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Food waste as potential bioresources for extraction of carotenoid of nutraceutical importance: Current research and future challenges

Jeet Nag Das[1#], Suradeep Basak[1*#], Vandana Sablania[2], Rajeshwari Negi[3], Neelam Yadav[4,5], Sarvesh Rustagi[6], Sangram Singh[7], Ashutosh Kumar Rai[8], Sheikh Shreaz[9], Ajar Nath Yadav[3]*

[1]Department of Biotechnology, University Institute of Biotechnology, Chandigarh University, Punjab, India.
[2]Institute of Home Economics, University of Delhi, Hauz Khas, New Delhi, India.
[3]Department of Genetics, Plant Breeding and Biotechnology, Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour-173101, India.
[4]Chitkara Center for Research and Development, Chitkara University, Himachal Pradesh, India.
[5]Centre of Research Impact and Outcome, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India.
[6]Department of Food Technology, School of Applied and Life sciences, Uttaranchal University, Dehradun, Uttarakhand India.
[7]Department of Biochemistry Dr. Ram Manohar Lohia Avadh University Faizabad, Uttar Pradesh, India.
[8]Department of Biochemistry, College of Medicine, Imam Abdulrahman Bin Faisal University, Dammam- 31441, Kingdom of Saudi Arabia.
[9]Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, PO Box 24885, 13109 Safat, Kuwait.
#Contributed equally in the manuscript

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ABSTRACT

Carotenoids are lipid soluble natural pigments found in various plants, animals, and microbes giving them their yellow, orange, or red hue. Carotenoids have been linked to a variety of health benefits as bioactive compound including antioxidant properties, reduced risk of certain cancers, improved ocular and cardiovascular health, and improved immune function and skin health to name a few. Global volume of wastage of edible part of food is accounted as 1.3 billion tons and a sizeable portion of this wastage have significant amount of carotenoid content which can be utilized for industrial purpose and economical values. However, most of these wastes are used as animal feed, composting and land filling. Although, chemical synthesis of carotenoids is possible, it has several disadvantages including complex extraction process, high cost, and low yield of final product and environmental impacts and safety concerns. The present review focuses on advances in extraction of carotenoid using non-thermal technologies, such as ultrasound assisted extraction, supercritical CO_2 extraction, and microwave assisted extraction, from various food wastes to utilize the waste. The green extraction of carotenoids from food waste materials is an area that has a lot of potential for future development. Using environmentally friendly extraction methods and utilizing food waste as a source of carotenoids, we can create a more sustainable and environmentally friendly food production system.

1. INTRODUCTION

Food is a necessary ingredient for existence of each living forms. Each and every living being consumes food for survival, from micro-organisms consuming macro- and micro-molecules, namely, fats, sugars, proteins, nitrogenous components, vitamins and minerals to human consuming fruits, vegetables, meat, and dairy products to name a few. Some major problems arise from the mismanagement of food in any stage of its life cycle result in serious outcomes at socioeconomic and environmental level. Food and Agricultural Organization (FAO) has predicted that 1.3 billion tons globally annual waste has been generated by edible part of food [1]. Food waste may be assumed as edible and inedible portion of food. These wastes are generated through all stages of food's life cycle starting from agricultural practices followed by postharvest operations to their processing and manufacturing in industries and finally distribution of the packaged food products. Most of the food wastes are generated in household activities, food manufacturing plants, food service sectors, and remainder of the food waste is contributed during storage and transport [2]. Landfill or incineration of surplus food products results in

**Corresponding Author:*
Suradeep Basak
Department of Biotechnology, University Institute of Biotechnology, Chandigarh University, Punjab, India.
E-mail: suradeepbasak@gmail.com
Ajar Nath Yadav
Department of Genetics, Plant Breeding and Biotechnology, Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India
E-mail: ajar@eternaluniversity.edu.in

production of greenhouse gases such as methane, carbon dioxide, and carbon monoxide and they directly affect climate change, air quality, and well-being of living organisms [3]. To maintain environmental stability and socioeconomic balance, valorization of food waste with an emphasis on extraction of value-added compounds is an approach gaining global attention.

Bioactive compounds have been consumed by humans from the very inception of their existence. Various evidences have been found throughout the years of usage of medicinal plants of specific foods for curing specific types of disease. Across South-East Asia, there are several ancient architecture that date backover a 1000 years, describing the usage of different foods for curing ailments [4]. It is proven that bioactive compounds from animal and plant-based food products have several beneficial effects on human [5]. There are varieties of bioactive components present including long chain polyunsaturated fatty acids, vitamins, carotenoids, peptides, tannins, flavonoids, phenolic acids, and minerals [6]. Food products from animal origin, such as meat and other meat originated products contains sizeable amount of bioactive compounds present in them [7].

Nutraceuticals has shifted to be the leading norm in the allied area of food and nutrition. The term nutraceutical was first coined by Stephen L. De Felice first in the year 1989 [8]. Nutrient factors combined with biologically active substances are thought to play an important role in overall human health. As presented by its inventers, the description of nutraceuticals can be elaborated as an object that may be food itself or part of food, providing medical and/or health advantages which may include the forestallment and treatment of some kind of illness or disease [9]. It could be comprised components such as isolated nutrients, dietary supplement, and processed food [8]. Nutraceuticals are therapeutic resources but cannot supersede chemically synthesized medicines. Metabolic syndrome, heart disease, and diabetes can be staved off with the aid of nutraceuticals or they can be used for those patients who do not qualify for standard pharmacological treatments [10,11]. The possibilities that nutraceuticals provide to support or as an alternative to traditional pharmacological treatments, may be a possible path to cure pathological, chronic, and long-term diseases which previously cannot be cured by traditional treatments. Simultaneously, new sources of nutraceuticals from edible source and their wastes are being explored which might provide novel nutraceuticals and/or their new sources that can be used in some specific health conditions [12].

Carotenoids are from the tetraterpenes family, a colorful liposoluble natural pigment, giving fruits and vegetables their bright red, orange, and yellow color. An array of things features carotenoids in them including plants, microbes such as bacteria, fungi, and algae, and in many fruits, vegetables, and aquatic flora and fauna [13]. Various extraction method of carotenoids are Soxhlet solvent extraction (SE), microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), super critical fluid extraction, enzyme aided extraction, high-shear dispersant extraction, and pulsed electric field (PEF)-assisted extraction. The trend to utilize carotenoids as bioactive agents or valued nutraceutical component has skyrocketed over past decade. Being a nutraceutical, carotenoids can be characterized according to its source, similar to prebiotics, probiotics, and polyphenols [8]. In some research, work conducted in the past by several research groups showed various nutraceutical applications of carotenoid in human diseases such as reducing obesity-related pathophysiology, type two diabetes and cardiovascular disease, as well as anti-carcinogenic and antioxidant properties. Suggestions were made on the antioxidant, anti-apoptotic, and anti-inflammatory effects of carotenoid helps in suppressing various effects of diabetes. α-carotene, β-carotene, γ-carotene, and lycopene have antioxidant activities. Beta-carotene is also precursor of Vitamin A [14]. Astaxanthin, a xanthophyll carotenoid, is suggested for use as therapeutic agent for cardiovascular diseases [15]. Lutein and zeaxanthin have pharmacological effects on visual disorders and cognition disease [16].

