (mg/g)	Xiao et al. (2015)
			Total saponin contents	5.61 ± 0.19 (mg/g)	6.82 ± 0.19 (mg/g)	

Table 3 (continued)

Source/product	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Cowpeas	*Lactobacillus plantarum ATCC 14917*	48 h at 37 °C	Vanillic acid	2.51 ± 0.87 (mg/g)	4.44 ± 1.00 (mg/g)	Duenas et al. (2005)
			Quercetin	ND	22.02 ± 0.40 (mg/g)	
			trans-Ferulic acid	1.60 ± 0.07 (mg/g)	4.10 ± 0.14 (mg/g)	
			cis-Ferulic acid	1.24 ± 0.09 (mg/g)	0.36 ± 0.02 (mg/g)	
Bran	*Baker's yeast*	20 h at 35 °C	Total phenolic	ND	383 (mg/100 g)	Katina et al. (2007)
		13 h at 27.5 °C	Ferulic acid	ND	30 (mg/100 g)	
Black soybean	*Bacillus natto*	48 h at 37 °C	Total phenolic	614.82 ± 13.12 (μg/ g)	668.41 ± 31.26 (μg/ g)	Hu et al. (2010)
Pea	*Trichoderma viride IF-26*	5 days at 25 °C	Total phenolics	0.633 ± 90.054 (mg/g)	0.717 ± 90.078 (mg/g)	Zheng and Shetty (2000)
	Trichoderma harzianum ATCC 24274	5 days at 25 °C	Total phenolics	0.633 ± 90.054 (mg/g)	0.746 ± 90.044 (mg/g)	
	Trichoderma pseudokoningii ATCC 26801	5 days at 25 °C	Total phenolics	0.633 ± 90.054 (mg/g)	0.738 ± 90.047 (mg/g)	
Common bean	*Lactobacillus plantarum DSM 20174*	18 h at 30 °C	Total phenolics	ND	1.61 (mg/g)	Starzyńska-Janiszewska (2014)
	R. microspores var. *chinensis*	18 h at 30 °C	Total phenolics	ND	1.69 (mg/g)	
Kidney beans	*Bacillus subtilis*	96 h at 30 °C	Total phenolic	15.89 ± 0.56 (mg/g)	35.93 ± 0.69 (mg/g)	Limón et al. (2015)
Kidney beans	*Lactobacillus plantarum*	48 h at 37 °C	Total phenolic	20.68 ± 1.04 (mg/g)	21.96 ± 0.54 (mg/g)	
Adlay	*B. subtilis*	24 h at 37 °C	Total phenolic	8.58 ± 0.62 (mg/g)	13.29 ± 1.67 (mg/g)	Wang et al. (2014)
	Lactobacillus plantarum	24 h at 37 °C	Total phenolic	8.58 ± 0.62 (mg/g)	11.91 ± 1.94 (mg/g)	
Chestnut	*B. subtilis*	24 h at 37 °C	Total phenolic	12.95 ± 0.57 (mg/g)	15.28 ± 1.85 (mg/g)	Wang et al. (2014)
	Lactobacillus plantarum	24 h at 37 °C	Total phenolic	17.52 ± 1.67 (mg/g)	28.67 ± 2.95 (mg/g)	
Lotus seed	*B. subtilis*	24 h at 37 °C	Total phenolic	17.52 ± 1.67 (mg/g)	28.67 ± 2.95 (mg/g)	Wang et al. (2014)
	Lactobacillus plantarum	24 h at 37 °C	Total phenolic	17.52 ± 1.67 (mg/g)	24.62 ± 3.54 (mg/g)	
Walnut	*B. subtilis*	24 h at 37 °C	Total phenolic	22.80 ± 4.23 (mg/g)	33.89 ± 3.84 (mg/g)	Wang et al. (2014)
	Lactobacillus plantarum	24 h at 37 °C	Total phenolic	22.80 ± 4.23 (mg/g)	28.61 ± 4.24 (mg/g)	
Antioxidant activity						
Soybeans	*Aspergillus oryzae*	120 h at 30 °C	DPPH	ND	81.6%	Wardhani et al. (2010)
Buckwheat (*Fagopyrum esculentum*)	*Lactobacillus rhamnosus*	24 h at 37 °C	FRAP	49.43 ± 0.49 (nmol/mg)	51.54 ± 0.65 (nmol/mg)	Dordevic et al. (2010)
	Saccharomyces cerevisiae	24 h at 30 °C	FRAP	49.43 ± 0.49 (nmol/mg)	49.76 ± 0.62 (nmol/mg)	
Barley (*Hordeum vulgare*)	*Lactobacillus rhamnosus*	24 h at 37 °C	FRAP	15.56 ± 0.67 (nmol/mg)	20.0 ± 0.54 (nmol/mg)	
	Saccharomyces cerevisiae	24 h at 30 °C	FRAP	15.56 ± 0.67 (nmol/mg)	19.83 ± 0.51 (nmol/mg)	
Wheat (*Triticum durum*)	*Lactobacillus rhamnosus*	24 h at 37 °C	FRAP	12.15 ± 0.60 (nmol/mg)	15.11 ± 0.57 (nmol/mg)	Dordevic et al. (2010)
	Saccharomyces cerevisiae	24 h at 30 °C	Antioxidant: DPPH	ND	> 200 (μg/ml)	
		24 h at 30 °C	FRAP	12.15 ± 0.60 (nmol/mg)	12.25 ± 0.62 (nmol/mg)	
Rye (Secale cereal)	*Lactobacillus rhamnosus*	24 h at 37 °C	FRAP	8.94 ± 0.86 (nmol/mg)	13.94 ± 0.91 (nmol/mg)	Dordevic et al. (2010)
	Saccharomyces cerevisiae	24 h at 30 °C	FRAP	8.94 ± 0.86 (nmol/mg)	10.68 ± 0.83 (nmol/mg)	
Black bean koji	*Rhizopus* sp.	3 days at 30 °C	DPPH radical-scavenging	1.95 ± 0.01	2.11 ± 0.12 (mg/ml)	Lee et al. (2008)
			Fe2+-chelating ability	2.68 ± 0.09 (mg/ml)	3.11 ± 0.85 (mg/ml)	

