International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2023; 7(1): 105-117
www.biochemjournal.com
Received: 11-01-2023
Accepted: 21-03-2023

Monika Chaudhary
Shobhit Institute of Engineering and Technology NAAC A Grade Deemed-to-be University, NH-58, Modipuram, Meerut, Uttar Pradesh, India

Amar P Garg
Shobhit Institute of Engineering and Technology NAAC A Grade Deemed-to-be University, NH-58, Modipuram, Meerut, Uttar Pradesh, India

Corresponding Author:
Amar P Garg
Shobhit Institute of Engineering and Technology NAAC A Grade Deemed-to-be University, NH-58, Modipuram, Meerut, Uttar Pradesh, India

Bioactive compounds from plants and animals: A review

Monika Chaudhary and Amar P Garg

DOI: https://doi.org/10.33545/26174693.2023.v7.i1b.175

Abstract
Secondary metabolites that have been isolated from plants, fungi, bacteria, or mammals are referred to as bioactive chemicals. Besides being important due to their pharmacological or toxicological effects on organisms, which have led to their use in the food and pharmaceutical industries, the discovery of novel properties of such compounds has resulted in an expansion of their uses, ranging from beauty products and modified biological materials to bioremediation and alternative fuels. Due to its significance in mitigating a range of chronic diseases, bioactive chemicals such as polyphenols, carotenoids, vitamins, omega-3 fatty acids, organic acids, nucleosides and nucleotides, and phytosterols have been receiving a lot of interest. As a result, there are numerous applications of bioactive compounds such as in energy sector, pharmaceutical sector, food sector and so on. This review will provide information about the different type of bioactive compounds, their sources, extraction method and their application.

Keywords: Bioactive, omega-3 fatty acid, phenols

Introduction
There is a growing interest in bioactive compounds for a wide range of uses: Geo-medicine, plant science, contemporary pharmacology, agrochemicals, cosmetics, the food industry, nano- bioscience, and other related fields There have been a rising number of research initiatives focused at boosting the resources accessible to bioactive chemicals and improving the salvage routes or synthesis of those compounds as a result of this very promising field, which is now in full growth.

Even though there has been a lot of research done in a variety of areas, the term "bioactive compounds" is still hard to define. It is difficult to generalize these definitions since the term "bioactive" is only used in a small number of references, generally in a single, concise paragraph that stays inside the confines of the scientific community.

Bio- and -active are two words that make up the word "Bioactive." Bio- is derived from the Greek word "Bios" (o-), which means "life," according to etymology and the prefix "active," which comes from the Latin "actives," denotes something that is dynamic, energetic, or includes an action. This activity displays every phenomenon that gives rise to a type of life, a working system, or a process.

Bioactive chemicals are extra nutritional substances that are biologically active and occur naturally. A wide range of food & food items of plant, animal, and aquatic sources include bioactive compounds in trace concentrations. Due to the bioactive chemicals they contain, these meals may provide benefits beyond providing the necessary nutrients. Many chemicals have positive effects on health because of their ability to regulate and control one or more important metabolic processes and activities. These physiologically active substances are typically generated by microbes and plants as secondary metabolites (Kitts 1994, Kris-Etherton *et al*. 2002, Galanakis 2017) [57, 58, 37].

Compounds such bioactive peptides, phytosterols, vitamins, fibre, fatty acids, free radical scavengers, gene expression inhibition or stimulation, receptor activity, and enzymes can regulate a variety of metabolic processes in the human body. Numerous food companies and start-ups focused on the food industry are progressively using these components to suit the growing customer demand for natural, nutrient-dense, and affordable goods. Regular and affordable sources, for example, food industry squander, unpalatable bits of food like seeds, strips, fish head, and so forth (Bansal, *et al*., 2023) [12].

These substances are being isolated from secondary metabolites (microorganisms, plants, and animals) and aquaculture by-products. Such exploitation is advantageous to both the economy and the environment. These bioactive substances should be assessed for their bio-accessibility (release of the compounds from the food system into the digestive tract), bioavailability (amount in the bloodstream following metabolism and absorption), and bioactivity (neurobiological response of the human to their initial response with other compounds) before being used in food applications.

Bioactive compounds could be encapsulated to control their release, stabilize their bioactivities, and make them more bioavailable. Numerous synthetic or artificial supplements and additives could be replaced with these elements. However, in order to utilize these compounds to their full potential, extensive study and laboratory research are required.

Bioactive compounds can be classified in many ways but the most important classification is based on source, as it is the best way to determine the usage of certain kind of bioactive compound.

Due to rising customer demand, the food industry must continue to place more emphasis on the health-promoting qualities of food and food ingredients than only their safety. The addition of natural bioactive components in processed food items is becoming increasingly important to the food industry given the current situation. Additionally, it will help shift consumer perceptions that minimally processed or unprocessed foods are healthier than their processed counterparts. Therefore, a growing number of enterprises participate in the extraction of naturally occurring bioactive chemicals so that these substances may be used as food additives, where they will improve both the processing technology and the health of consumers (Day *et al*. 2009; Shahidi 2009, Galanakis *et al.* 2013) [26, 91, 38].

Types of bioactive compounds found in plants

Among the bioactive substances that are largely present in fruits and vegetables are glucosinolates, anthocyanins, tannins, betalains, carotenoids, and plant sterols (Table 1). In addition to providing a variety of nutrients, many fruits and vegetables also include a number of bioactive substances, including phytochemical (phenolics, flavonoids, and carotenoids), which may have specific physiological and cellular effects.

Table 1: Types and sources of bioactive compounds in common plants

Compound	Source	References
Phenolic acid	Caffeic acid (Fruits, artichoke), Ferulic acid (Cereals), Protocatechuic acid (Raspberry)	Zhao *et al*., 2015 [110]
Coumarins	Cinnamon bark oil, Cassia leaf oil,Green tea	Jain and Joshi, 2012 [51]
Flavonoids	Onion, Broccolis, Berries	Shahidi and Naczk 2003 [92]
Betalains	Beetroot	Aanchal Walia., *et al*, 2019 [1]
Anthocyanins	Berries, Pomegranate	Shahidi and Naczk, 2004 [94]
Quinones	Aleo-vera	Martı´nez andBermejo Benito, 2005 [68]
Tannins	Chocolate, Cinnamon bark	Gruenwald *et al*., 2010 [42]
Alkaloids	Coffee	Wink *et al*., 1998 [107]
Carotenoids/terpenes	Tomato, Mango	Dewick 2001 [27]

Flavonoids

Flavonoids, the largest and most diverse class of bioactive compounds known as phytochemicals or phytonutrients, make up the majority of polyphenols and are divided into flavanols, flavones, isoflavones, flavanones, anthocyanidins, flavanonols, and flavans (Catechins and proanthocyanidins). Each subgroup of flavonoids has a unique plant source, functions, and health advantages (Table 2). This group of plant bioactive substances is recognised to be advantageous to human health because of its recognised antioxidant and anti-inflammatory actions. Flavonoids, together with carotenoids, are the pigments that give every fruit and vegetable its particular colour. The human diet benefits from the approximately 6,000 different forms of flavonoids that have been found (Ververidis, 2007, Kris-Etherton *et al.*, 2004) [104, 59].