Although carotenoids are present in lot of foods such as fruits and vegetables, the wastage part of those food components provides an enormous opportunity to collect the important bioactive compound from food waste. This property will add value to the waste utilization of surplus postharvest loss of such food products. Advances in current scientific and technological capabilities allow us to extract, characterize, and use nutraceuticals and bioactive components from foods as well as their wastage parts. Fruits and vegetables of bright red and yellow colors such as mango [17], passion fruit [18], peach [19], banana, persimmon [20], tomato [21,22], and carrot [23] have high quantity of carotenoids present in their peels which usually get thrown out and wasted. The present review discusses the various sources and extraction methods of carotenoids from food wastes that can be utilized as potential nutraceutical components.

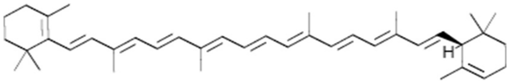
2. CHEMICAL NATURE OF CAROTENOIDS

Carotenoids are tetraterpenoids which belong to the groups of lipids named terpenoids. It displays orange, red, yellow, and purple color. They are lipophilic compounds, which tend to be insoluble in water due to their extreme hydrophobia. Carotenoids are wide-ranging in nature, from photosynthetic bacteria to fungi, algae, archaea, animals, and plants [24]. Natures composition contains over 650 types of carotenoids. Among them almost 100 of them are present in the human food diet [25].

Most of the carotenoids are made up of eight isoprene units along with a 40-carbon skeleton. Overall, structure of carotenoids is made up of a polyene chain with nine conjugated double bonds and an end group at both ends of the polyene chain [24]. The structures of various types of carotenoids are shown in Figure 1 below. Carotenoids can be classified into provitamin A, and non-provitamin A compounds. However, on the basis of their functional groups, they can be divided as: carotenes, which does not have any functional group except the parent hydrocarbon chain (such as α-carotene, β-carotene, and lycopene) and xanthophylls, that contain oxygen as a functional group (such as lutein and zeaxanthin). In xanthophyll molecules, oxygen atoms are present as hydroxyl, carboxyl, carbonyl, aldehyde, epoxide, and furanoxide groups [13,24]. Carotenoids can have different isomeric configurations, trans and cis isomers, from their carbon-carbon bond. The isomers of carotenoids differ in their solubility, melting points, stability, and ultraviolet characteristics [26,27]. In Figure 1, different chemical structures of various carotenoids compounds are shown.

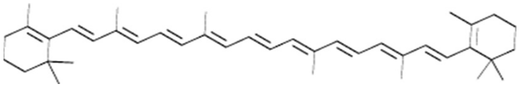
Besides the general classifications, carotenoids may have sub-classes based on their number of carbon atoms and double bonds. Normal carotenoids are formed from 40 carbon atoms and eight C5 isoprenoid unit. Despite the most abundance of C40 carotenoids in nature, some of them might have shorter (C30) or longer (C45, C50) carbon chain. As the carbon chain gets shorter or longer, the isoprenoid units also decrease or increase, respectively. For example, C30 carotenoids contain six C5 isoprenoid units whereas C45 and C50 are made up of 9 and 10 units of isoprenoids, respectively [Figure 1]. Decaprenoxanthin is an example of C50 carotenoids. Another subclass is secocarotenoids. In this subclass, a bond between the adjacent carbons is broken, except the first and sixth carbon in ring [28].

α-CAROTENE



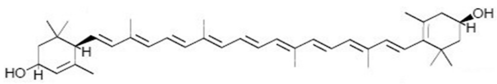
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 6419725, alpha-Carotene. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/alpha-Carotene.

β-CAROTENE



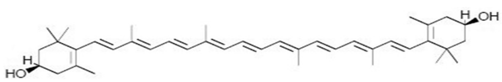
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 6419725, alpha-Carotene. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/alpha-Carotene.

LUTEIN



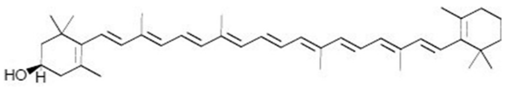
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5281243, Lutein. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Lutein.

ZEAXANTHIN



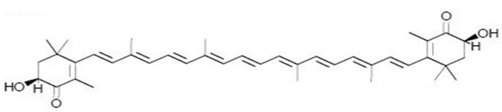
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5280899, Zeaxanthin. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Zeaxanthin.

β-CRYPTOXANTHIN



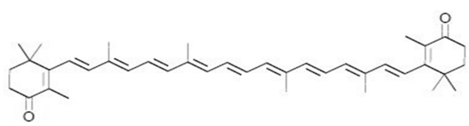
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5281235, beta-cryptoxanthin. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/beta-Cryptoxanthin.

CANTAXANTHIN



National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5281227, Canthaxanthin. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Canthaxanthin.

ASTAXANTHIN



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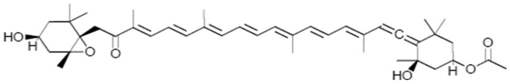
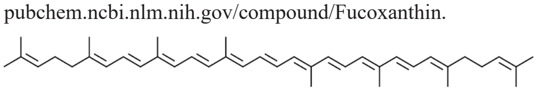
FUCOXANTHIN



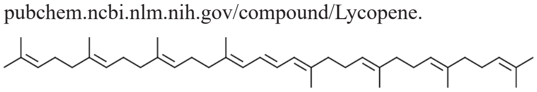
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5281239, Fucoxanthin. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Fucoxanthin.

LYCOPENE



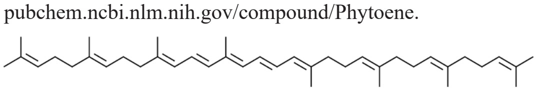
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 446925, Lycopene. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Lycopene.

PHYTOENE



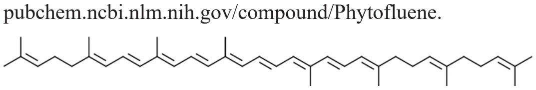
National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5280784, Phytoene. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Phytoene.

PHYTOFLUENE



National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 6436722, Phytofluene. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Phytofluene.

NEUROSPORENE



National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 5280789, Neurosporene. Retrieved March 31, 2023, from https://pubchem.ncbi.nlm.nih.gov/compound/Neurosporene.

Figure 1: Structures of different carotenoids.

3. SOURCES OF CAROTENOIDS

An abundance of carotenoids can be found in the natural world, which can be seen in various parts of plants (leaves, flowers, vegetables, fruits, seeds, and roots). Further, they are located in fatty matter like yolks of eggs or other internal fats. In fatty fishes like tuna, salmon carotenoids are found in fat tissues or bound with flesh. A variety of plant and animal material, as well as microbial life, produces carotenoids.

3.1. Plants

Carotenoids, considered as secondary metabolites, are necessary for many biological activity and growth of plants. They give the bright red, yellow, and orange color to plants, leaves, flours, and fruits. Many flowers contain chromoplasts that contain carotenoids giving them their bright colors. Similar thing occurs in case of fruits. Phytoene, phytofluene, lycopene, and β-carotene are found in red-, yellow-, and orange-colored fruits and xanthophylls are found in green vegetables. Dark green leaves such as spinach and kale have higher concentration of carotenoids than light green vegetables such as lettuce and cabbages. Bright colored fruits such as tomato, watermelon, apricot peaches, mango, guava, and orange have high concentrations of carotenoids. Other vegetables such as beet roots, carrot, sweet potatoes, and bell papers also contain carotenoids [27,29].

