Phytochemicals from Selected Tropical Spices and Agro-Food Wastes. Utilization and Applications in Health Sectors: A Review

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Abstract:
This review analyzes how modern activities in several food sectors, including agriculture, industry, and residences, are producing more byproducts as a result. These food wastes, which are derived from fruits, vegetables, cereals, and food processing operations, have been demonstrated in studies to hold promise as sources of bioactive compounds and nutraceuticals that may be useful in treating a range of ailments. Researchers have effectively extracted secondary metabolites, minerals, proteins, enzymes, vitamins, phytochemicals and bioactive compounds from these food waste items using various extraction techniques. The article provides a comprehensive overview of different extraction strategies, highlighting successful study efforts, and emphasizes their effective applications in nutraceutical manufacture, health benefits, bioprocess development, and the added value of food waste resources. These technologies offer an interesting way to enhance the

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production of particular compounds, which can be utilized as nutraceuticals or incorporated into functional beverages in the future.

**Keywords:** Tropical spices, agriculture, bioactive substances, food wastes, nutraceuticals, extraction, disease.

**Introduction**

**Background**

Every stage of the food manufacturing process, including farming, business, processing, and distribution, is affected by the problem of food waste. According to statistics, 42% of food waste results from household activities, followed by 39% from the food manufacturing industry, 14% from the food service industry, and 5% from distribution. Food waste is expected to exceed 126 million metric tons by 2020 if appropriate preventive measures are not taken (Mirabella et al., 2014). Over the last couple of decades, efforts have been made to investigate the medicinal use of fruit and vegetable waste. The majority of the time, agro-industrial wastes were utilized as fertilizers or animal feed, but recent research has shown that they may also be transformed into high-value goods including cosmetics, food, and medications (Rudra et al., 2015). To cure and prevent human diseases, researchers are actively looking for naturally occurring bioactive compounds. Natural medicine can be created by utilizing the interactions of these chemicals with proteins, DNA, and other biological components (Ajikumar et al., 2008). A thorough understanding of food bioactives is essential for the development of acceptable functional food items as consumer interest in foods that promote health increases. The therapeutic foods known as nutraceuticals, which increase immunity, promote health, and prevent and treat particular diseases, have drawn a lot of interest. For their ability to prevent cancer, phytochemicals, which play specific roles and function as antioxidants, are of great importance (Kumar, 2015).

Due to rising consumer demand for "healthy" foods, the food industry is observing a growing trend in the development and manufacture of functional and nutraceutical products. New natural bioactive substances that can be employed as drugs, functional food ingredients, or nutraceuticals are of interest to both the food and pharmaceutical industries (Joana Gil-Chávez et al., 2013). Bioactives can be extracted from food waste using a variety of extraction techniques, and then added to functional meals and nutraceuticals to provide potential therapeutic advantages for chronic and lifestyle-related illnesses.

**Some Selected Tropical spices**

**Ginger (Zingiber officinale)**

Zingiber officinale Roscoe, also known as ginger, is a herb that has been used for millennia as a spice and medicine. It belongs to the Zingiber genus and to the family Zingiberaceae. Ginger root has long been used to treat a number of common illnesses, including headaches, colds, nausea, and vomiting. This is due to its wide variety of bioactive substances, such as phenolic and terpene chemicals. Notably, the phenolic chemicals gingerols, shogaols, and paradols are in charge of many of the bioactivities of ginger (Young, et al 2015).

According to recent studies, ginger provides a variety of health benefits, including antioxidants, anti-inflammatory effects, antibacterial activity, and even potential anticancer characteristics. Additionally, research suggests that ginger may be used as a preventive measure as well as a treatment for a number of ailments, including neurological diseases, cardiovascular disease, obesity, type 2 diabetes, dyspepsia brought on by chemotherapy, and respiratory problems (Young, et al 2015). In this study, ginger's bioactive elements and bioactivities are examined, with an emphasis on how it might be used in nutraceutical beverages. The ginger plant
and its rhizome are seen in the accompanying pictures 1(a) and 1(b), respectively.