Table 2: Sources and health benefits of Flavonoids

Chemical Structure	Sources	Health benefits	Reference
Flavonoids often develop in cell vacuoles and are water soluble. Their basic chemical structure is two benzene rings connected by a three-carbon chain to form a closed pyranring.	Many different fruits and vegetables are rich in flavonoids. Berries, leeks, ginger, grapefruit, carrots, apples, onions, cabbage, kale, tomatoes, parsley, buckwheat, and legumes are some of its main food sources. Additionally rich in flavonoids, which are beneficial to your health, are red wine, coffee, tea, chocolate, various spices, herbs, and other foods.	A diet high in phytonutrients has been shown in numerous studies to be beneficial to human health. Flavonoids, which function as potent antioxidants, are advantageous in this regard. They also prevent free radicals from harming cells and other biological parts. They also have anti-inflammatory and anti-aging effects. They can also influence the function of certain enzymes and cell receptors. According to research, flavonoids may also assist in controlling cerebral blood flow, which may enhance cognitive performance.	Lotito *et al.*, 2006 [66] Izzi Valerio., *et al.*, 2012 [50]

Anthocyanins: These compounds are soluble in water and can be found in cell sap (Table 3). They are accountable for the red, purple, and blue hues of flowers, fruits, and vegetables.

Table 3: Sources and health benefits of Anthocyanins

Chemical Structure	Source	Health benefits	References
Fundamentally, an anthocyanin is a phenolic particle with 15 carbon molecules and seen as two benzene rings consolidated with a three-carbon chain. It is extremely reactive due to the flavylium nucleus' presence.	Despite being present in a wide range of plants, anthocyanins are most prevalent in the following: acai, blackcurrant, blueberry, bilberry, cherry, red grape and purple maize.	Anthocyanins are powerful antioxidants *in vitro*, but due to limited absorption and low stability, their biological activity is often minimal. Anthocyanins have been shown to have positive effects on vascular health, anti-cancer activity, and anti-inflammatory properties in several studies.	Lotito Silvina and Balz Frei, 2006 [66]

Tannins: A family of astringent, polyphenolic biomolecules known as tannins precipitates proteins, as well as other compounds and macromolecules, by binding to them (Table 4).

Table 4: Sources and health benefits of Tannins

Chemical structure	Source	Health benefits	References
Tannins, sometimes referred to as gallo-tannic acid, are intricate combinations of polymeric polyphenols with gallic acid as their basis unit. The tannin content of oak gallnuts ranges from 50% to 70%. There are two types of tannins: dense tannins and hydrolysable tannins. The first category includes compounds with ether or carbon-carbon linkages connecting their nuclei, whereas the second category includes compounds that resemble ester compounds, such as polymers of gallic acid and ellagic acid. Tannins can be brown, yellow, or colourless, among other hues. It causes astringency in some food types and enzymatic searing reactions.	The majority of berries (cranberries, strawberries, and blues), tea, coffee, pomegranates, persimmons, grapes, red wine, chocolate (with a cocoa content of at least 70%), and spices (cinnamon, vanilla, cloves, and thyme) are key sources of tannins.	Tannins have been reported to have an adverse effect on the feed consumption, growth rate, feed efficiency, net metabolic energy, and protein digestibility of experimental animals. Tannins have also been proven to control immunological responses, reduce serum cholesterol levels, lower blood pressure, and speed up blood clotting, all of which are good for your health. These effects depend on the kind and quantity of tannins utilized.	Srilakshami 2018 [98] Chung King *et al.*,1998 [23] Santos-Buelga Celestino, *et al.*,2000 [86]

Betalains: They have red and yellow pigments and they have a visual similarity to flavonoids and anthocyanins (Table 5). The betalains, on the other hand, contain nitrogen.

Table 5: Sources and health benefits of Betalains

Chemical Structure	Source	Health benefits	References
Two kinds of indole-derived pigments, red-violet betacyanins and yellow betaxanthins, are characterised by the colours they produce owing to their resonant double bonds. Because they dissolve in water, they can be incorporated into an aqueous food system.	The food sources of betalains include red and yellow beetroot, coloured Swiss chard, leafy or grainy amaranth, prickly pear, red pitahaya, and other cacti.	Due to their antioxidant, anti-cancer, anti-lipidemic, and antibacterial qualities, betalains have progressive impacts on health. As functional foods and a possible alternativeto supplemental medicines for illnesses brought on by dyslipidemia, oxidative stress, inflammation, artery stenosis, hypertension, and cancer, among other conditions, they are harmless in diet.	Gengatharan *et al.*, 2015 [39] Salisbury Frank *et al.*, 1991 [84] Rahimi *et al.*, 2018 [79]

Carotenoids: Plants that contain carotenoids, also known as carotenes, produce xanthophylls, which are the oxygenated versions of these compounds. The word "carotenes" derives from the red colour of carrots (Table 6). The bulk of the yellow and red fruits, as well as numerous roots in a range of other plants, also contain them.

Table 6: Sources and health benefits of Carotenoids

Chemical structure	Source	Health benefits	References
A carotenoid is made up of eight isoprenoid units that are bonded together in such a manner that the isoprene units in the centre of the molecule are arranged in the opposite direction. Because they absorb light with wavelengths between 400 to 550 nanometers (from violet to green light), carotenoids have intensely coloured yellow, orange, or red pigments. This is directly related to how they are set up.	Reliable sources of carotenoids include carrots, apricots, mangoes, cantaloupes, sweet potatoes, kale, spinach, cilantro (coriander), collard greens, fresh thyme, turnip greens, and winter squash.	Carotenoids defend against many malignancies in addition to improving vision and skin health. A strong immune system, healthy skin and mucous membranes, and keen vision all depend on vitamin A, which is also a precursor to beta-carotene.	Vieira AR., *et al.* 2016 [105] Soares Nathalia da Costa Pereira., *et al.* 2015 [96] Chajès, Véronique, *et al.* 2014 [21] Leoncini Emanuele., *et al.* 2015 [63]

Plant sterols: All plants naturally contain plant sterols, also known as phytosterols (Table 7). Numerous of these substances have been linked to bioactive food characteristics.