3.2. Micro-organisms

Microalgae are a great source of carotenoids. They can be classified according to their photosynthetic pigments such as red algae (rhodophyta), green algae (chlorophyta), and brown algae (phaeophyta). Bioactive compounds such as lutein, β-carotene, and lycopene are widely available in microscopic algae. They are some significant carotenoids with high economic merit [26]. Many bacteria are able to produce carotenoids by chromatophores. They act as secondary metabolites to play key roles in cell adaptability. Bacteria, namely, *Flavobacterium* spp., *Agrobacterium* spp., *Chromobacterium* spp., *Arthrobacter* spp., *Pseudomonas aeruginosa*, and *Rheinheimera* spp. are some prominent producer of carotenoid pigments [27,30]. In comparison with other micro-organisms, fungi have the ability for production and accumulation of appreciably greater levels and concentrations of carotenoids intracellularly. Several classes of fungi including zygomycetes, ascomycetes, basidiomycetes, and the deuteromycetes are capable of producing greater level of carotenoids. Some example include *Basidiomycete yeast*, *Blakeslea trispora*, *Neurospora crassa*, and *Xanthophyllomyces dendrorhous* [27,31].

3.3. Animals

In case of bright colored birds, their red, orange, yellow, pink, and various color are the result of carotenoids colorization. These colors come from the various carotenoid rich diets of the birds, such as fruits and seeds high in α and β-carotene. Some examples of these birds are song birds and flamingo [32]. In case of fishes, most of the red fish and fishes with more fat concentration have high carotenoids stored in them, such as salmon, trout, and tuna. These carotenoids mainly come from their diet of microalgae, plankton, small insect, and shrimps. Red shrimps and lobsters also contain high level of dietary carotenoids such as astaxanthin which got released while cooking [33]. In case of eggs, the yellow-orange color comes from carotenoids also. β-carotene can also be detected in cow milk.

3.4. Human Diet

Human body can acquire carotenoids from various fruits and vegetables, animal foods, and other nutritional supplements. Microalgae are widely used to produce nutritional supplements containing carotenoids. Some of the examples are brown sea-weed (*Undaria pinnatifida*) and red algae (*Chondrus crispus*) [34]. When it comes to foods derived from animals, the yolk of eggs is particularly high in carotenoids. Milk, flesh, liver, and fat tissues of poultry and cattle also contain significant level of carotenoids. Red fishes, such as salmon and trout, have carotenoids in their tissue [35,36]. In case of plant and plant-based food products, carotenoids are available in bright red, yellow, and orange colored fruits (mango, orange, guava, papaya, watermelon, apricot, and peach) and vegetables (tomato, bell paper, carrot, beet roots, spinach, and kale), herbs (basil and coriander), legumes [37], cereals (wheat, maize, rice, and corn) [38], and seeds and seed oil (palm oil). In Table 1, various carotenoids found in a human's daily dietary intake are shown.

3.5. Food Wastes

Although carotenoids are present in several human dietary sources, a huge amount of them get wasted as a form of food waste such as, some of fruits peels contain more carotenoids than the pulp. Such fruits and vegetables of which the peels and pulps (after extracting juice out of it) get wasted as most of the time those things were used in landfill or animal feed or in biofertilizer/biogas production. Food waste such as mango peel, peach peels and pulp, apricot waste, tomato peel and pulp, carrot peels, and passion fruit peels are high sources of carotenoids. Some other food waste except fruits and vegetables include coffee grounds, having rich number of carotenoids present in them. Sea food waste like shrimp shells also contain collectable amount of carotenoid.

4. HEALTH BENEFITS OF CAROTENOIDS

Apart from using as a natural dye in food to make it more appealing to customers, carotenoids have various health benefits.

4.1. Lutein-Zeaxanthin

Zeaxanthin is the stereoisomer of lutein. Both of them have similar function in human health, first as an antioxidant [12]. They act as a screen to safeguard one's skin from ultraviolet (UV)-light; in addition, lutein has been suggested as having the potential to diminish

Table 1: The different sources of carotenoids that can be found in human dietary intake.

Carotenoids	Sources	References
α-Carotene	Tomato, Carrot, Broccoli, Spinach, and Corn	[141]
β-Carotene	Carrot, Mango, Tomato, Apricot, Pumpkin, Spinach, and Kale	[141,142]
Lutein	Egg yolk, Corn, Tomato, Banana, Kale, and Spinach	[143,144]
Zeaxanthin	Paprika, Red paper, Maize, and Green vegetables	[143,144]
Astaxanthin	Crab, Trout, Green Algae, and Salmon	[145]
Lycopene	Watermelon, Tomato, Guava, and Peach	[146,147]
Canthaxanthin	Mushroom, Salmon, and Crustacea	[148]
Fucoxanthin	Brown sea weed	[149]
β-Cryptoxanthin	Orange, Papaya, Mango, Peas, and Peach	[141,150]

cardiovascular system risks. Zeaxanthin and lutein are found in the macular pigment of human retina. Supplementation of lutein and zeaxanthin can increase macular pigment optical density (MPOD) values and reduce the risk of age-related macular degeneration in individuals with low MPOD (0.2 or lower) [39,40]. They also protects retina from photochemical injury and UV-induced peroxidation [41]. Several studies showed lutein having anti-cancerous properties against certain types of cancer. It improves the immune response also, both humoral and cell mediated [42].

4.2. Astaxanthin

It has similar antioxidant properties such as lutein as well as anti-inflammatory properties. Human clinical trials on eye health showed positive effects of dietary astaxanthin on diabetic retinopathy, eye strain and fatigue, and macular degeneration [27]. It increases the phagocytic and fungicide capacity of neutrophils. It increases lymphocyte proliferation and the cytotoxic activity of natural killer cells [43]. Increased consumption of astaxanthin decreases the risks of certain types of cancers [44]. Moreover, it has been shown to reduce cardiovascular health disease since it reduces low-density lipoprotein peroxidation and improves the blood flow capacity and blood lipid profiles [45]. It is one of the strongest antioxidant of carotenoids family, exhibiting Vitamin E and β-carotene. Application of astaxanthin with aspirin shows sun-proofing and anti-aging properties as well as anti-inflammatory activities [26].

4.3. Canthaxanthin

Canthaxanthin shows positive effect on neurological disorders, as a neuroprotective agent due to its antioxidant and anti-inflammation properties [13]. It enhances the communication between cells through gap junctions either directly or by forming 4-oxo-retinic acid, stimulating the retinoic acid stimulator. These mechanisms provide it with antitumor activities. Canthaxanthin can prevent some blood disorder disease; however, consumption of large quantity is required which might be unsafe [27,46].