Figure 1(a). A Ginger Plant

Figure 1(b). A Ginger Rhizome

Chemical and Bioactive Components of Ginger

Ginger contains a variety of nutrients, including about 50% carbohydrates, 6–8% fatty acids and lipids, and about 9% amino acids, as well as vitamins, minerals, and other bioactive compounds like phenolic and terpene compounds. Gingerols, such as 6-gingerol, 8-gingerol, and 10-gingerol, are some of the main polyphenols present in fresh ginger. Gingerols can change into shogaols when heated or kept for a long time, and subsequent hydrogenation can change shogaols into paradols (Zhang et al., 2016). Along with these phenolic compounds, ginger also contains quercetin, zingerone, gingersinone-A, and 6-dehydrogingerdione. Along with these, ginger also comprises polysaccharides, lipids, natural acids, and dietary fibers. Bisabolene, curcumene, zingiberene, farnesene, and sesquiphellandrene are other terpene components found in ginger that are also thought to be the primary components of ginger oil extracts.

Therapeutic Uses of Ginger (*Zingiber officinale*)

For thousands of years, ginger has been prized for its ability to reduce inflammation and provide pain relief. According to studies, the ginger component 6-gingerol has analgesic and anti-inflammatory properties (Young et al., 2005). Additionally, in the presence of soybean lipoygenase, it has been discovered that aqueous and alcoholic extracts of popular spices like garlic, ginger, onion, mint, cloves, cinnamon, and pepper prevent linoleic acid oxidation, showing their dose-dependent antioxidant effect. These extracts demonstrated synergistic antioxidant properties when mixed in spice mixes, significantly lowering lipid peroxidation. Due to their use as dietary supplements, food additives, and medicinal herbs, ginger species have a considerable economic impact. Traditional uses of ginger include the treatment of malaria, asthma, headaches, as well as functioning as an anti-inflammatory and antibacterial agent (Young et al., 2005). Ginger products also include aromatic oils and fresh and dried rhizomes.

Additionally, studies by Kim, *et al.* (2005) have shown that ginger has antiviral, antifungal, and antibacterial properties and it demonstrated antitumorigenic, anticarcinogenic, antilipidemic, cardiotonic, cytotoxic, apoptotic, and immunomodulatory characteristics. Also, studies on rats showed that ginger juice lowers blood sugar levels in both diabetic and non-diabetic rats in a small but substantial way. Additionally, 6-gingerol has been shown to block angiogenesis, suggesting that it may be useful in the treatment of disorders including tumors and malignancies that depend on angiogenesis (Kim *et al.*, 2005).
Antioxidant Activity of Ginger

Reactive oxygen species (ROS), a type of free radical that is produced in excess, have been linked to the emergence of a number of chronic diseases (Poprac et al., 2017). Antioxidant capabilities have been discovered in a variety of natural sources such as fruits, vegetables, edible flowers, cereal grains, medicinal plants, and herbal infusions. Ginger is well-known for its strong antioxidant properties, according to Lien et al. (2013).

Researchers evaluated ginger's in vitro antioxidant activity using three different techniques: 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and ferric-reducing antioxidant power (FRAP). When compared to the other types of ginger that were examined, dried ginger's phenolic components were 5.2-, 1.1-, and 2.4-fold higher than those of fresh, stir-fried, and carbonized ginger, respectively. Dried ginger came in first, followed by stir-fried ginger, carbonized ginger, and fresh ginger in terms of antioxidant activity. Dried ginger has strong antioxidant qualities due to its high polyphenolic content.

**Bioactive Components and Applications of Tetrapleura tetraptera**

The anti-inflammatory qualities of T. tetraptera preparations contribute to their preventive benefits against some human disorders. This plant is frequently used to treat a variety of medical ailments, including seizures, leprosy, irritation, arthritis pains, schistosomiasis, asthma, hypertension, and delivering quick relief...
from illnesses like malaria fever. The bioactive phytochemical components of *T. tetraptera* are what give it its therapeutic potential since they cause particular physiological reactions in people's bodies (Ko et al., 2016).

The tannins, alkaloids, sugars, triterpenoids, steroids, and flavonoids present in medicinal plants all perform important physiological functions in the human body. Known as phytochemicals, these organic compounds help to give plants their color, scent, and flavor in addition to safeguarding them against harm and disease. Furthermore, phytochemicals serve as a plant cell's defensive mechanism against environmental dangers such pollution, stress, drought, ultraviolet (UV) exposure, and pathogenic attacks (Ko et al., 2016).