Table 7: Sources and health benefits of Plant Sterols

Chemical structure	Source	Health benefits	References
Phytosterols, phytostanols, and their unsaturated lipid esters are all included in plant sterols. They are substances	The primary source is vegetable oils, although minor quantities can also be found in nuts,	The cholesterol-like characteristic of plant sterols may impact the intestinal absorption of cholesterol. Plant sterols are better at absorbing low-density	Trautwein Elke., *et al.* 2018 [103]

that resemble cholesterol; as a result, they may have comparable effects on the metabolism and absorption of cholesterol in both humans and animals.	legumes, grains, cereals, wood pulp, and leaves.	lipoprotein (LDL) cholesterol, commonly referred to as the "bad cholesterol," than LDL cholesterol, which has the ability to naturally reduce blood levels of LDL cholesterol.	Srilakshami 2018 [98]

Glucosinolates
Glucosinolates and their secondary metabolites, which contain sulfur and nitrogen, are naturally occurring components of mustard, cabbage, and horseradish, among other pungent plants (Table 8). The glucosinolates in this plant material produce mustard oils when it is chewed, cut, or otherwise damaged. These oils give these plants and products their distinctive spiciness.

Table 8: Sources and health benefits of Glucosinolates

Chemical structure	Source	Health benefits	References
Every glucosinolate has a crucial carbon atom that is joined by a nitrogen atom to the sulphate group and a sulphur atom to the thioglucose group to produce a sulfated aldoxime.	The most plentiful sources of glucosinolate are cruciferous vegetables such wasabi (Wasabia japonica), broccoli, cabbage, kale, watercress, and garden cress.	Studies have demonstrated the protective effects of certain glucosinolates and their physiologically active metabolites, notably the isothiocyanates, against dementia and cancer.	Agerbirk *et al*. 2012 [2] Redovniković., *et al*. 2008 [80]

Bioactive compounds of animal sources

Table 9: Types and sources of Bioactive Compounds from Animal Sources

Comound	Source (S)	Reference
Omega-3-fatty acid	Fatty fish, Cod liver oil	Zhang *et al*., 2015 [109]
Conjugated linolenic acid	Lamb meat, Pork, Turkey	Schmid *et al*. 2006 [89], Belury 2002 [14]
Bioactive peptides	Milk	Meisel 2005 [69]
L-carnitine	Milk (cow), Meat (beef, chicken)	Flanagan *et al*. 2010 [36]
Chitin & chitosan	Crab shell, Shrimp shell	Jeon *et al*. 2000 [53], Bhatnagar and Sillanpaa 2009 [112]
Choline	Egg, Bovine milk, Beef Steak	Sanders and Zeisel, 2007 [85]
Glucosamin	Meat, Fish, Poultry	James and Uhl, 2001 [52]

Omega-3-fatty acid
Omega-3 fatty acids are polyunsaturated fatty acids (PUFAs), as suggested by their name that include two or more double bonds, one of which is located at the third carbon atom along the carbon chain, beginning at the methyl (CH3) end. The most significant omega-3 fatty acid kinds that are present in foods (DHA) include alpha-linolenic acid (ALA), Eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (Meyer *et al*., 2003) [70].

The advantages of omega-3 fatty acids in reducing the risk of heart disease. Additionally, omega-3 fatty acids might lessen the signs and symptoms of long-term diabetic issues such hypertension, atherosclerosis, hypertriglyceridemia, and hypercholesterolemia. The most well-known biological activity of omega-3 fatty acids is perhaps the crucial part they play in brain development, function, and mental wellness. The regulation of neurotransmitters and maintaining the fluidity of brain membranes depend on DHA and other omega-3 fatty acids (Ruxton *et al*., 2004) [82].

Conjugated linolenic acid (CLA)
The phrase "conjugated linoleic acid" describes a group of linoleic acid's geometric and positional isomers. Among the food groups high in CLA are meat and dairy products derived from ruminants. CLA has a wide range of bioactive properties, some of which include its anti-adipogenic, anti-diabetic, anti-atherosclerotic, and anticarcinogenic properties (Schmid *et al*., 2006) [89].

According to animal model studies, CLA administration is advantageous in lowering body weight and changing body composition by reducing adipose tissue mass. The anticarcinogenic bioactivity of CLA is asserted on the basis of the inhibition of numerous cancer models, including skin tumour, stomach neoplasia, breast, prostate, and colon carcinogenesis in experimental animals (Belury 2002) [14].

Bioactive peptides
The bulk of bioactive peptides, which are precursors and suppliers of milk proteins, remain inert until they are released from the protein sequence by enzymatic proteolysis. Increasing evidence suggests that milk protein may be a source of peptides with cytomodulating properties. The antiproliferative and apoptosis-inducing peptides may be useful in the treatment of cancer, whilst the cell growth-promoting peptides have advantages in promoting the development of newborns' digestive systems. Casomorphins, -lactorphin, -lactorphin, Lactoferroxins, Casoxins, Casokinin, Lactokinins, Immunopeptides, Lactoferricin, Casoplatelins, and Phosphopeptides are examples of bioactive peptides discovered in milk (Meisel 2005) [69]

L-C Arnitine
Lysine and methionine, two important amino acids, serve as precursors and cofactors for the production of carnitine, which mostly takes place in the liver. The kidney and brain can also produce carnitine. Carnitine may be found in a variety of animal and dairy products, including cooked steak, raw beef (tenderloin, shoulder and rump), cooked ground beef, raw beef liver, cooked chicken, cooked chicken egg, and cow milk. Clinical L-carnitine therapy may improve Alzheimer's disease, cardiovascular disease, painful neuropathies, and immunological function. Carnitine may also aid in the treatment of obesity, improve glucose

tolerance, and increase overall energy expenditure, according to growing body of research (Flanagan *et al*., 2010) [36]

Chitin and Chitosan

Chitin and chitosan are biopolymers made of amino-polysaccharides. Because of their distinctive structural characteristics, chitin and chitosan are highly insoluble substances with minimal chemical reactivity that serve supporting and protective roles in the exoskeleton and internal organisation of invertebrates. Chitin and chitosan have certain uses in food, nutrition, agriculture, pharmaceuticals, medicine, and biotechnology. New applications for chitin and chitosan are continually being developed. To remove metal ions, radionuclides, dyes, phenols, and other ad hoc pollutants from water and wastewater, for instance, derivatives of chitin and chitosan are utilised (Jeon *et al*. 2000, Bhatnagar *et al*., 2009) [53, 111].