4.4. Lycopene

The carotenoid is reported to have anticancer properties especially prostate cancer. A study conducted by Zu *et al.* [47] on 49,898 male health professionals showed lower risk of fatal prostate cancer for the candidates having dietary intake of lycopene as compared to those who consumed less lycopene. The sources of lycopene in diet were pink grapefruit, tomato, tomato sauce, tomato juice, watermelon, and pizza [47]. Lycopene enhances the integrity of vascular barrier, inhibits the barrier permeability, cells adhesion molecule, and prevents leucocyte adhesion and trans-endothelial migration. Doing so lycopene suppresses pro-inflammatory response. It also shows antioxidant activities and has potential roles in cardiovascular health [48].

4.5. β-carotene

Beta-carotene shows provitamin A functions in human body. It is used as a supplement for Vitamin A deficiency. Regular intake of β-carotene can affect eye health and reduce macular diseases. It also shows anti-cancerous and antioxidant activities. In various studies, β-carotene has shown protection against sunburns [49].

5. EXTRACTION METHODS OF CAROTENOIDS FROM VARIOUS SOURCES

The stability and yield of carotenoids depend on their source and extraction methods or conditions [Table 2]. Usage of organic solvent is a traditional method for extraction but it is getting replaced by green extraction techniques for being challenging and time consuming. One of the more traditional methods is Soxhlet SE method, but new methods, such as MAE, UAE, and supercritical fluid extraction (SCF) methods, are replacing it. New studies are investigating and comparing them for better quality and yield [50]. In Figure 2, various processes for the extraction of carotenoids are shown.

5.1. Soxhlet SE

SE is one of the traditional methods. It utilizes a solid-liquid extraction method that employs continuous reflux of natural solvents to enable the transfer of non-harmful biological molecules in large quantities. Some of the solvents used for carotenoids extraction include hexane, ethanol, acetone and chloroform. Although this technique extracts the largest amount of carotenoids from a given sample; nowadays, it is not preferred due to more time consumption, lengthy processing time, requirement of high amount of organic solvents, and increased extraction cost [51,52].

5.2. MAE

This method employs microwave radiation to heat up the solvent that further enhances transfer of solutes present in the matrix to the solvent. Microwave radiation is capable of rupture plant cell walls, resulting in an easy release of bioactive compounds present in cells into solvents. Both polar and non-polar solvent are used in microwave extraction such as aglycones, flavonoid glycosides, acetone, chloroform methanol, and ethanol with different concentration. This method is more appreciated presently, for being simple, time convenient and cost effective. Although this method requires less time and less amount of solvent, the yield of this technique is very low as compared to Soxhlet extraction method. Increase of extraction time can cause thermal degradation of bioactive compound, so microwave time and power optimization is critical issue in this technique [51,53].

5.3. UAE

This technique utilizes the mechanical energy produced by ultrasound waves. The sonication generates small bubbles or gaps in the liquid,

Table 2: The methods of extraction of carotenoids.

S. No.	Source	Method of extraction	Extraction yield	References
1.	Carrot waste	Ultrasound-assisted extraction	83.32%	[85]
2.	Lemon waste	Microwave-assisted extraction	3.2–6.2% w/w	[151]
3.	Tomato pulp waste	Soxhlet solvent extraction	94.7%	[152]
4.	Pumpkin rind	Super critical fluid extraction	20.50 mg/100 g	[153]
5.	Blueberry byproducts	Pulsed electric field-assisted extraction	55%	[154]
6.	Tomato peel	Enzyme-aided extraction	55.15 mg/100 g	[69]
7.	Bael fruit pulp	High-shear dispersant extraction	4.14 µg/100 g	[155]

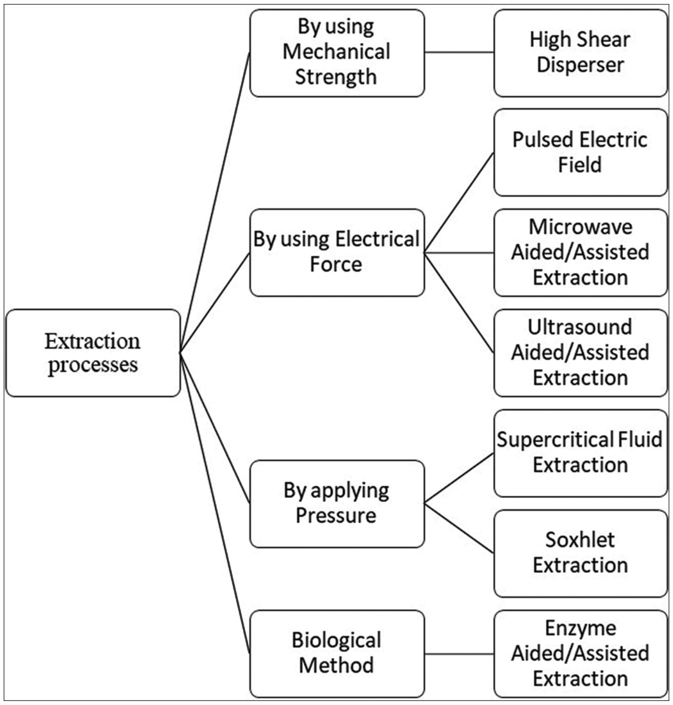


Figure 2: Various extraction processes of carotenoids.

resulting in the falling apart of the internals, due to reaching high temperature (4500°C) and pressure (50 MPa) [54]. In this method, ultrasonic probe is submerged in the solution and generates ultrasonic power at least 100 times greater than that of the bath, with a typical sonication time of 5 min or less. In the study of Goula *et al.*, [55] a Ti-Al-V sonoprobe (13 mm) equipped 130 W maximum nominal output power, 20 kHz frequency VCX-130 Sonics and Materials (Danbury, CT, USA) sonicator was employed for pulsed mode ultrasound-assisted extraction for extracting carotenoids from pomegranate waste. The sample was combined with 200 mL solvent to obtain different peels/solvent ratios. The sample container was kept in a thermostat-controlled water bath during the extraction procedure. The extracts were collected at 10, 20, 30, 40, 50, and 60 min and filtered through glass microfiber paper to eliminate particle residues before to carotenoids analysis. As this technique is performed in low temperature, thermal damages can be avoided [55].

5.4. Super Critical Fluid Extraction of Carotenoids

Supercritical fluids are either liquid or gas used above critical pressure and temperature where gas and liquid can coexist. For this nature, gas and liquid phase become indissociable form each other. In this method, mostly pressurized fluid is used as solvent and carbon dioxide gas is being used. It becomes advantageous for its greater range of extraction ability [56]. Total carotenoids were extracted by super fluid extraction (SFE) utilizing S-CO_2 at 15 g/min and optimized processing settings were 30 min at 59°C, 350 bar, and 15.5% (v/v) ethanol [57].

5.5. Enzyme-Aided Extraction

Enzymes act as catalysts in the process of extracting bioactive compounds. The raw material is treated with enzymes, allows it to hydrolyze the cell wall and the phytochemicals will come out along with carbohydrate chains and lipid molecules. Drawback of this process is factors affecting the extractions such as type, dosage, and condition of enzyme particle size of sample materials and its water content among other factors. Some of its advantages compared to previous methods are high yield and low-energy consumption. Some of the enzymes used in this method are proteases, tannases, pectinases, and cellulose [50].