**Ehuru or Calabash nutmeg** *(Monodora myristica)*

The tropical tree *Monodora myristica*, also called "calabash nutmeg," is indigenous to a number of West African nations, including Angola, Benin, Cameroon, Gabon, Ivory Coast, Kenya, Liberia, Nigeria, and the Republic of the Congo. The use of its seeds as a less expensive alternative to nutmeg has decreased over time outside of its native region. According to Teixeira et al. (2014), this tree is also known by a number of other names, including Jamaican nutmeg, African nutmeg, ehuru, ariwo, awerewa, chiri, airama, and African nutmeg. Please refer to figures 2(c) and 2(d) for visual examples.

![Figure 2(c). Mature *Monodora myristica* fruits](image)

![Figure 2(d). Dried *Monodora myristica* seeds](image)

**The Chemical Components and Therapeutic Properties of *Monodora myristica***

Caryophyllene, humulene, and pinene can be found in *Monodora myristica* essential oil, which is extracted from the plant's leaves. On the other hand, according to a study, the essential oil made from the seeds contains ingredients including - phellandrene, pinene, myrcene, limonene, and pinene. However, from phytochemical investigations, *M. myristica* seeds contain significant amounts of alkaloids, glycosides, flavonoids, tannins, saponin, and steroids (Teixeira, et al., 2014).

The herb is utilized for a variety of things, including as stomachics and stimulants, and also used as an insect repellent, to cure wounds, and to relieve headaches. Pepper soup is frequently made from the plant's ground kernel and is well-
known for its stimulating properties, which can help relieve constipation and lessen women's passive uterine bleeding shortly after childbirth (Teixeira, et al., 2014). The powerful antioxidants found in Monodora myristica are also known to have features including metal binding and oxygen elimination (Lemes, et al., 2010).

**Food Wastes as a Source of Bioactive Substances**

Food additives, functional foods, and nutraceuticals can all be developed using the bioactive compounds found in diverse food waste residues (Joana Gil-Chávez, et al., 2013). Due to their high concentration of bioactive chemicals, fruits and vegetables are regarded as the most fundamental category of functional foods. Fruits high in polyphenols and carotenoids may have antioxidant characteristics that reduce the chance of developing certain malignancies. Trimmings, peelings, stems, seeds, shells, bran, and leftovers from the extraction of juice, oil, starch, and sugar are examples of waste products from the processing of vegetables. Animal-derived trash also includes byproducts from the fisheries and dairy industries. The development of functional foods, pharmaceutical formulations, and medical applications can all benefit from the use of these byproducts and biomolecules. Beneficial elements like phenolic compounds, carotenoids, vitamin C, and dietary fiber are reported to be present in mango peels. These compounds may lower the chance of acquiring cancer, cataracts, Alzheimer’s disease, and Parkinson’s disease, according to studies by Ayala-Zavala et al. (2010).

Both in vitro and in vivo studies have shown that bioactive compounds taken from by-products of winemaking, such as stems, skins, and seeds, have health-promoting properties. These ingredients can be used as potent degenerative process preventatives in functional meals, nutraceuticals, and cosmetics (Teixeira, et al., 2014).

One of the most common fruit crops in the world is citrus, and processing citrus produces waste. Emerging as biologically active regulators that can prevent oxidation and microbiological food spoilage, bioactive peptides may have medicinal advantages. Peptides will be used more frequently in the food and pharmaceutical industries as a result of effective recovery and purification techniques (Lemes et al., 2016).

Waste coffee products like coffee grounds that have been used and coffee capsules include beneficial bioactive substances like polyphenols and tannins. In order to maximize their potential for usage in value-added goods, researchers have improved the extraction of antioxidant phenolic compounds from coffee waste (Zuorro and Lavecchia, 2012).

As a result, different food waste residues are important sources for the creation of functional foods and nutraceuticals since they include biologically active components that may have positive health effects. A list of some biologically active chemicals that can be found in various food waste residues is shown in Table 1.