Table 3 (continued)

Source/product	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Cowpeas	*Lactobacillus plantarum ATCC 14917*	48 h at 37 °C	Antioxidant activity	ND	8.89 ± 0.02 (mg/g)	Duenas et al. (2005)
Black cow gram	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	20.0 ± 1.14 (µg/g)	23.6 ± 1.10 (µg/g)	Gan et al. (2016)
			ABTS	16.5 ± 0.94 (µg/g)	16.6 ± 0.45 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	20.0 ± 1.14 (µg/g)	25.1 ± 0.72 (µg/g)	
			ABTS	16.5 ± 0.94 (µg/g)	17.3 ± 0.85 (µg/g)	
Mottled cowpea	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	32.1 ± 1.13 (µg/g)	48.7 ± 2.30 (µg/g)	Gan et al. (2016)
			ABTS	29.2 ± 0.74 (µg/g)	35.0 ± 35.0 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	32.1 ± 1.13 (µg/g)	47.9 ± 2.56 (µg/g)	
			ABTS	29.2 ± 0.74 (µg/g)	34.9 ± 0.80 (µg/g)	
Speckled kidney bean	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	17.7 ± 0.49 (µg/g)	30.0 ± 0.40 (µg/g)	Gan et al. (2016)
			ABTS	18.0 ± 1.08 (µg/g)	28.2 ± 0.94 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	17.7 ± 0.49 (µg/g)	28.1 ± 0.30 (µg/g)	
			ABTS	18.0 ± 1.08 (µg/g)	26.7 ± 0.72 (µg/g)	
Lentil	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	17.5 ± 0.37 (µg/g)	20.6 ± 0.80 (µg/g)	Gan et al. (2016)
			ABTS	17.3 ± 0.31 (µg/g)	16.7 ± 0.44 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	17.5 ± 0.37 (µg/g)	19.7 ± 0.26 (µg/g)	
			ABTS	17.3 ± 0.31 (µg/g)	16.2 ± 0.48 (µg/g)	
Small rice bean	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	25.9 ± 0.26 (µg/g)	34.0 ± 1.02 (µg/g)	Gan et al. (2016)
			ABTS	24.6 ± 1.27 (µg/g)	29.1 ± 0.92 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	25.9 ± 0.26 (µg/g)	34.5 ± 0.79 (µg/g)	
			ABTS	24.6 ± 1.27 (µg/g)	29.7 ± 0.94 (µg/g)	
Small runner bean	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	31.8 ± 1.27 (µg/g)	24.0 ± 1.18 (µg/g)	Gan et al. (2016)
			ABTS	25.4 ± 0.80 (µg/g)	24.4 ± 1.58 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	1.27 (µg/g)	28.0 ± 0.27 (µg/g)	
			ABTS	25.4 ± 0.80 (µg/g)	25.2 ± 0.66 (µg/g)	