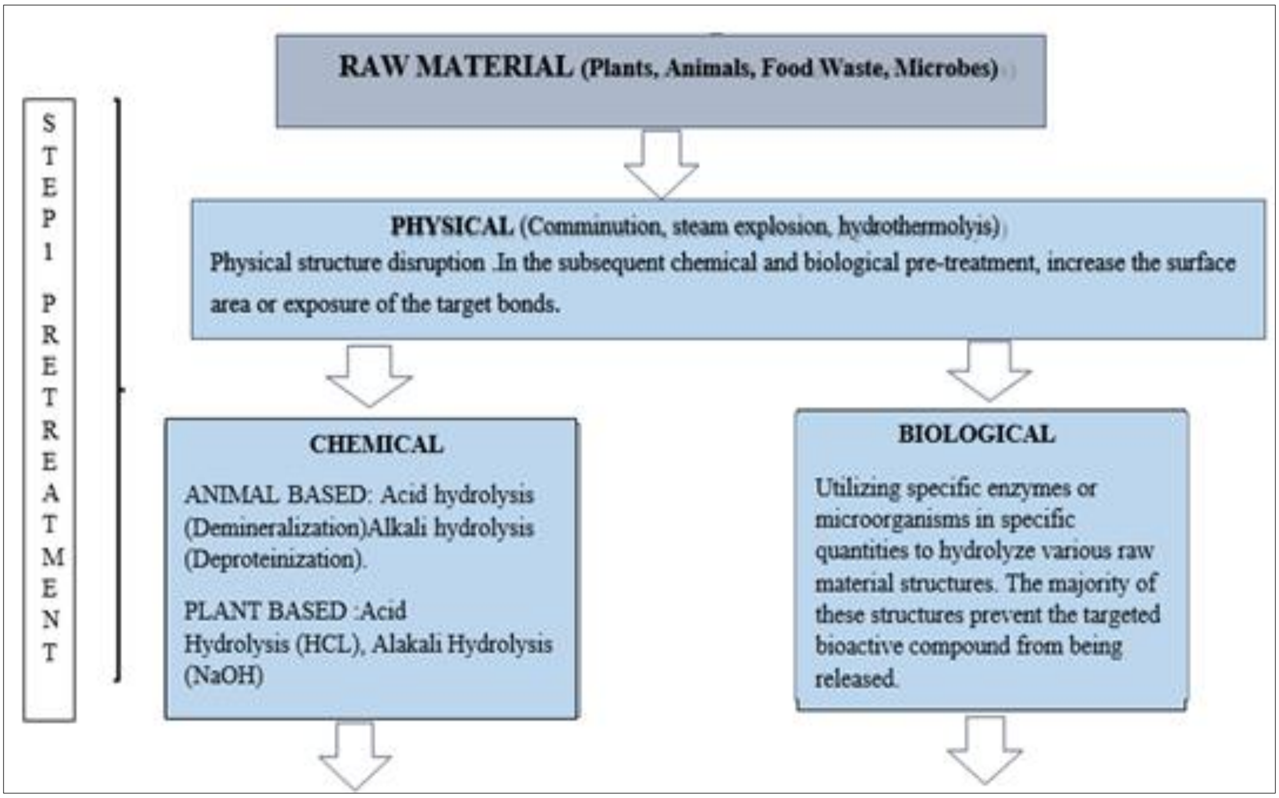
Choline

Choline, a quaternary ammonium molecule, was first discovered in an isolation of pig bile. The phospholipid "lecithin" (phosphatidylcholine) makes up the majority of the choline that individuals get via their meals. Choline can be created endogenously, despite the fact that extra choline must be obtained from meals in order to prevent liver and muscle damage. The ideal choline intake levels are influenced by a number of factors, including sex, pregnancy and breastfeeding, clinical status, folate, vitamin B12, methionine diet, and gene polymorphisms. Human health depends on choline, which has also been used medicinally for a long time. Diseases in several different physiological systems and organs will emerge from a choline deficit (Sanders *et al*., 2007) [85].

Only a few of the biological functions of choline include the production of acetylcholine, methyl donors, renal osmolytes, internal cell messengers and hormones, phosphotidyl-choline, and sphingomyeline (Gossell *et al*., 2006) [41].

Glucosamin

Glucosamine is an amino monosaccharide that the body makes from glucose. Glucosamine may be found in meat, poultry, and fish, while one of the most well-liked dietary supplements is glucosamine sulphate, a salt of D-glucosamine with sulfuric acid. Nearly all human tissues contain glucosamine, with the largest concentrations found in the liver, kidney, and cartilage. In the liver, glutamine is combined with plasma proteins, disassembled into smaller molecules, or used for other biological processes. The fact that glucosamine builds up in cartilage indicates that glucosamine is very important for the structure and makeup of cartilage. A substrate for the production of glycosaminoglycans and proteoglycans, which make up the extracellular matrix of cartilage, is glucosamine, which is created by chondrocytes from glucose (Anderson *et al*., 2005, James and UHL 2001) [7, 52].