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Source</th>
<th>Residue</th>
<th>Bioactive components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Apple</td>
<td>Peel and pomace</td>
<td>Epicatechin, catechins, anthocyanins, quercitin glyco-Chlorogenic acids, hydroxycinnamates, phloretin glycosides, procyanidins</td>
</tr>
<tr>
<td>2.</td>
<td>Avocados</td>
<td>Peels, seed</td>
<td>Epicatechins, catechins, gallates, chlorogenic acids, cyanogenic glucosides, homogentisic acids</td>
</tr>
<tr>
<td>3.</td>
<td>Bananas</td>
<td>Peels</td>
<td>Gallocatechins, anthocyanins, delphinidins, cyanidins, catecholamines</td>
</tr>
<tr>
<td>4.</td>
<td>Citrus fruits</td>
<td>Peels</td>
<td>Hesperidins, naringins, enocitrin, narirutins</td>
</tr>
</tbody>
</table>
5. Grape Seeds and skins Coumaric acids, caffeic acids, ferulic acids, chlorogenic acids, cinnamic acids, neochlorogenic acids, p-hydroxybenzoic acids, protocatechuic acids, vanillic acids, gallic acid, proanthocyanidins, quercetin 3-o-gluuronide, quercetin, resveratrol

6. Guavas Skins and seeds Catechins, cyanidin 3-glicosides, galangins, gallic acids, homogentisic acids, kaempferols

7. Litchi Pericarps, seed Cyanidin-3-glucosides, cyanidin-3-rutinosides, malvidin-3-glucosides, gallic acids, epicatechin-3-gallate

8. Mangos Kernels Gallic acids, ellagic acids, gallate, gallotannin, condensed tannin

9. Palms By-product of palm oil milling Tocopherol, tocotrienol, sterol, and squalene, phenolics, and antioxidants

### Vegetables

10. Pomegranates Peels, pericarps Gallic acids, cyanidin-3,5-diglucoside, cyanidin-3-diglucosides, delphinidin-3,5-diglucosides

11. Carrots Peels Phenols, beta-carotenones

12. Cucumbers Peels Chlorophylls, pheophytins, phellandrene

13. Potatoes Peels Gallate, caffeic acid vanillic acids

### Cereal crops

14. Tomatoes Skins and pomaces Carotenoids

15. Barley grains Brans β-Glucan

16. Rice grains Brans γ-Oryzanol, bran oil

17. Wheat Brans and germ Phenolics, antioxidant

**Sources:** Joana Gil-Chávez et al., 2013.

### Extraction Technologies for bioactive compounds from food waste

Waste from the agro-industrial sector has important bioactive components that can be recovered in a number of ways. The availability of these many extraction techniques enables the best possible recovery of particular compounds. The usage of enzymes, ultrasound, and microwaves were some of the main extraction techniques for bioactive substances that were found in a literature review, along with solvent extraction (SE), supercritical fluid extraction (SFE), and subcritical water extraction (SCW) (Nwokenkwo, et al., 2020). The next sections examine how each of these approaches has been studied and cited in recent research on its own.

### Solvent Extraction Technique

Hexane, chloroform, ethyl acetate, acetone, methanol, and water are listed in sequence of increasing polarity, starting with the least polar. In a 2013 study, Bandar et al. looked at the efficiency of several organic solvents for bioactive chemical extraction. The most effective solvent tested, ethanol, provided the highest extraction yield, whereas hexane produced the lowest yield. The maximum phenolics content (32.48 mg GAE/g extract) was produced using ultrasound-assisted extraction with 80% methanol, while the lowest amount (8.64 mg GAE/g extract) was obtained using the maceration method with 80% ethyl acetate. Additionally, the researchers found that extending the extraction time increased the yield of isolated bioactive chemicals (Alara, et al, 2018).

### Supercritical Fluid Extraction

A common technique for obtaining bioactive compounds from natural sources like plants, food waste, algae, and microalgae is supercritical fluid extraction. Supercritical carbon dioxide (SC-CO$_2$) is frequently chosen as a secure, non-toxic, and economical replacement for organic solvents since it is an environmentally beneficial procedure. According to Wang and Weller (2006), SC-CO$_2$ may solubilize lipophilic molecules and is simple to remove from the finished products.
The raw material is put into an extraction container with temperature and pressure controls to carry out the extraction. The container is then flooded with SC-CO₂. The products are collected from a tap in the lower part of the separators after the fluid and dissolved chemicals have been delivered to the separators. The SC-CO₂ can be recycled or released back into the environment.