5.6. High-Shear Dispersant Extraction

In this technique, cell wall and membrane of source is disrupted by mechanical pressure, using high-shear dispersant, releasing the compound present within the cells. To effectively and selectively extract water-soluble proteins, carbohydrates, and C-phycocyanin, the use of a mechanical pre-treatment like high-shear homogenization (HSH - 20,000 rpm, 96 kJ/kgSUSP) in combination with (PEFs - 20 kV/cm, 100 kJ/kgSUSP) has been advocated [58]. This process is less time consuming than many other traditional techniques. Vegetable oils are used as an organic solvent in this process, which reduces the energy consumption as well as environment friendly. It also avails the possibility to obtain uncontaminated carotenoids, directly usable without any need of purification. A disadvantage of using vegetable oil is its viscosity, elevated viscosity reduces solvent diffusivity [55,59].

5.7. PEF-Assisted Extraction

PEF-assisted techniques are based on the electroporation, or electropermeabilization, phenomenon, which depicts the development of pores in cell membranes as a result of electric pulses with short durations (from several nanoseconds to several milliseconds) and high electric field strengths (from 100–300 V/cm up to 300 kV/cm) [60]. Using electric fields for extraction processes can decrease the necessary temperature and increase the overall yield. This is extremely important for thermolabile compounds like carotenoids. The cellular components must be exposed to a strong electric field (external) in range of 1–50 kV/cm for a brief period during the extraction process. The cell membrane barrier allows for the electrical potential to divide molecules depending on its charge. The formation of pores is a result of this electro-permeabilization technique, which may or may not be reversible, in the cell membrane or wall, allowing the components of the cells to come out. Low-energy consumption and processing cost along with high efficiency and low temperature are some of the advantages of this process. The absence of any petrochemical solvent makes this technique environment friendly. Without damaging the matrix, the technique enhances the selective separation of biologically active components. However, the technique must be adjusted differently for different types of samples, as the parameters for a process depend on the texture and electrical conductivity of the sample [61-64].

6. EXTRACTION OF CAROTENOIDS FROM VARIOUS SOURCES

Industrialization and progressive globalization has increased the demand for production of more food. Along with the lack of infrastructure and management for this huge quantity of food contributed to a huge loss and wastage of food and its by-products. As reported by food loss index of 2016, in between harvest and distribution, about 13.8% of food is being wasted worldwide. In 2020, this decreases very little making it 13.3% (FAO, 2023). Most of these loses are in fruits and vegetables due to their short shelf life and high expenses of storage. In addition, processing the gathered fruits and vegetables generates a sizable number of by-products in the form of pieces that are not edible, including peels, cores and pomace as well as damaged, rotten, and unripe ones. However, these waste products are rich in bioactive compounds and nutraceuticals as plants hold them in both their edible and nonedible segments of veggies and fruits. In case of carotenoids, they are stored more in non-consumable sections of edible fruits and veggies, like skin, as they give them their bright red/orange colors. Some examples include tomato, carrot, oranges, and grape, and these parts are often discarded producing a huge amount of food waste, for example, juice production facilities produce 5.5 million metric tons of by-products [65]. The following article presents extraction process of carotenoids from various types of food wastes.

6.1. Extraction from Tomato Waste

Tomato (*Lycopersicon esculentum*) one of the most important components in Mediterranean diet making it the second most important vegetable worldwide. Approximately 80 million tons of waste is generated from over 130 million tons of production worldwide. After industrial processing, the remaining tomato pomace including peels and seeds are mostly used as animal feed. However, these wastes contain a plethora of bioactive compounds, including phenolic components, vitamins, and carotenoids. Of all the pigments, lycopene [Table 1] makes up about 80–90%. Consumption of lycopene shows various health benefits including cardiovascular and anticancer activities, supported by various epidemiological studies [66,67].

The rudimentary carotenoids present in tomato are lycopene and β-carotene, where lycopene is present mostly in the peels and the seeds contain β-carotene. For being beneficial to human health, the demand of low cost available and high purity carotenoids is increasing. The extraction of lycopene from tomatoes is commonly done using traditional methods that involve the application of a range of organic solvents and their combinations in established protocols. One of the most efficient ways to obtain lycopene is by utilizing the peels of tomato generated by juice production industries.

Using enzymes to aid in extraction is often viewed as a pre-treatment step rather than a standalone method of extraction. This technique breaks down the polysaccharide chains of the tomato cell wall in which the majority of pigments are located. This helps the solvents to penetrate and improve the release of carotenoids and reduce extraction time and temperature [68]. Using cellulolytic and hemicellulolytic enzymes as a pre-treatment method for tomato peels is an effective method for recovering carotenoids [69]. In an experiment of Catalkaya and Kahveci, the study demonstrated that the polar nature of the solvent used is a significant factor in the process of extraction (e.g., 1:2 acetone-chloroform, 50:25:25 hexane-acetone-ethanol [70].

It is one of the safest techniques where carbon dioxide is used as super critical solvent among many, for being environmentally safe, non-toxic, and easily available. In an experiment performed by Kehili *et al*., the extraction yield for lycopene and β-carotene was up from 32.02% to 60.85%, and 28.38% to 58.8%, respectively. The raw material used here was Tunisian industrial tomato peels [71]. Latest research has shown that usage of additional cosolvent can increase the carotenoids solubility. de Andrade Lima and the team used ethanol as a cosolvent in SFE method, that increases the polarity of CO_2 which ultimately increases the recovery rate of more than 90% of carotenoid. Lycopene recovery was also efficient (almost 95%) due to the high content of moisture found in peels of tomato [57].

The electrical and/or heat treatment's induction of cell disintegration at the cuticular level enhances the solvent's entry into the cytoplasm, amplifying the carotenoids' ability to be extracted. Degradation is made possible by PEF extraction technology, which also cuts down on time, energy costs, and solvent usage. An investigation was conducted to determine the relationship between the breakdown index of cells present in tomato peel tissues and different electric field strengths as well as temperatures used in steam blanching (SB). The result of steam blanch treatment 60°C applied with PEF treatment with an intensity more than 0.75 kV/cm shows a much higher yield of extraction of total carotenoids (PEF-188% and steam blanching-189%) and power of antioxidant (PEF-372% and steam blanching- 305%) when compared to untreated peels of tomato (Pataro *et al*., 2018). In case of solid liquid extraction, pretreatment with PEF (5 kV/cm, 5 kJ/kg) increases the extraction yield of lycopene to 12-18% and total extraction rate to 27–38%, in acetone or ethyl lactate solvent [72].

Application of UAE method on tomato pomace for lycopene extraction using ethyl lactate and ethyl acetate mixture as solvent along with optimized extraction conditions (30% v/v ethyl acetate in solvent mixture, 63.4°C, 100 mL/g solvent to sample ratio, 20 min) yielded higher (1334.8 ± 83.9 μg/g) at shorter time and lower temperature. Compared to this, the yield without UAE was 9% lower [73]. Combined treatment of UAE and freeze drying increases the yield by 4.12 folds from industrial tomato waste of lycopene extraction [74]. Hydrophobic eutectic mixtures of DL-methanol (hydrogen-bond acceptor) and lactic acid (hydrogen-bond donor) in the UAE yielded as high as 1.45 g of lycopene/Kg dry weight of tomato pomace. The yield is reportedly higher than the traditional organic solvent mixture of ethyl acetate and ethyl lactate for the same raw material [75,76].