Black soybean	*Lactobacillus paracasei 279*	48 h at 37 °C	FRAP	21.2 ± 0.59 (µg/g)	22.7 ± 0.29 (µg/g)	Gan et al. (2016)
			ABTS	18.0 ± 0.57 (µg/g)	15.4 ± 0.75 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	21.2 ± 0.59 (µg/g)	24.1 ± 0.5 (µg/g)	
			ABTS	18.0 ± 0.57 (µg/g)	15.8 ± 0.68 (µg/g)	
Yellow soybean	*Lactobacillus paracasei 279*	8 h at 37 °C	FRAP	9.20 ± 0.17 (µg/g)	8.00 ± 0.40 (µg/g)	Gan et al. (2016)
			ABTS	10.8 ± 0.33 (µg/g)	5.22 ± 0.21 (µg/g)	
	Lactobacillus plantarum WCFS1	48 h at 37 °C	FRAP	9.20 ± 0.17 (µg/g)	7.30 ± 0.08 (µg/g)	
			ABTS	10.8 ± 0.33 (µg/g)	5.49 ± 0.13 (µg/g)	
Flavonoids						
Cheonggukjang Soybean	*B. subtilis CS90*	60 h at 37 °C	Catechin	6.64 (mg/kg)	48.60 (mg/kg)	Cho et al. (2011)
			Epicatechin	12.37 (mg/kg)	54.1 (mg/kg)	

Table 3 (continued)

Source/product	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Cheonggukjang Soybean	*B. subtilis CS90*	36 h at 37 °C	Daidzein	0.00	372.28 (mg/kg)	Cho et al. (2011)
		60 h at 37 °C	Genistein	0.00	25.62 (mg/kg)	
		36 h at 37 °C	Acetyl daizin	0.00 (mg/kg)	335.99 (mg/kg)	
		24 h at 37 °C	Acetyl glycitin	172.50d (mg/kg)	187.24 (mg/kg)	
		24 h at 37 °C	Malonylglycitin	61.10 (mg/kg)	62.81 (mg/kg)	
Brown Soybean	*B. subtilis*	48 h at 37 °C	Daidzein	3.7 ± 0.08 (μg/g)	156.5 (μg/g)	Shin et al. (2014)
			Glycitein	12.5 ± 0.11a (μg/g)	10.2 (μg/g)	
			Genistein	ND	2.5 (μg/g)	
Soybean	*Rhizopus oligosporus*	32.06 h at 29.39 °C	Daidzin	ND	1284.14 (μg/g)	Yaakob et al. (2011)
		48 h at 35 °C	Daidzein	ND	1663.85 (μg/g)	
Moringa oleifera seeds	*Anaerobic fermentation*	72 h at 25 °C	Flavanoids	ND	5.00 (mg/100 g)	Ijarotimi et al. (2013)
Black soybeans	*B. subtilis*	18 h at 40 °C	Total flavanoids	0.89 ± 0.10 (mg/g)	1.89 ± 0.17 (mg/g)	Juan and Chou (2010)
Black soybean	*Bacillus natto*	48 h at 37 °C	Genistein	132 ± 12 (μg/g)	186 ± 10 (μg/g)	Hu et al. (2010)
			Daidzein	160 ± 20 (μg/g)	238 ± 16 (μg/g)	
Pigment						
Red beans	*B. subtilis*	120 h at 30 °C	Anthocyanin	ND	1.00 (μmol/g)	Chung et al. (2002)
Black soybean	*Bacillus natto*	48 h at 37 °C	Anthocyanin	0.52 ± 0.10 (μg/g)	1.28 ± 0.14 (μg/g)	Hu et al. (2010)