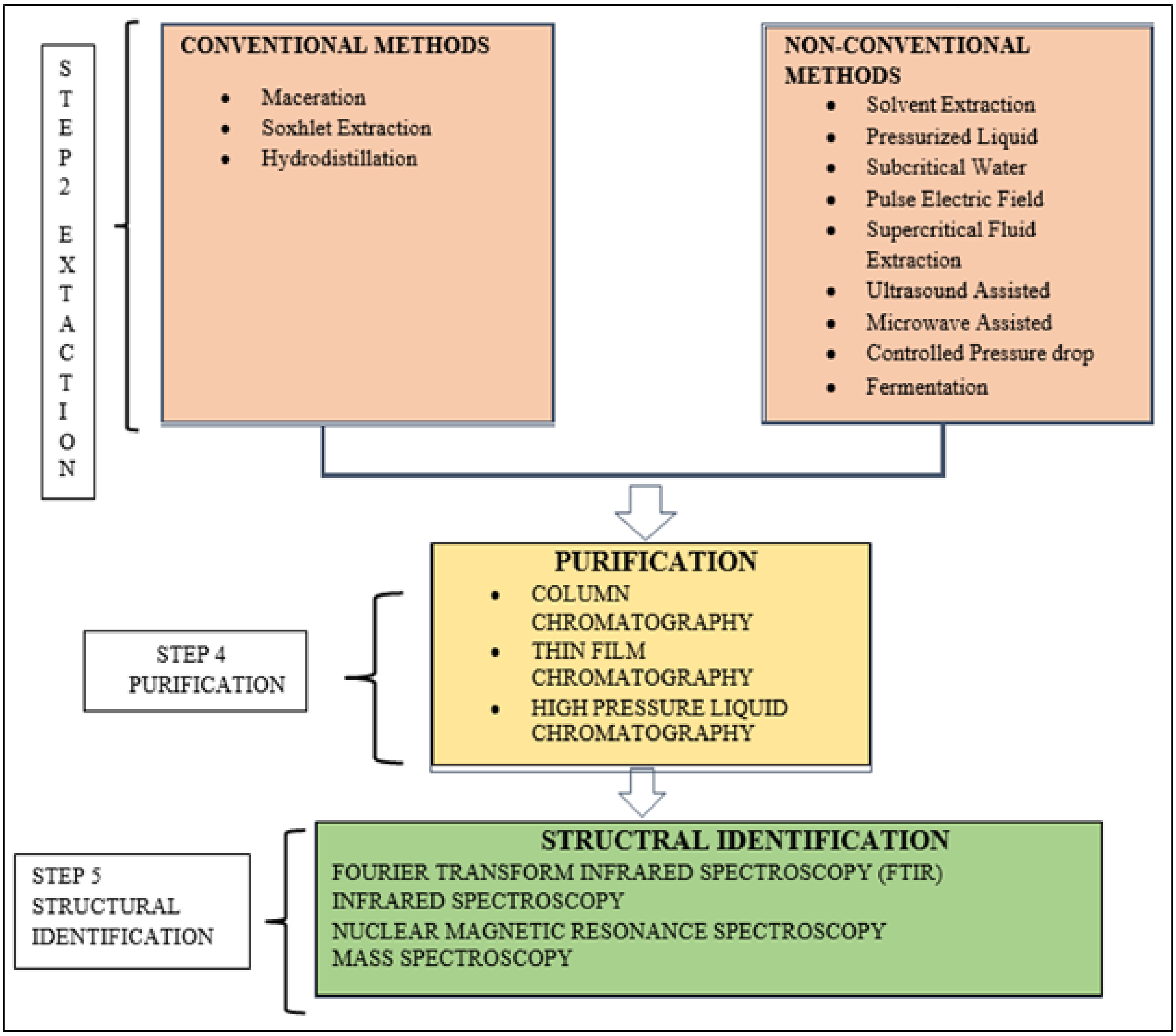


Fig 1: Steps in the production of bioactive compounds (Source: Azeez *et al*., 2017) [10]

Production of bioactive compounds

The production of bioactive compound takes place using the following 4 steps

- Biological Pre-treatment.
- Extraction.
- Purification.
- Structural Identification.

Biological pre-treatment

In biological pretreatment, fungus and bacteria that break down wood, such as white rot fungi, brown rot fungi, or soft rot fungi, are employed to change the lignocellulosic biomass' chemical make-up and/or structural makeup. The aforementioned chemical pretreatments are combined with or replaced by bio-delignification; It is easier, less expensive, better for the environment, doesn't need a lot of infrastructure, and is safer for people's health than physico-chemical or chemical-based pretreatment procedures. One of the disadvantages of biological pretreatment is that it is a sluggish procedure that needs careful management of growth conditions and a sizable treatment area. The majority of lignolytic microorganisms also solubilize and consume hemicellulose and cellulose. The commercial appeal of biological pretreatment is diminished by these technological and economic obstacles (Eggeman and Elander 2005, Bhavsar *et al*., 2015) [30, 17].

Extraction

The primary goal of extraction is to fully dissolve the desired bioactive chemical substances in the solvent while leaving other elements, such as cells and tissues (other inert substances), unaltered in the system (solvent + pretreatment raw material). This is done by mixing a raw material that has already been treated with the right solvent.

Temperature, solvent type, pressure, and the nature and amount of the raw material (plant, animal, microbes, etc.) are all important variables in this procedure. Different methods can be employed to extract various kinds of bioactive substances. These extraction methods fall into two broad categories: conventional (maceration, hydrodistillation, and Soxhlet extraction) and nonconventional (fermentation, controlled pressure drop, as well as pressurised liquid, pulse electric field, microwave-assisted, solvent extraction, subcritical water, and supercritical fluid extraction) (Smith 2003; Sasidharan *et al*., 2011; Khoddami *et al*., 2013; Baiano 2014) [95, 87, 56, 11].

Conventional methods

Conventional method includes three processes for the extraction of bioactive compounds. The three processes are described below-

Maceration
A appropriate solvent is soaked in a closed vessel with pulverised material that has been physically processed in order to extract the bioactive component. The leftover marc is squeezed to remove the remaining solution, the solution (containing the solvent and the bioactive component) is separated (Azeez *et al*., 2017) [10].

Soxhlet extraction
In a distillation unit, dried raw material and a particular solvent are heated and condensed repeatedly until complete extraction of the components is accomplished.
It ensures that the directed component will be removed from the solvent and collected in the distillation flask (Azeez *et al*., 2017) [10].

Hydrodistillation
In order to extract bioactive molecules from the targeted material using water as a solvent, either boiling water is packed inside of it or steam is injected into it. Diffusion, hydrolysis, and heat-induced breakdown using water are all involved (Silva *et al*., 2005) [94].

Non-conventional method
Pulse electric field
By subjecting raw materials to a mild electric field (between 500 and 1000 V/cm) for 10 to 20 seconds, the permeability of the cells is increased. The pulsed electric field rips the raw material's cell membranes, increasing the extraction's efficiency (Fincan and Dejmek 2002) [35].

Solvent extraction
A number of solvents, including methanol, acetone, ether, ethanol, and hexane, are used to selectively separate the polar and nonpolar bioactive compounds (Plaza *et al*., 2010) [77].

Supercritical field extraction
For the extraction of bioactive compounds, targeted material is combined with solvents such methane, nitrogen, and ethylene in temperature-controlled and pressured chambers. Supercritical solvents at high temperatures and pressures have superior transportation qualities because of their density and viscosity that are similar to those of liquids and gases (Herrero *et al*., 2006; Cavero *et al*., 2006; Daintree *et al*., 2008) [48, 20, 25].

Pressurized liquid
This type of extraction is done at greater pressures (1450-2175 psi) and temperatures (50-200 C) to lessen the polarity of the solvents. Temperature can be used to match the solvent's and the desired compounds' polarities. Pressure will be used to push the solvent into the raw materials matrix (Dunford *et al*., 2010; Miron *et al*., 2011) [28, 71].

Subcritical water
In order to substitute organic solvents, which are generally used, with water for the extraction of the bioactive compounds from the necessary raw material, a technique is used that utilises hot water (100-374 C) at high pressure (10 to 60 bar) (Herrero *et al*., 2006) [48].

Fermentation
Fermentation is employed in submerged (in liquid medium containing nutrients) or solid state (on solid particles with the absence or presence of direct water) for the production of various bioactive compounds. After a certain strain of bacteria on the source material has fully developed, these chemicals are produced as secondary metabolites. These compounds are also produced when one of the crucial nutrients in the medium for their development is depleted (Pandey 2003, Barrios-González *et al*., 2005, Nigam 2009) [76, 13, 74].

Controlled pressure drop
Following a brief exposure to saturated steam, there is a rapid pressure fall, which triggers the material's volatile compounds to begin vaporising on their own. As the temperature decreases further as a result of the pressure reduction, the material expands to shield heat-sensitive chemicals from thermal degradation. This improves the mass transfer and recovery (Ben Amor *et al*., 2009; Allaf *et al*., 2013) [6, 4].

Microwave assisted
Microwaves evaporate the moisture inside cells by heating the water that is already there. When organelles and cell walls are ruptured by evaporation, the pressure in these tissues is increased and the porosity of the biological matrix is increased. The targeted compounds are exposed to more solvent due to the increased porosity of the raw material, which raises the yield of the same molecule (Routray and Orsat 2012) [81].