6.2. Extraction from Carrot Waste

Carrots are a kind of tuber or root vegetables, present in various colors, including, purple, red, orange, yellow, and white [77]. Carrots are considered the most abundant source of β-carotene [Table 1] [78]. Carrot waste is abundant in carotenoids, particularly β-carotene. Researchers have shown that the peel of carrots contains a higher concentration of β-carotene (204.5 mg/g) as compared to carrot pomace waste (19.81 mg/g) and carrot pulp waste (39.2 mg/g) [79,80]. β-carotene is the rudimentary carotenoid present in carrot. Selective SE techniques are used to extract both polar and non-polar carotenoids using various mixtures of organic solvents [81]. Other green extraction processes such as MAE, ultrasound extraction, and super critical CO_2 assisted extraction methods are also can be used. Water-induced hydrocolloidal complexation method was used to co-extract β-carotene and pectin from carrot peels where complexation of these two bioactive components under different operating stirring conditions yielded in 1.17 mg of β-carotene in 100 g wet sample [82].

Carrot juice processing waste was frozen at –40°C and then freeze dried to reduce moisture content to <1%. A definite amount of waste powder was mixed in flaxseed oil, used as solvent. The mixture was placed in an extraction vessel and it was put in a microwave extraction device. The temperature and time can be set in different variation to obtain maximum yield but should not exceed 110°C. A closed microwave system is used to carry out the process. After extraction process, the flaxseed oil, enriched with carotenoids, was stored at –20°C in a dark or black glass bottle. The highest recovery yield was achieved at 170 W microwave power, 9.46 min of extraction time with oil to waste ratio as 8:1. The recovery percentage was 77.91 ± 0.33 [83]. The quantification of extracted β- carotene was done by high-performance liquid chromatography (HPLC) using methanol/acetonitrile (9:1) with 9 μM triethylamine mixture as mobile phase at 0.9 mL/min flowrate, 450 nm wavelength [83]. Changes in carrot tissue caused by sonication impacted total carotenoid content and color change [84]. Carrot pomace was used as a raw material, while the UAE was carried out for

16 min of sonication at 29°C under 59% v/v concentration of ethanol yielded 14.37 μg/g of β-carotene, 5.35 μg/g of lutein, and 2.5 μg/g of lycopene [23].

The aim of this process was to assess and improve the method for extracting carotenoids from peels of carrots using supercritical CO_2 (SCO_2) in combination with a cosolvent like ethanol. The factors that were assessed included temperature and pressure and the concentration of a cosolvent [23]. Carrot peels were used as sample, which were dried and mixed 5 g of it with 95 g inert glass beads for homogenization. The mixture was put in an extraction vessel and CO_2 flow was applied at a rate of 15 g/min with ethanol as a cosolvent. The extraction time was 80 min. After every run, the collected carotenoids, dissolved into ethanol, were evaporated using a rotavapor to remove the ethanol and the collection was weighed and redissolved in methanol for total carotenoid concentration analysis [85]. According to a validated model, the best conditions for achieving the highest mass yield (5.31%, d.b.) were determined to be 58.5°C, 306 bar, and 14.3% ethanol. In addition, the most efficient conditions for carotenoid recovery (86.1%) were identified as 59.0°C, 349 bar, and 15.5% ethanol [85].

The results of this study indicate that using PEF technology can effectively enhance the carotenoid resistance of natural food ingredients, such as carrot pomace. The use of electroporation in PEF treatment has the potential to enhance the ability to extract carotenoids from carrot pomace. Roohinejad *et al.* [79] have optimized β-carotene extraction through microemulsion (made of medium chain triglycerides, phosphate buffer, and tween 80) using Box–Behnken experimental design. The optimal conditions at 49.4 min of extraction time under temperature of 52.2°C having carrot to microemulsion ratio as 1:70 (w/w) yielded 19.6 μg/g of β-carotene in the microemulsion. Based on the given conditions, it was predicted that the β-carotene content would have a response value of 19.6 μg/g [79,86].

6.3. Extraction from Mango Waste

Mango (*Mangifera indica* L.) is cultivated in sub-tropical and tropical regions, which belongs to *Anacardiaceae* family. It is produced in more than ninety countries [87-89]. Mangoes contain a diverse array of bioactive compounds, such as phenolic compounds and carotenoids [Table 1], that can be found in ripe mangoes [90,91]. Depending on cultivars and weight of pulp can vary from 33 to 85%, skin 7-24%, and seeds 9–40% (w/w). Therefore, the processing of mangoes generates 35-60% (w/w) agro-industrial waste [92,93]. Peeling and recovery of skins and seeds, respectively, as rich source of bioactive compounds can not only aid in managing waste but also yield substances that can be utilized in various industries, such as food and beverages, pharmaceutical, and cosmetic products [94]. Peel and seed are the main by-product of mango fruit. Ripen mango skin contains various kind of carotenoids including α and β-carotene. Green extraction process such as MAE and supercritical CO_2 ($SrCO_2$) extraction is used to extract the bioactive compounds present in the mango waste. Mango peels were freeze dried at –35°C for 48 h under 4.0 Pa pressure or air dried (50°C, 24 h), size reduced and extracted using $SrCO_2$ (operated at 40°C temperature, 30 MPa pressure, and 1.1 L/min CO_2 flow rate). The process yielded total carotenoid of 5.6 ± 0.51 mg β-carotene/g dry basis of mango peel [95,96]. High pressurized ethanol can be used as a co-solvent [97] or the residue of $SrCO_2$ extraction can be treated with it under the same conditions [96]. The output of extracted carotenoid is affected by the duration of extraction, the temperature, the pressure, and the concentration of the cosolvent. The amount of carotenoids can be determined through methods such as UV-visible spectrophotometry and ultra-performance liquid chromatography having diode array detector [97]. Application of polar solvent such as ethanol in $SrCO_2$ extraction increases the extraction yield due to the presence of polar components in sample [98]. Segatto *et al.* [99] extracted secondary metabolites, namely, hyperoside (flavonol) and mangiferin (xanthone) under MAE system and matrix solid-phase dispersion (MSPD) technique from mango processing waste (MPW). They revealed higher extraction yield of hyperoside (398.52 mg/Kg of dried MPW) and mangiferin (352.90 mg/Kg of dried MPW) using MSPD technique as compared to MAE system [100].

6.4. Extraction from Orange Waste

Orange has various biochemical compounds loaded with secondary metabolites including amino acids, proteins, carbohydrates, phenolic compounds, flavonoids, and carotenoids [101]. Carotenoid is one of the main natural pigment presents in orange give it its orange color. A variety of carotenoids are present in orange including mutatoxanthin, β-cryptoxanthin, violaxanthin, zeaxanthin, and antheraxanthin. The main compound in orange juice is α- and β-carotene measuring almost 1.5 μg/mL [102]. Of the oranges grown worldwide, four out of ten are used to manufacture concentrated juice. While extracting the juice, it produces by-products including peels core and frit. The pulp is also produced as by-product during filtration of extracted juice. These by-products contain a variety of carotenoids which can be extracted using green extraction methods [101]. After extraction of juice, the by-products can be treated for carotenoid extraction. Orange peel is the most favorite sample for these extraction process probably due to less moisture content in it. Traditional green SE techniques can be used to extract carotenoids from orange as well as green extraction techniques such as ultrasound-assisted extraction can be used.