ND not detected

2016). In some cases, such as the microbial maceration of yellow soybean, black soybean, small runner bean, lentil may lead to the decrease in antioxidant activity (Gan et al. 2016).

Fruits and vegetables

It was reported that fruits and vegetables contain high amount of phytochemicals, nutrients and dietary fibers and many more compounds, which are essential for the human nutrition (Boeing et al. 2012). Epidemiological studies narrated that long-term consumption of fruits and vegetables reduces the risk of cancer and many other chronic diseases especially because of phytochemicals (Batra and Sharma 2013). Many industries are utilizing these phytochemicals for the production of value-added products after extracting them from fruits and vegetables with the help of microbial maceration technique (Boeing et al. 2012). It has been reported that maceration significantly increased the soluble total phenolics, antioxidant and flavonoids content in *Citrus sinensis*, cabernet sauvignon grapes, tempranillo grapes, kiwifruit, green olive, varicoloured olives, black olives, *Brassica pekinensis* Skeels (Mayen et al. 1995; Sun et al. 2009; Othman et al. 2009; Escudero et al. 2013; Li et al. 2013) (Table 4). In addition, there is an increase in antioxidant activity of *Citrus sinensis; Basella rubra* (Escudero et al. 2013; Kumar et al. 2015), flavonoids in cabernet sauvignon grapes, black mulberry (Mayén et al. 1995; Pérez-Gregorio et al. 2011), pigment composition in *Citrus sinensis*, cabernet sauvignon grapes, tempranillo grapes, black mulberry (Mayén et al. 1995; Pérez-Gregorio et al. 2011; Escudero et al. 2013) as compared to the control samples (Table 4).

Food industry waste

Nowadays, food processing industry has been recognized as a sunrise sector in terms of production, consumption, export and growth prospects and no doubt in the generation of waste materials too (Joshi et al. 2012). The waste obtained from fruit processing industry is extremely diverse due to the use of wide variety of fruits and vegetables, the broad range of processes and the multiplicity of the product. These wastes are novel, natural and economic sources of numerous phytochemicals (Joshi et al. 2012). In recent years, researchers are showing more interest in agro-industrial waste, for their effective utilization as whole or as extracted components (that is the fiber or phytochemicals) in food products to enhance the health effects and phytochemicals potential (Joshi et al. 2012). It has been found that agro-industrial waste contains numerous phytochemicals, especially phenolics, antioxidant, flavonoids and anthocyanin. It has been reported that microbial maceration in apple pomace, green

Table 4 Effect of microbial maceration on extraction of phytochemicals from fruits and vegetables