The efficacy of the extraction process depends on the choice of supercritical fluids (Wang and Weller, 2006). Researchers have shown that SC-CO₂ is effective at removing bioactive substances. For instance, Giannuzzo et al. (2003) discovered that ethanol treatment of SC-CO₂ led to better yields of naringin extraction from citrus trash than did pure SC-CO₂. By using SFE to extract procyanidins and polyphenols from grape seeds, they were able to significantly release catechin and epicatechin with grape seed methanol-enhanced CO₂ (40%). The supercritical approach is a useful substitute for traditional organic solvent extraction procedures, according to Wang and Weller (2006). The parameters for SC-CO₂ extraction, recovery, and characterization of bioactive compounds from food and plants are shown in Table 2.

![Figure 3. Different Extraction Techniques and health potentials of Food Wastes](Source: Alara, et al, 2018)

### Table 2. Extraction, Recovery and Characterization of Bioactive Compounds Using Supercritical Fluid Extraction

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Sources</th>
<th>Temperature (°C)</th>
<th>Pressure (Bar)</th>
<th>Co-solvent</th>
<th>Bioactive compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blueberry residues</td>
<td>40</td>
<td>150–300</td>
<td></td>
<td>Anthocyanin</td>
</tr>
<tr>
<td></td>
<td>Apricots pomaces</td>
<td>39.85–59.85</td>
<td>304–507</td>
<td>Dimethoxy propane</td>
<td>Carotenoid</td>
</tr>
<tr>
<td></td>
<td>Red grape residues</td>
<td>45</td>
<td>100–250</td>
<td>Methanol</td>
<td>Pro-antocianidin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Citrus peels</td>
<td>58.6</td>
<td>95</td>
<td>Ethanol</td>
<td>Naringins</td>
</tr>
<tr>
<td>5.</td>
<td>Grape by product</td>
<td>35</td>
<td>400</td>
<td>Ethyl alcohol</td>
<td>Resveratrols (19.2 mg/100 g)</td>
</tr>
<tr>
<td>6.</td>
<td>Banana peels</td>
<td>40–50</td>
<td>100–300</td>
<td>Ethanol</td>
<td>Essential oil</td>
</tr>
<tr>
<td>8.</td>
<td>Orange peels</td>
<td>19.85–49.85</td>
<td>80–280</td>
<td>Ethyl acetate,</td>
<td>Limonenes and linalool</td>
</tr>
<tr>
<td>9.</td>
<td>Guava peels</td>
<td>40–60</td>
<td>100–300</td>
<td>Ethyl acetate,</td>
<td>Phenolics</td>
</tr>
<tr>
<td>10.</td>
<td>Apricot by products</td>
<td>59</td>
<td>310</td>
<td>Ethyl alcohol</td>
<td>β-Carotenes</td>
</tr>
</tbody>
</table>

| Vegetables |
|---|---|---|---|---|
| 11. | Pistachio hulls | 45 | 355 | Methyl alcohol | Polyphenol (7810 mg GAE/100 g) |
| 12. | Tomato wastes | 40–80 | 200–300 | Ethyl alcohol | Trans-lycopenes |
| 13. | Tomato skins | 75 | 350 | Ethyl alcohol | Carotenoids |
| 15. | Carrot press cakes | 55 | 345 | Ethyl alcohol | β-Carotenes |
| 16. | Green tea leaves | 60 | 310 | Ethyl alcohol | Catechins |
| 17. | Tea seed cakes | 80 | 200 | Ethyl alcohol | Kaempferols glycosides (11.4 mg/g) |
| 18. | Spearmint leaves | 40–60 | 100–300 | Ethyl alcohol | Flavonoids |


**Subcritical Water Extraction**

An increasingly popular alternative technique for removing phenolic chemicals from a variety of foods is subcritical water extraction (SCW). Subcritical water is defined as water that is between 100 and 374 °C in temperature and with a pressure that is high enough to keep it liquid but lower than the critical pressure of 22 MPa. Faster extraction times, lower solvent costs, better extraction quality, and environmental friendliness are just a few advantages SCW has over traditional extraction techniques (Herrero et al., 2006).

According to research (Zakaria and Kamal, 2016), SCW is a viable engineering technique for ecologically friendly component extraction from plants and algae. According to studies (Mayanga-Torres et al., 2017), SCW extraction can produce higher levels of phenolic compounds than conventional solvent-based methods.