Ultrasound assisted
Acoustic cavitation is a phenomenon that occurs when bubbles or cavities form in the liquid being utilised for extraction as a result of the expanding cycles of ultrasonic vibrations. After receiving the energy from the ultrasonic waves, these bubbles start to violently collapse, shattering the cells as they strike the surface of the raw material's solid matrix. The release of bioactive chemicals is made possible by this break (Leighton 2007; Soria and Villamiel 2010; Esclapez *et al*., 2011) [62, 97, 32]

Purification of bioactive compounds
The process of identifying and describing bioactive chemicals still faces significant separation- related challenges. It is common procedure to extract these bioactive chemicals using a variety of separation techniques, including TLC, HPTLC, paper chromatography, column chromatography, gas chromatography, OPLC, and HPLC, in order to get pure molecules. The structure and biological activity are then determined using the pure molecules (Sasidharan *et al*., 2011) [87].

Chromatography
The molecules are divided using the chromatography process according to their size, shape, and charge. Analyte is moved through a solid phase that serves as a sieve material during chromatography while in a solvent. The molecular sieve separates molecules as they go through it. The chromatographic methods that quickly convey qualitative information and make it easy to get quantitative data include thin layer & paper chromatography (Heftmann, 1992) [47].

High Performance Liquid Chromatography (HPLC)
HPLC is an analytical technique for the separation and quantification of organic and inorganic solutes in any samples, including biological, pharmaceutical, food, environmental, industrial, etc. A technique for separating substances based on how they interact with the mobile

phase's solvent and the solid particles of a tightly packed column is high-pressure liquid chromatography, or HPLC. In contemporary HPLC, non-polar solid phases like C18 and polar liquid phases, frequently a mixture of water and another solvent, are employed. Before passing through a DAD, the analyte must be eluted down a column at a high pressure of up to 400 bars. A DAD looks at the analytes' absorption spectra to assist in identifying them. HPLC is useful for identifying chemicals for substances that cannot be vaporised or that degrade at high temperatures. It complements gas chromatography nicely (Hancock 1990, Katz 1995) [44, 54].

Column Chromatography (CC)

Column chromatography uses ion exchange, molecular sieves, and the adsorption phenomenon. In traditional chromatography, the material is significantly diluted during the flushing, and the fractions often require an additional stage of concentration. Displacement chromatography, a more recent technique, elutes with some substances that have a high affinity for the adsorbent. The initial solution applied to the column may not be as concentrated as some fractions of the elute components (Khelurkar *et al*., 2017) [55].

Thin Layer Chromatography (TLC)

Thin layer chromatography's first practical use was from Stahl. TLC's flexibility, speed, and sensitivity over paper chromatography are its main advantages. In TLC, tiny layers of adsorbent bonded to the plate interact with one another to separate samples via adsorption chromatography. The method is mostly used to separate low molecular weight molecules (Stahl 1965, Hahn- Deinstrop, 2000) [99, 43].

Adsorption chromatography

Adsorption chromatography, sometimes referred to as displacement or liquid/solid chromatography, is based on interactions between the solute and fixed active sites on the stationary phase. The stationary phase's active sites engage in noncovalent bonding, nonpolar contacts, van der Waals forces, and hydrophobic interactions with the functional groups of molecules. Different groups of compounds can be separated because the mobile phase will elute out the weakly bound compounds first (Khelurkar *et al*., 2017) [55].

Affinity chromatography

Affinity chromatography separations are based on the specific relationships between interacting pairs of substances, such as macromolecules and their substrates, cofactors, allosteric effectors, or inhibitors. During this chromatography, a variety of compounds were introduced to the columns. In order for the desired chemical to bind to the ligand, the buffer is employed to eliminate molecules that have no affinity for it. A buffer with a modified pH or greater ionic strength is used to elute the analyte out (Khelurkar *et al*., 2017) [55].

Ion-exchange chromatography

Ion-exchange chromatography allows the separation of ions and polar molecules based on the electrical properties of the molecules (Weiss *et al*., 2004) [106].

Partition chromatography

The particles that need to be separated in partition chromatography procedure will interact between two immiscible liquid phases depending on their relative solubility. This process is also known as liquid/liquid chromatography (Khelurkar *et al*., 2017) [55].

Gas Chromatography (GC)

Gas chromatography is a method for separating volatile substances. In this process, species are divided between a liquid phase and a gas phase. The gas phase is in motion, whereas the liquid phase is at rest. On the basis of how evenly distributed a chemical species is in the gas phase, one may estimate its rate of migration. A species that completely disperses into the gas phase, for example, would migrate at the same speed as the gas, but a species that completely disperses into the stationary phase would not move at all. The distribution of species will alternate between the two stages and progress at a modest rate (Littlewood 1962, Burchfield *et al*., 1962) [62, 19].

Identification of bioactive compounds

Fourier-transform infrared spectroscopy (FTIR)

Finding functional groups in plant extracts may be done with the use of infrared spectroscopy and the Fourier transform. It makes it easier to recognize the molecule and determine its structure. To prepare samples for FTIR, there are numerous methods. Liquid samples should be handled in the simplest way possible by placing one drop of the specimen between two sodium chloride plates.

The drop deposits a thin layer between the plates. Solid materials can be ground using potassium bromide (KBr), and the resulting thin pellet can then be studied. As an alternative, solid samples may be dissolved in a methylene chloride-based solvent. A single High Attenuated Total Reflectance (HATR) plate is then treated with a few drops of the resultant solution, and the spectra are then recorded in terms of the % transmittance. The peaks at a certain wave number were assigned by bonding and functional group, per the reference found in the Varian FTIR instrument manual (Eberhardt *et al*., 2007, Hazra *et al*., 2007, Anonymous, 2009) [29, 45, 9].

Nuclear Magnetic Resonance Spectroscopy (NMR)

The physical, chemical, and biological properties of the substance are revealed through nuclear magnetic resonance spectroscopy. Instead of the often used one dimensional methodology, two dimensional NMR techniques may be used to create the complicated structure of the molecules. Through the use of solid state NMR spectroscopy, materials molecular structure may be determined (Cosa *et al*., 2006) [24].

Mass Spectrometry (MS)

The structure and chemical properties of molecules may be determined, as well as the composition of known compounds, as well as the quantity of unknown chemicals, using mass spectrometry. The MS spectrum may be used to determine the sample's molecular weight.

This method is primarily used for the structural elucidation of organic compounds, peptide or oligonucleotide sequencing, and for highly specific monitoring of the presence of previously characterized compounds in complex mixtures because it simultaneously defines the molecular weight and a diagnostic fragment of the molecule (Khelurkar *et al*., 2017) [55].