Sources/products	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Fruits						
Phenolic						
Citrus sinensis L.	*Saccharomycetaceae* var. *Pichia kluyveri*	1 day at 20 °C	Total phenolics	793 ± 0.5 (mg/l)	801 ± 7.3 (mg/l)	Escudero-López et al. (2013)
Cabernet Sauvignon grapes	*Saccharomyces cerevisiae*	8 days at 25 °C	Quercetin	< 0.001 (mg/l)	0.666 ± 0.144 (mg/l)	Mayén et al. (1995)
		44 days at 25 °C	Gallic acid	0.162 ± 0.024 (mg/l)	11.1 ± 0.666 (mg/ml)	
Kiwifruit	*S. cerevisiae* (*RA17*)	25 ± 1 °C 2 weeks	Total phenolics	298 ± 11 (mg/l)	305 ± 15 (mg/l)	Li et al. (2013)
	S. cerevisiae (*RC212*)	25 ± 1 °C 2 weeks	Total phenolics	298 ± 11 (mg/l)	317 ± 10 (mg/l)	
Tempranillo grapes	*Saccharomyces cerevisiae*	44 day at 25 °C	Gallic acid	0.258 ± 0.039 (mg/l)	6.51 ± 0.774 (mg/l)	
Antioxidant activity						
Basella rubra	*Saccharomyces cerevisiae*	6 h at 30 °C	DPPH scavenging activity	1.9 mg/ml	2.4 µg/ml	Kumar et al. (2015)
Citrus sinensis L. var. Navel late	*Saccharomycetaceae var. Pichia kluyveri*	9 days at 20 °C	ORAC	6044 µM	9355 ± 678 (µM)	Escudero-López et al. (2013)
		1 days at 20 °C	FRAP	10.3 mM	10.9 ± 0.4 (mM)	
Flavonoids						
Cabernet Sauvignon grapes	*Saccharomyces cerevisiae*	14 h at 25 °C	Catechin	0.180 ± 0.030 (mg/l)	86.1 ± 9.00 (mg/l)	Mayén et al. (1995)
Black mulberry	*Saccharomyces cerevisiae*	24 h at 18 °C	Flavanols	62 ± 7 (mg/kg)	65 ± 1 (mg/kg)	Pérez-Gregorio et al. (2011)
Pigments						
Citrus sinensis L. var. Navel late	*Saccharomycetaceae var. Pichia kluyveri*	13 day at 20 °C	Total carotenoids	5.8 (mg/l)	6.5 ± 0.2 (mg/l)	Escudero-López et al. (2013)
Cabernet Sauvignon grapes	*Saccharomyces cerevisiae*	3 day at 25 °C	Z-Anthocyans	42.6 + 7.07 (u.a)	238 ± 34.8 (mg/l)	Mayén et al. (1995)
Tempranillo grapes	*Saccharomyces cerevisiae*	5 day at 25 °C	Z-Anthocyans	42.6 + 7.07 (u.a)	239 + 18.27 (u.a.)	
Black mulberry	*Saccharomyces cerevisiae*	24 h at 18 °C	Cyanidin 3-glucoside	2048 ± 146 (mg/kg)	2084 ± 15 (mg/kg)	Pérez-Gregorio et al. (2011)
Vegetables						
Phenols						
Brassica pekinensis Skeels	*Lactobacillus plantarum*	2 days at 25 °C	Total phenolic	3.18 ± 0.24 (µg /mg)	4.38 ± 0.02 (µg /mg)	Sun et al. (2009)
Green olive	*Lactobacillus plantarum*	8 days at 25 °C	Total phenolic	1556 ± 46.7(mg/100 g)	1204 ± 36.8 (mg/l)	Othman et al. (2009)
Varicoloured olives	*Lactobacillus plantarum*	8 days at 25 °C	Total phenolic	384 ± 16.6 (mg/100 g)	461 ± 11.3 (mg/100 g)	
Varicoloured olives	*Lactobacillus plantarum*	8 days at 25 °C	Total phenolic	652 ± 30.2 (mg/l)	1065 ± 27.1 (mg/l)	
Black olives	*Lactobacillus plantarum*	8 days at 25 °C	Total phenolic	311 ± 9.84 (mg/100 g)	403 ± 17.8 (mg/100 g)	
Black olives	*Lactobacillus plantarum*	8 days at 25 °C	Total phenolic	311 ± 9.84 (mg/l)	1060 ± 57.7 (mg/l)	
Antioxidant activity						
Brassica pekinensis Skeels	*Lactobacillus plantarum*	2 days at 25 °C	DPPH radical-scavenging activity	33.21 ± 0.47 (mg/ml)	42.18 ± 5.39 (mg/ml)	Sun et al. (2009)