Overall, SCW extraction has many advantages over traditional procedures, including better extract quality, quicker processing times, cheaper extraction agents, and a more ecologically friendly approach (Joana Gil-Chávez, 2013). The extraction of bioactive chemicals from agricultural waste and diverse natural sources has the potential to be a useful method.

**Enzyme-Supported Extraction**

A popular technique for obtaining bioactive components from food waste is enzyme-assisted extraction. Due to their intricate structure, plant tissues and cell walls that are rich in antioxidants and polysaccharides like cellulose, hemicellulose, and pectins can be difficult to extract. Enzymes are used to dissolve the plant cell walls, depolymerize polysaccharides, and release the necessary bioactive substances. Examples of these enzymes include cellulases, glucosidases, xylanases, gluconases, and pectinases Puri et al. (2012).

Singh et al. (2016) explored the enzyme-assisted extraction of lycopene from tomato peel waste and discovered that utilizing a combination of enzyme preparations with cellulolytic and pectinolytic activity considerably increased lycopene recovery on a wide scale, making it a financially viable method. Similar to this, Puri et
al. (2012) researched the enzyme-assisted extraction of stevioside from Stevia rebaudiana and came to the conclusion that enzyme-based extraction might successfully replace traditional solvent-based procedures for food and nutraceutical applications. Enzyme-assisted extraction is a potential procedure since enzymes have the capacity to catalyze reactions in water-based solutions under mild processing conditions.

**Ultrasound-Based Extraction**

In comparison to conventional extraction methods, ultrasound-assisted extraction is thought to be a more effective and simple way for obtaining bioactive chemicals from natural sources. By enhancing the penetration of solvents into cellular materials with ultrasonic, more mass is transferred, cell walls are broken down, and bioactive components are more easily released. The frequency employed, which varies based on the type of plant material being extracted, determines how well ultrasound-assisted extraction works. For instance, Wang et al. (2011) isolated three dibenzylbutyrolactone lignans from Hemistepta lyrata using ultrasound-assisted extraction, and high-performance liquid chromatography was used to evaluate the derived materials.

Using a mix of stirring techniques, various extraction times, and several solvents, Rostagno et al. (2003) investigated the extraction effectiveness of four isoflavone derivatives from soybean. Depending on the type of solvent used, they discovered that ultrasonic enhanced the extraction yield. Bimakr et al. (2013) utilized this technique to extract bioactive components from winter melon seeds (Benincasa hispida), whereas Ghafoor et al. (2011) used it to extract anthocyanins and phenolic compounds from grape peel. In both instances, the desired bioactive chemicals from the natural sources could be extracted successfully with the help of ultrasonic technology.

**Microwave Assisted Extraction**

A cutting-edge method called microwave-assisted extraction (MAE) combines microwave technology with conventional solvent extraction techniques. MAE has a number of benefits over traditional extraction techniques, including faster extraction times, greater recovery rates, less solvent usage, and lower overall costs (Delazar et al., 2012). In comparison to methods like ultrasonic-assisted extraction and the Soxhlet method, MAE is reported to extract plant metabolites more effectively and quickly.

According to research, changing the microwave strength can boost the presence of some chemicals, such as mangiferin, to a certain extent. For instance, Delazar et al. (2012) found that the optimal yield of mangiferin was achieved at 500 W microwave power and 15.32 seconds of extraction time. According to Kerem et al. (2005), MAE worked better than Soxhlet extraction while removing chickpea saponins since it required less time, energy, and solvent.

MAE has demonstrated to be extremely effective, requiring less solvent, effort, and shorter extraction durations than other methods (Bandar et al., 2013). As a result, it is the method of preference for the extraction of bioactive chemicals. MAE is a promising and advantageous method for the extraction of bioactive compounds since it combines microwave technology with conventional solvent extraction.