Application of bioactive compounds food products

The significance of bioactive substances to the food business is significant. Food colours, meat and animal products, food supplements, and other items all include bioactive chemicals that are required by the human body. Additionally, they are utilised as food enhancers. Ascorbic acid is widely used as an addition to prevent food from oxidising, carotenoids, curcumin, and anthocyanins are used as colour agents, and vanillin and cinnamaldehyde are used as flavour enhancers. Fermentation is one of the crucial processes in the food industry that generates a lot of bioactive compounds. (Talekar *et al*., 2018, Pogorzelska-Nowicka *et al*., 2018 Chhikara *et al*., 2019) [101, 78, 22].

Common fruits including apple, mango, plum, banana, and citrus fruits include phenolic acids, favanols, carotenoids, anthocyanins, and lipids. Common veggies including broccoli, beets, carrots, and potatoes include carbohydrates, phenolic acids, carotenoids, and flavonoids. Additionally, *Helianthus annuus L*. Wastes (petals, forets), *Neochloris Oleoabundans, C Annuum Baydgi, T Chuii and P Tricornutum* contain carotenoids. Chokeberry fruit, the papery peel of *Allium cepa L. var. Ascalonicum*, strawberry, raspberry, blueberry, blackberry, and Tannat grape pomace are a few examples of foods that contain anthocyanins (Gorte *et al*., 2020, Shahi *et al*., 2021) [40, 90]

The primary beverages that contain flavonoids are tea, wine, and beer. They serve as the primary sweetening agents in these beverages. In some cases, they also contribute to some degree of sweetness in tea, wine, and beer. The two primary types of flavonoids present in wine are anthocyanin, which gives it its unique colour, and pro-anthocyanin, which mostly contributes to the astringent flavour.

Bioremediation

Coagulants, biofilms, bioactive extracts, and other bioactive substances have a variety of applications in the bioremediation industry. Numerous bioactive compounds have shown promise activity against harmful algal blooms (HAB), including -linolenic, oleic, and palmitic acids from *Botryococcus braunii*, diethyl phthalate from *Stoechospermum marginatum*, and others. Similar to this, there are three benefits to sargassum's bioaccumulation of nutrients and metals (Cd, Cu, Zn, Pb, Cr): It also sequesters metals, lessens eutrophication and coastal metal pollution, and generates beneficial bioactive molecules for the pharmaceutical, cosmetic, and fertiliser industries (Zerrif *et al*., 2018, Saldarriaga-Hernandez *et al*., 2020) [108, 83].

Tannins have been widely used in sewage treatment plants as well. Turbidity has been reduced and suspended particles have been focused using tannin-based coagulants. The utilization of wattle tannins and tannin cryogels to remove methylene blue and heavy metals from contaminated water, respectively (Ibrahim *et al*., 2021) [49].

The use of biofilms made by intertidal and marine bacteria in bioremediation has a lot of promise. Studies have demonstrated that bacteria populations and biofilm compositions in surface and deep-sea water change when exposed to crude oil or chemical dispersants, which is encouraging for the management and cleaning of oil spills. Consequently, bioactive substances show promise in fields including wastewater treatment and hydrocarbon breakdown (Mugge *et al*., 2021) [72].

Energy sector

Biofuels and other sustainable methods are now crucial due to the increase in human population. In the food and agroforestry sectors, waste biomass amounts to five billion tonnes. It has a lot of potential for creating bioactive substances that can be used to make biofuels and lessen the waste from harvested biomass. Ethanol and vegetable oil are routinely produced by bio refineries for use as biofuels (Ferreira-Santos *et al*., 2020) [34].

Other sources of bioenergy and biofuels, such as ethanol, methanol, and butanol, are sugar-based waste (sugar cane, sugar beets), animal waste (cows, swine, poultry), food-related waste, starch-based waste (corn), lignocellulosic residue (switch grass, micanthus, corn stover, corn ber), and glycerine (Swain 2017) [100].

Microbes are used to produce electricity in microbial fuel cells (MFCs). Epigallocatechin-3-gallate, gallic acid, gallocatechin, and anthocyanin are a few secondary metabolites that have shown enhanced power density with electron shunting capabilities. The addition of fungus and algae metabolites to MFCs improves energy output (Nath and Ghangrekar 2020) [73].

Fortification and texturizing

Many dietary fibres (soluble and insoluble), nutritious and non-nutritive gums, etc. are texturizing agents. These compounds boost solubility and viscosity, which have a direct influence on the texture component of food products due to their exceptional capacity to hold both water and oil. Dietary fibre will also promote intestinal health and assist with weight management (Elleuch *et al*., 2011) [31]

Following extraction and purification, bioactive compounds can be utilised to strengthen a variety of basic foods (such as rice, salt, milk, and oils) and food items aimed at vulnerable populations to supplement their diets with critical and lacking nutrients (functional and nutraceutical products).

Pharmaceutical

With the right planning, natural resources may be turned into attractive goods with a high added value. Bio-products originating from the sea are thought to be viable options because they include a large number of pharmacologically active components with a wide range of chemical and structural variety. This naturally occurring marine-based bioactive compound has been thought of as a potential replacement for commercially available steroidal drugs due to its many potent qualities, including its anticoagulant, antiviral, antiangiogenic, antitumor, anti-inflammatory, antioxidant, anti-proliferative, and immune modulating properties.

Ayurveda

The ancient medical system of Ayurveda utilises hundreds of medicinal plants for its therapeutic benefits, many of which are abundant in secondary metabolites, among which phenolic compounds are a prominent one. Plant phenolic compounds are one of the major families of phytomolecules with great therapeutic and nutraceutical promise. Indian medicinal plants including Emblica, Terminalia spp., Withania, Tinospora, and others may be sources of bioactive phenolics that have been used in diverse Ayurvedic formulations for ages and have received scientific validation. Plant phenolics and flavonoids have a wide range of biological effects, from maintaining the body generally to treating specific illnesses like cancer and diabetes, among others. Numerous studies demonstrate that consuming plant-based foods lowers your risk of contracting a number of diseases, including cancer and cardiovascular issues. (Kumar *et al.*, 2022) [61].

Bio accessibility, bioavailability, and bioactivity of bioactive compounds

Because a bioactive substance must be present in a biological system in order for it to perform its primary function on that system, the three ideas are tied to one another. This drug has to be taken out of the matrix it was consumed with in order to be utilised in the living system. The behaviour of the bioactive compounds in the biological system is influenced by their bio accessibility, bioavailability, and bioactivity. So, prior to its use in fortification and the creation of functional foods, extensive research is needed to understand the compound's bio accessibility, bioavailability, and bioactivity in the human body as well as its suitable food delivery techniques.

Bio accessibility

It pertains to the quantity of substance that was ingested along with the food in the gastrointestinal tract. To prepare bioactive substances for bloodstream absorption/ assimilation via intestinal epithelial cells, gastric secretory action on the food matrix for digestion is necessary (Benito and Miller 1998; Heaney 2001) [15, 46].