ND not detected

Table 5 Effect of microbial maceration on extraction of phytochemicals from food industry waste

Sources/products	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Phenolic						
Apple pomace	*Phanerochaete chrysosporium*	7 days at 37 °C	Total phenolics	15.53 (mg/g)	29.28 (mg/g)	Ajila et al. (2012)
Cranberry pomace	*Lentinus edodes*	15 days at 28 °C	Ellagic acid	ND	350 μg/g	Vattem and Shetty (2003)
		10 days at 28 °C	Total phenolic	ND	118 (mg/10 g)	
Cranberry pomace	*Rhizopus oligosporus*	14 days at 28 °C	Ellagic acid	ND	330 (mg/g)	Vattem and Shetty (2002)
			Total phenolic	ND	120 (mg/10 g)	
Apple pomace	*Trichoderma viride IF-26*	5 days at 25 °C	Total phenolics	0.633 ± 0.054 (mg/l)	0.289 ± 0.005(mg/ml)	Zheng and Shetty (2000)
	Trichoderma harzianum ATCC 24274	5 days at 25 °C	Total phenolics	0.633 ± 0.054 (mg/l)	0.303 ± 0.013 (mg/ml)	
	Trichoderma pseudokoningii ATCC 26801	5 days at 25 °C	Total phenolics	0.633 ± 0.054 (mg/l)	0.383 ± 0.012 (mg/ml)	
Brewers' spent grain	*Lactobacillus plantarum ATCC 8014*	19 h at 37 °C	Phenolic	ND	268.6 (mg/ ml)	Gupta et al. (2013)
Apple bagasse	*A. niger AUMC 4301*	3 days	Gallic acid	0.50 (mg/ml)	1.96 (mg/ml)	El-Fouly et al. (2012)
Green tea waste		3 days	Gallic acid	2.51 (mg/ml)	3.95 (mg/ml)	
Mango seed kernel		3 days	Gallic acid	9.60 (mg/ml)	10.6 (mg/ml)	
Olive mill		12 days	Gallic acid	0.00 (mg/ml)	0.43 (mg/ml)	
Palm kernel cake		3 days	Gallic acid	0.30 (mg/ml)	0.46 (mg/ml)	
Peat moss		3 days	Gallic acid	0.00 (mg/ml)	0.31 (mg/ml)	
Tamarind		3 days	Gallic acid	0.00 (mg/ml)	0.45 (mg/ml)	
Citrus peel	*Rhizopus oryzae NCIM 1009*	35 °C	Total phenolics	ND	9.0–44.4 (mg/g)	Mannepula et al. (2015)
Mango peel			Total phenolics	ND	26.3 (mg /g)	
Antioxidant activity						
Brewers' spent grain	*Lactobacillus plantarum* ATCC 8014	19 h at 37 °C	FRAP	ND	33.7 (mg /ml)	Gupta et al. (2013)
Flavonoids						
Sambucus nigra L. berry pomace	*A. niger*	3 h at 25 °C	Quercetin 3-rutinoside	40.25 ± 2.10 (mg/100 g)	45.50 ± 1.90(mg/100 g)	Dulf et al. (2015)
Sambucus ebulus L. berry pomace	*A. niger*	3 h at 25 °C	Quercetin 3-rutinoside	12.80 ± 0.65 (mg/100 g)	13.01 ± 0.65 (mg/100 g)	Dulf et al. (2015)
			Quercetin 3-glucoside	9.85 ± 0.45 (mg/100 g)	10.69 ± 0.45 (mg/100 g)	
Brewers' spent grain	*Lactobacillus plantarum ATCC 8014*	19 h at 37 °C	Quercetin	ND	135 mg/ml	Gupta et al. (2013)
Citrus peel	*Rhizopus oryzae NCIM 1009*	35 °C	Total flavonoids	ND	0.2 to 3.25 (mg /g)	Mannepula et al. (2015)
Mango peel			Total flavonoids	ND	0.48 (mg /g)	
Mango Raspuri peel	*Rhizopus oryzae NCIM 1009*	35 °C	Kaempferol	ND	10.29 (μg/g)	Mannepula et al. (2015)
			Quercetin	ND	56.83 (μg/g)	
Mango Badami peel	*Rhizopus oryzae NCIM 1009*	35 °C	Kaempferol	ND	52.73 (μg/g)	
			Quercetin	ND	18.58 (μg/g)	
Totapuri peel	*Rhizopus oryzae NCIM 1009*	35 °C	Total flavanoids	ND	48 (μg/g)	
Pigments						