Carotenoids are extracted from homogenized orange peels by SE technique. In this process, various organic solvents, such as acetone, hexane, petroleum ether, and KOH, is used to extract the carotenoids from the peels. Final separation of carotenoids from solvent is done using separating funnel and diethyl ether and distilled water for washing, where the upper lipophilic phase contains carotenoids. Rota vapor and nitrogen was used to concentrate the final extract [103]. Orange peels were dried to reduce moisture content and then grounded using electric mill. An ultrasound-assisted extraction method was utilized by combining powdered orange peel with various solvents, including olive oil and different types of ionic liquids including olive oil [104] and different types of ionic liquid such as 1-n-butyl-3-methylimidazolium tetrafluoroborate, 1-hexyl-3-methylimidazolium chloride, and 1-butyl-3- methylimidazolium chloride [105] and 1-butyl-3- methylimidazolium hexafluorophosphate [106]. In case of ionic liquids, ethanol is used as a cosolvent. The utilization of frequency and power of ultrasonication can vary depending on the specific experiment, as well as factors such as time required for extraction, temperature, and the ratio of liquid to solid. Utilizing a 4000 rpm speed on the centrifuge, the plant material was divided through spinning for a quarter of an hour [104,105]. The analysis of extracted carotenoid can be done using HPLC with DAD detector [104,107].

6.5. Extraction of from Shrimp Waste

Shrimp, a highly sought-after seafood item, is prepared for consumption by removing the shell, head, and tail, which are typically considered as unusable parts. These were part measures almost 60% of shrimp's body weight [108,109]. The waste parts are good source of proteins, lipids, chitins, and carotenoids, having potential industrial uses [110,111]. In terms of carotenoid representation within raw shrimp, astaxanthin and β-carotene dominated with astaxanthin contributing 75.18–

88.86% of the total carotenoid content [112]. Astaxanthin having high antioxidant activity and anti-diabetic, neuroprotective, and anti-inflammatory activity [113-116] and the current pollution issues faced by the sea food industries for dumping the waste generate a demand for utilization of shrimps wastes to produce astaxanthin [117]. The main carotenoid content of shrimp waste is astaxanthin and there is very little information available on its extraction process. Powdered sample of shrimp waste is mixed with different solvents (acetone and methanol) with different ratio and put in a high-pressure container and different pressure (210 MPa) and holding time (10 min) is applied. The research team then used a centrifuge to separate the sample and collected the liquid layer on top. Mixture of distilled water and hexene (1:1 v/v) was added to it and the resulting upper layer was collected and dried using oxygen free nitrogen [118].

Total carotenoid content was determined using spectrophotometer and the yield of astaxanthin was measured using HPLC [118,119]. Utilizing commercial, crude and unconstructed enzymes for the purpose of enzymatic hydrolysis are a technique that has been investigated for the extraction of astaxanthin from shrimp. A combination of proteolytic enzymes (barbel and bovine trypsin) and ethylenediamine tetraacetic acid EDTA (0.5 M) is used on Dried Shrimp shell powder to obtain the dry matter "carotenoprotein." This carotenoprotein underwent treatment with lipase and protease for hydrolysis, resulting in the production of 900 mg/g of soluble protein and 66 mg/g of total carotenoids through the use of 10 lipolytic and 15 proteolytic units [120,121].

The enzyme alcalase can also be used for recovering carotenoids although suitable range of pH is needed for proper activity of this enzyme. The range of recovery was 57.5–64.6% measuring 4.7–5.7 mg/100 g of dry waste [113]. Cabanillas-Bojórquez *et al.* [122] used super critical CO_2 and ethanol to extract astaxanthin from dried exoskeleton of shrimp. After extraction, the supernatant was collected form the extract through centrifugation, dried, and resuspended into ethyl acetate for astaxanthin concentration analysis using HPLC.

6.6. Extraction from Pumpkin Waste

Pumpkin is a good source of bioactive compound which includes more than 800 varieties of its species [123]. Pumpkin pulp is considered a good source of carotenoids. Major carotenoids present in pumpkin is β-carotene, as well as little amount of lutein, lycopene, and α-carotenes are present also [124]. In spite of having the potential to use pumpkin waste as an alternative for carotenoid production, most of the waste of pumpkin is used as landfill material or converted into biofertilizer. It is also used for animal feeding [125]. To extract bioactive compounds from vegetables, green extraction technologies using vegetable oil as a solvent or cosolvent were studied before. These techniques are environment friendly and do not require any use of harmful chemicals. To harvest carotenoids from pumpkin waste, it is suggested to use freeze dried sample. Using methods such as ultrasound-aided extraction and microwave-aided extraction can be implemented to implement green extraction techniques.

In their experiment, M. Sharma and Bhat extracted carotenoids from pumpkin peels and pulp, using corn oil as a green solvent and ultrasonication technique. The final extract was separated from the oil through centrifugation. The total carotenoid content was determined by spectrophotometer at 470 nm [126]. In the same experiment, they used MAE technique to extract carotenoids from pumpkin waste using same solvent and MAE extractor (130W, 30 min, 45°C). After extraction process, the cooled extract were separated from the oil through centrifugation [126]. The total carotenoid content was determined by and the antioxidant capacity of extracted carotenoid was estimated by 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) assay. Ghosh, Biswas [127] used pumpkin peels and pumpkin industrial waste in their experiment to extract carotenoids, such as lycopene, using enzymes such as cellulase and pectinase. The hand blended pumpkin wastes are treated with these two enzymes separately to extract carotenoids and the extracts are filtrated and undergone SE using acetone and petroleum ether. Effects of pectinase were shown better than cellulase in case where the raw material was fruit pulp waste. Same conclusion can be drawn in case of whole carotenoid extraction and lycopene extraction from pumpkin pulp. However, pectinase showed better yield in case where industrial pumpkin waste, such as peels, were used as raw material [127].

6.7. Extraction from Passion Fruit Waste

Passion fruit waste refers to the parts of the passion fruit that is not typically consumed, such as the peel and seeds. The waste created by juice processing industries weigh almost 60% of the whole fruit gets discarded [128]. These waste parts may contain valuable nutrients such as carotenoids, vitamins, and minerals. Passion fruit waste parts contain carotenoids such as beta-carotene and lutein. These carotenoids have antioxidant properties and may have health benefits such as promoting eye health and reducing the risk of certain diseases [12]. Passion fruit waste can be used for various purposes such as animal feed, composting, and extraction of bioactive compounds. The extraction of biologically active compounds from these types of waste materials has the potential to provide significant industrial benefits.

Conventional extraction process using petrochemical solvents is useful for extraction of carotenoid from plant based materials but they comes with issues such as generates harmful chemical compounds, having low extraction rates and long extraction time [129]. Therefore, methods of green extraction such as ultrasound-assisted and microwave-assisted extraction using bio-based solvents like vegetable oils are gaining popularity due to its low to zero chances of environmental harming by products production, low extraction time, and high efficiency and low-energy costs [130,131].