**A Comparison of the Evaluation of Various Extraction Methods for Obtaining Bioactive Compounds**

In order to extract alkaloids from the fruit of Macleaya cordata (Willd) R. Br., Zhang et al. (2005) compared various extraction techniques. They discovered that microwave-assisted extraction (MAE), which produces considerable levels of sanguinarine and chelerythrine in about 5 minutes, is the most effective technique. Compared to the seed, the fruit shell had a greater alkaloid content.
Using cutting-edge techniques like pulsed electric fields, ultrasonics, and high hydrostatic pressure, Corrales et al. (2008) extracted anthocyanins from grape by-products. By using these cutting-edge techniques, the total phenolic content was increased by 50% in comparison to control samples, and the extracts' antioxidant activity was markedly increased. Orange juice's bioactive components were examined by Plaza et al. (2011) to determine how different extraction techniques affected them. High pressure treatment was shown to be the most effective way to extract healthy compounds.

Using various solvents and extraction methods, Drosou et al. (2015) investigated the extraction yield of phenolic compounds from Agiorgitico red grape pomace by-products. Ethanol was determined to be the most efficient solvent for ultrasound-assisted water extraction.

Using solvent extraction and supercritical CO2 extraction to extract lycopene and carotene from tomato peels, Kehili et al. (2017) compared the results. Under particular processing conditions, supercritical CO2 extraction provided higher lycopene yields than solvent extraction.

Espinosa-Pardo et al. (2017) recovered the total phenolic contents of orange juice pomace using supercritical fluid extraction under various pressures and co-solvents. The best extraction and improved antioxidant activity in the extracts came from high-pressure recovery using 90% ethanol as a co-solvent.

Table 3. Comparative Evaluation of Different Extraction Techniques for Extraction of Bioactive Components

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Bioactive component</th>
<th>Sources</th>
<th>Method</th>
<th>Extraction solvent used</th>
<th>Optimum conditions</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Alkaloids</td>
<td><em>Macleaya cordata</em></td>
<td>Maceration MAE</td>
<td>HCl, HCl</td>
<td>100 °C/30 min, 280 W/5 min</td>
<td>16.87±1, 17.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>UAE</td>
<td>HCl</td>
<td>250 W/30 min</td>
<td>10.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Percolation</td>
<td>HCl, NaOH</td>
<td>–</td>
<td>6.14</td>
</tr>
<tr>
<td>2.</td>
<td>Anthocyanins</td>
<td>Grapes</td>
<td>WE</td>
<td>H2O</td>
<td>70 °C</td>
<td>7.93±b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ultrasonics</td>
<td>H2O, ethyl alcohol</td>
<td>600 MPa</td>
<td>7.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HHP</td>
<td>H2O, glycols</td>
<td>35 kHz</td>
<td>11.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PEF</td>
<td>H2O, ethyl alcohol</td>
<td>3 kV cm⁻¹, 750 ms</td>
<td>14.05</td>
</tr>
<tr>
<td>3.</td>
<td>Hesperetins</td>
<td>Oranges</td>
<td>LPT</td>
<td>–</td>
<td>70 °C, 30 s</td>
<td>11.56±c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HPT</td>
<td>–</td>
<td>400 MPa/40 °C/1 min</td>
<td>13.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PEF</td>
<td>–</td>
<td>35 kV cm⁻¹, 750 ms</td>
<td>11.09</td>
</tr>
<tr>
<td>4.</td>
<td>Luteins</td>
<td>Oranges</td>
<td>LPT</td>
<td>–</td>
<td>70 °C, 30 s</td>
<td>226.42±</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HPT</td>
<td>–</td>
<td>400 MPa/40 °C/1 min</td>
<td>361.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PEF</td>
<td>–</td>
<td>35 kV cm⁻¹, 750 ms</td>
<td>260.86</td>
</tr>
<tr>
<td>5.</td>
<td>Lycopenes</td>
<td>Tomato wastes</td>
<td>SFE</td>
<td>Liquid CO₂</td>
<td>400 bar/80 °C/4 g CO₂/ min/105 min</td>
<td>728.98±c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>Hexane</td>
<td>–</td>
<td>608.94</td>
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<td></td>
<td></td>
<td>Ethyl acetate</td>
<td>–</td>
<td>320.35</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ethyl alcohol</td>
<td>–</td>
<td>284.53</td>
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<tr>
<td>6.</td>
<td>Naringenins</td>
<td>Oranges</td>
<td>LPT</td>
<td>–</td>
<td>70 °C, 30 s</td>
<td>3.87±c</td>
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<tr>
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<td></td>
<td></td>
<td>HPT</td>
<td>–</td>
<td>400 MPa/40 °C/1 min</td>
<td>4.43</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>PEF</td>
<td>–</td>
<td>35 kV cm⁻¹, 750 ms</td>
<td>3.42</td>
</tr>
<tr>
<td>7.</td>
<td>Total phenolics</td>
<td>Red grape pomaces</td>
<td>SE</td>
<td>H₂O</td>
<td>Refluxing for 2–3 h</td>
<td>96,386±</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ethyl alcohol</td>
<td>Refluxing for 5–6 h</td>
<td>102,995</td>
</tr>
</tbody>
</table>
Use of bioactive compounds as nutraceuticals and functional foods for human Health