Table 5 (continued)

Sources/products	Microorganism	Time and temperature	Phenols	Control samples	Macerated samples	References
Sambucus nigra L. berry pomace	*A. niger*	3 h at 25 °C	Cyanidin 3-sambubioside-5-glucoside	44.94 ± 2.50 (mg/100 g)	46.88 ± 2.20 (mg/100 g)	Dulf et al. (2015)
			Cyanidin 3-sambubioside	4.46 ± 0.15 (mg/100 g)	4.62 ± 0.18 (mg/100 g)	
			Cyanidin 3,5-diglucoside	18.70 ± 1.10 (mg/100 g)	23.04 ± 1.18 (mg/100 g)	
Sambucus ebulus L. berry pomace	*A. niger*	3 h at 25 °C	Cyanidin 3-sambubioside-5-glucoside	28.90 ± 1.40 (mg/100 g)	29.61 ± 1.62 (mg/100 g)	Dulf et al. (2015)
			Cyanidin 3,5-diglucoside	13.71 ± 0.72 (mg/100 g)	13.75 ± 0.75 (mg/100 g)	

ND not detected

tea waste, mango seed kernel, olive mill, palm kernel cake, peat moss, tamarind, citrus peel, mango peel increased the yields of phenolic content (Zheng and Shetty 2000; Vattem and Shetty 2002, 2003; Gupta et al. 2013; Ajila et al. 2012; El-Fouly et al. 2012; Mannepula et al. 2015) (Table 5). Some scientists have reported that the yield of phenolic content is getting reduced in apple pomace. Phenols are water-soluble compound and get leach out with water while extracting juice from the apple (Joshi et al. 2009). Microbial maceration also increased the yield of flavonoids in *Sambucus ebulus* L. berry pomace, brewers' spent grain, citrus peel, mango peel, mango raspuri peel (g/100 ml), mango badami peel, totapuri peel as per reported by (Gupta et al. 2013; Mannepula et al. 2015; Dulf et al. 2015). An increase in the anthocyanin of *Sambucus nigra* L. berry pomace and antioxidant activity of brewer's spent grain as compared to the control samples have also been reported by Gupta et al. (2013) and Dulf et al. (2015) (Table 5).

Future prospect and conclusions

The demand for healthy foods having phytochemicals is increasing in the industry with every passing day. Microbial maceration has proved to be a successful cost-effective technique in terms of extraction of phytochemicals without being hazardous. The use of agro-industrial waste as a substrate for microbial growth has reduced pollution caused by the waste, has made the process cheaper and easier due to the availability of the substrate, therefore rendering this method as a cleaner technique. More research is required to improve the understanding of extraction mechanism of microbes and scale up of the novel extraction system for their industrial application. Only few reports are available until date for the extraction of active compounds from the agro-industrial waste and still some part is untouched, which needs to be explored in the coming era. Toxicity caused by microbes needs to be considered while standardizing the extraction process and conditions. In nutshell, this technique can be advantageous in the near future for the development and supplementation of value added products.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding publication of this paper.

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