In their experiment, Chutia and Mahanta used UAE technique and MAE technique to extract carotenoids from freeze dried passion fruit peels. In both techniques, olive oil and sunflower oil were taken as solvent and in case of UAE method; the mixture of solvent and passion fruit peels were ultrasonicated using a probe and in case of MAE method microwave system was used for extraction process. Further, filtration was done using glass microfiber paper [18]. The total antioxidant activity of extracted carotenoid was measured using DPPH free radical scavenging activity.

Passion fruit peel powder was mixed with a solvent containing mixture of n-hexane, ethanol, ethyl acetate, and acetone (2:1:1:1) in volumetric ratio. The mixture was put into extraction thimble and extraction was done inside Soxhlet apparatus. After the end of extraction process, the solvents were evaporated using vacuum evaporator to separate the extracted carotenoids [83]. To quantify the amount of carotenoids and βcarotene, a dilution of carotenoids extract in n-hexane was performed for the investigation [18].

6.8. Extraction from Guava Waste

Guava fruit contains several carotenoids, including lycopene, beta-carotene, and lutein. These compounds are responsible for the red or yellow color of the fruit and have been found to have antioxidant properties [132]. Guava is used in food industry for production of juice, syrup, jelly, and flavored food. It is a popular tropical fruit. However, during various stages of industrial productions, it produces wastes containing seeds, peel, and leftover pulp, making almost 30% of the fruit weight [133]. This waste can create environmental problems. However, the amount of carotenoids left in the waste parts of guava holds industrial value if extracted properly [132]. The extraction of carotenoids from guava waste products can be done through maceration but is not accepted well due to its labor intense process, high extraction time, and use of excessive solvents. Hence, alternative non-conventional green extraction techniques, such as UAE, are now being interested due to their high extraction yield, low extraction time, and processing labor and most importantly by production of less to none toxic chemicals [134,135]. da Silva Lima *et al.* [136] used different UAE techniques to extract carotenoids, mostly lycopene and β-carotene from dried guava pulp, peel, and left-over waste. Three different methods, maceration extraction, bath type and probe type UAE, were used for comparison purpose to understand the best possible method for extraction while ethyl acetate was being used as a solvent. Lycopene was found to be the major carotenoid present in the extract. Ultrasonic bath type extraction method was found to be most effective with high yield, where probe type extraction method showed the most degradation of carotenoids. Maceration extraction process was also found to be efficient for extraction but did not get entertained due to its high usage of organic solvent making it impractical for large scale commercial use [136].

6.9. Extraction from Pomegranate Waste

Pomegranate fruit contains various carotenoids, including lycopene, β-carotene, and lutein. Research has demonstrated that certain carotenoids possess antioxidant properties and may offer potential health advantages, such as a decreased likelihood of heart disease, cancer, and diabetes. In addition, pomegranate fruit also contain high amounts of punicalagins and punicic acid, which are unique antioxidants found in pomegranate and are responsible for many of its health benefits. As the yield of extracted juice from pomegranate is less than half of its weight, it produces a lot of waste by-products. Pomegranate waste, such as the peels and seeds, also contain various carotenoids, including lycopene, beta-carotene, and lutein. Although previously pomegranate peels are mostly applied as animal feed with recent advance in studies, the industrial value of it came to known for carotenoid production [137,138]. There has not much studies been published regarding the extraction of carotenoids from pomegranate. Instead of using traditional method, green SEs such as use of vegetable oils as solvents are now being considered as alternatives.

Goula *et al.* [55] used vegetable oil as an alternative solvent to extract carotenoids from pomegranate peels by applying ultrasound-assisted techniques. They used both bath type and probe type ultrasonication device and sunflower and soy oil for extraction and the extracts were filtered using glass microfiber. In this process, they managed to extract almost 85.7 and 93.8% of total carotenoid present in the peel waste. Moreover, with increase in temperature (20–40°C), the extraction yield was also increased [55].

7. FUTURE SCOPE AND PROSPECT

Carotenoids are a class of naturally occurring pigments that are widely distributed in the plant kingdom, and are responsible for the bright red, orange, and yellow colors of fruits and vegetables. These pigments are not only important for the esthetic appeal of fruits and vegetables but they also have important health benefits, such as acting as antioxidants and protecting against cancer and heart disease. To create carotene radicals with various characteristics, carotenoids can also squelch other free radicals. These antioxidant effects include reducing the oxidation of lipids during digestion in the gastrointestinal lumen, blocking the oxidation of lipids in brain cells, preventing the oxidation of polyunsaturated lipids in the retina, and preventing the oxidation of low-density lipoprotein particles. One of the most promising areas for the extraction of carotenoids from food waste materials is in the field of food processing. Food processing industries generate large amounts of waste, such as peels, cores, and pulp from fruits and vegetables, which can be a rich source of carotenoids. For example, orange peels are known to contain high levels of beta-carotene, a precursor of Vitamin A, which is essential for eye health. Similarly, tomato skins and pulp are rich in lycopene, which is known to protect against cancer.

Another area where carotenoid extraction from food waste materials has great potential is in the field of biotechnology. There is a growing interest in developing micro-organisms that can produce carotenoids as a mean of producing natural food colorants. Micro-organisms such as yeasts, fungi, and algae are known to produce carotenoids and research is currently underway to optimize the conditions for carotenoid production by these organisms.

In addition to food processing and biotechnology, carotenoid extraction from food waste materials also has great potential in the field of agriculture. Many farmers use chemical pesticides to protect their crops from pests and diseases, but these pesticides can have negative effects on human health and the environment. Carotenoids have been shown to have natural insecticidal and fungicidal properties, and thus, their extraction from food waste materials can be used as a natural alternative to chemical pesticides [139]. Furthermore, carotenoids extraction from food waste materials can also be used to produce animal feed. Many species of fish and poultry require carotenoids in their diet to maintain good health, and carotenoids are also used as natural colorants to enhance the appearance of fish and poultry products [140].

8. CONCLUSIONS

The extraction of carotenoids from food waste materials using green extraction processes is a promising field with many potential benefits. Green extraction methods, such as using solvents that are less toxic and more environmentally friendly, can help to minimize the environmental impact of carotenoid extraction. In addition, the use of food waste materials as a source of carotenoids can help to reduce waste and minimize the environmental impact of food production. The extraction of carotenoids from food waste materials not only has the potential to provide a source of natural colorants and health-promoting compounds but it also has the potential to reduce end product of food waste and minimize the environmental impact of food production. However, all the work in this area are still in research stages and to utilize the proper value of these waste by-products the systems need to be industrialized at a larger scale. That will increase the production and decrease the cost of the end product, making it available and affordable to byers. With further research and development, the extraction of carotenoids from food waste materials using green extraction processes may become a viable and sustainable industry in the future. Moreover, the use of food waste in the production of carotenoids can also help to promote sustainable agriculture by reducing the need for chemical pesticides, and providing a natural alternative for animal feed. This way, the green extraction of carotenoids from food waste can help to create a more sustainable and environmentally friendly food production system. The green extraction of carotenoids from food waste materials is an area that has a lot of potential for future development. Using environmentally friendly extraction methods and utilizing food waste as a source of carotenoids, we can create a more sustainable and environmentally friendly food production system.

9. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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11. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

12. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

13. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

14. PUBLISHER'S NOTE

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15. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declares that they have not used artificial intelligence (AI)-tools for writing and editing of the manuscript, and no images were manipulated using AI.

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