Using solvent extraction and supercritical CO2 extraction to extract lycopene and carotene from tomato peels, Kehili et al. (2017) compared the results. Under particular processing conditions, supercritical CO2 extraction provided higher lycopene yields than solvent extraction.

Espinosa-Pardo et al. (2017) recovered the total phenolic contents of orange juice pomace using supercritical fluid extraction under various pressures and co-solvents. The best extraction and improved antioxidant activity in the extracts came from high-pressure recovery using 90% ethanol as a co-solvent. However, oxidative damage that builds up over a person’s lifetime and contributes to aging, chronic diseases like cancer, cardiovascular disease, neurological conditions, and other illnesses associated with lifestyle occurs when free radical production outpaces the protective effects of antioxidants and co-factors.

Free radicals generated by normal metabolic processes can have an impact on important cellular functions and structures, which can result in a number of degenerative illnesses. In scavenging these free radicals and preserving the redox state of functioning proteins, antioxidant enzymes are essential. Redox regulators with antioxidant properties act on active intermediates, cell organelles, and the surrounding cellular environments in diseases that involve redox imbalance, such as neurological disorders, aging-related conditions, cancer, ischemia/reperfusion injury, and other illnesses associated with lifestyle (Yang and Lee, 2015).

Pharmaceutical preparations such pills, capsules, tablets, powder, and vials frequently contain nutraceuticals. Mangiferin, a naturally occurring bioactive xanthonoid present in plants such as mango trees, has showed promise in treating a number of cancers and has anti-inflammatory
and antioxidant properties that can be used alone or in conjunction with other anticancer medications (Nez Selles et al., 2016). Black bean seed coatings’ flavonoids and saponins have been researched for their potential to improve health. However, some food processing techniques may lessen the quantity of healthy ingredients added to the finished product, which could affect its possible positive health effects (Odimegwu et al., 2020). According to Lozano-Sánchez et al. (2017), a contemporary two-phase centrifugal processing method for olives yields a by-product called "pâté," which contains promising bioactive components with potential uses in the feed and nutraceutical industries. These constituents include hydroxytyrosol, -hydroxyverbascoside, oleoside derivative, and luteolin.

Conclusion and Recommendation
Food residues can yield a wide range of bioactive compounds, and cutting-edge measurement technologies have enormous potential for measuring metabolites in different food waste materials. Higher quantities of particular bioactive components can be obtained from food waste byproducts using extraction techniques, especially supercritical fluid extraction technologies. By using the right extraction methods, it is possible to develop a bioprocess that maximizes the recovery of bioactive elements, adds value to food waste, lowers product costs, and uses fewer synthetic chemicals.

Utilizing this waste as a source of bioactive substances might help farmers financially and solve waste management issues as the amount of food and agricultural waste rises as a result of increased food processing activities and post-harvest losses. Long-term sustainability will depend on using less or no solvents in sustainable bioprocesses.

Industrial waste disposal, which can be risky for the environment, is a major problem in India. Industrial organic waste, however, could be used as a potential bioresource to isolate bioactive components. This analysis focuses on investigating alternative technologies that can extract bioactive ingredients for nutritional supplements and nutraceuticals while substituting it with less damaging organic solvents, such as CO₂, ethanol, and water, for more environmentally friendly ones.

It is crucial to encourage the wise use of natural resources, and setting up businesses to utilize industrial waste calls for thorough financial analysis. By making use of such residues, businesses can increase revenue from the sale of leftovers while reducing environmental damage brought on by inappropriate disposal of industrial food waste.

Concurrent Interest
The authors have declared that they have no competing interests and the article has not been published in any other journal and no external funding source.

Contributions of the Authors
All the authors worked together to complete this review.

References