Bioavailability

The amount of bioavailable substances that are taken up by intestinal epithelial cells and transported to the body's circulatory system (via bloodstream or lymph circulation) in order to carry out the required physiological function Due to the existence of other molecules or interactions with them, not all bioactive substances that are accessed through the body are absorbed. In contrast, phytates limit the absorption of proteins and minerals, whereas vitamin D and ascorbic acid boost the uptake of calcium and iron, respectively (Blenford 1995; Lesser *et al*., 2006) [18, 64].

Bioactivity

When a chemical, such as an antioxidant, anti-inflammatory agent, or antidiabetic, comes into touch with the targeted tissue, it affects the particular physiological activity that the substance (such as a) engages in. The extent to which a medication interacts with other biomolecules while being absorbed and circulated, the impact of metabolism (gastric secretions), and other factors are all reflected in the drug's bioactivity at the target site (Fernández-García *et al.,* 2009) [33].

Limitations to bioactive compounds

The varied stability and loss of activity of bioactive chemicals, particularly in foods, is a significant barrier to their widespread usage because the majority of studies confirming their beneficial characteristics are conducted in controlled environments. While researching the nutritional and therapeutic advantages of bioactive compounds, variation across individuals is a crucial issue that must be taken into account. Varying processes, including absorption and metabolism, variations in age, gender, and lifestyle may cause certain compounds to have varying impacts on a population. From an ecological standpoint, it appears clear that supplying the increasing demand for bioactive chemicals will put a huge strain on biodiversity, land and marine resources, possibly jeopardising the survival of extremely rare species.

Conclusions

People are becoming more and more worried about their health as they age, which has increased interest in the role and security of dietary supplements. Over 300 million individuals worldwide, including more than 60% of the American population, regularly take dietary supplements. In particular, a sizeable and growing portion of the market is now occupied by botanical dietary supplements, which are isolated from actual plants that draw more attention than others. The health of humans will be significantly influenced by both plant- and animal-based bioactive compounds. Animals create a variety of natural products that have beneficial biological impacts on humans. Two examples of the chemical species are conjugated linoleic acid and omega-3 fatty acids. Additional chemical species include L-carnitine, choline, glucosamine, chitin, chitosan, chondroitin, peptides from milk protein, and ammonium compounds. These compounds have a wide variety of biological effects that are noteworthy, including but not limited to preventative and therapeutic effects against osteoarthritis, atherosclerosis, hypertension, neurodegenerative disorders, and cardiovascular conditions. As a result, the use of bioactive chemicals will become increasingly important in the future.

References

1. Walia A. Role of Bioactive Compounds in Human Health. Acta Scientific Medical Sciences. 2019;3(9):25-33.
2. Niels A, Olsen CE. Glucosinolate structures in evolution. Phytochemistry. 2012;77:16-45.
3. Alain R. Le Robert micro-poche (2nd Ed.) (In French). 1994;14:126.
4. Allaf T, Tomao V, Ruiz K, Chemat F. Instant controlled pressure drop technology and ultrasound assisted extraction for sequential extraction of essential oil and antioxidants. Ultrason Sonochem. 2013;20(1):239-246
5. Altemimi A, Lakhssassi N, Baharlouei A, Watson DG, Lightfoot DA. Phytochemicals: Extraction, isolation, and identification of bioactive compounds from plant extracts. Plan Theory. 2017;6(4):42.
6. Amor BB, Allaf K. Impact of texturing using instant pressure drop treatment prior to solvent extraction of anthocyanins from Malaysian Roselle (*Hibiscus sabdariffa*). Food Chemistry. 2009;115(3):820-825.
7. Anderson JW, Nicolosi RJ, Borzelleca JF. Glucosamine effects in humans: A review of effects on glucose metabolism, side effects, safety considerations and efficacy. Food and Chemical Toxicology. 2005;43:187-201.
8. Anonymous. Larousse de poche (in French). Les Editions Francaises Company; c1994. p. 8.
9. Anonymous. Characteristic Infrared absorption. Frequencies; c2009. http://www.chem.csustan/edu/Tutorials/INFRARED.HT M.
10. Azeez S, Narayana CK, Oberoi HS. Extraction and utilisation of bioactive compounds from agricultural waste. In: Utilisation of bioactive compounds from agricultural and food production waste. CRC Press; c2017. p. 5.

11. Baiano A. Recovery of biomolecules from food wastes-a review. Molecules. 2014;19(9):14821-14842.
12. Bansal M, Poonia A, Kolluri SRP, Vasundhara Introduction on Bioactive Compounds, Sources and their Potential Applications. In: Thakur, M., Belwal, T. (ed) Bioactive Components. Springer, Singapore; c2023. https://doi.org/10.1007/978-981-19-2366-1_1
13. Barrios-Gonzalez J, Fernandez FJ, Tomasini A, Mejia A. Secondary metabolites production by solid-state fermentation. Malaysian Journal of Microbiology. 2005;1(1):1-6.
14. Belury MA. Dietary conjugated linoleic acid in health: Physiological effects and mechanisms of action. Annual Review of Nutrition. 2002;22:505.
15. Benito P, Miller D. Iron absorption and bioavailability: an updated review. Nutrition Research. 1998;18(3):581-603.
16. Bernard G, Dromard A. Book of etymology and medical terminology: Lexicon etymology (in French). Livretd' Étymologieet De Terminologiemédicale: Lexiqued' Étymologie; c2011. p. 1-4.
17. Bhavsar NH, Raol BV, Amin SS, Raol GG. Production, optimization and characterization of fungal cellulase for enzymatic saccharification of lignocellulosic agro-waste. International Journal of Current Microbiology and Applied Sciences. 2015;4(3):30-46.
18. Blenford D. Bioavailability is key to nutrient effectiveness. Process Technology and Equipment For Food Ingredients. 1995;17:28-30.
19. Burchfield AP, Storrs EE. Biochemical Applications of Gas chromatography. Academic Press, New York. USA; c1962.
20. Cavero S, García-Riscoa MR, Marína FR, Jaimea L, Santoyoa S, Señoránsa FJ, *et al*. Supercritical fluid extraction of antioxidant compounds from oregano: chemical and functional characterization via LC-MS and *in vitro* assays. Journal of Supercritical Fluids. 2006;38(1):62-69.
21. Véronique C, Romieu I. Nutrition and breast cancer. Maturitas. 2014;77(1):7-11.
22. Chhikara N, Kushwaha K, Sharma P, Gat Y, Panghal A. Bioactive compounds of beetroot and utilization in food processing industry: A critical review. Food Chemistry. 2019;272:192-200. https://doi. org/10.1016/j.foodchem.2018.08.022
23. King-Thom C, *et al*. Tannins and Human Health: A Review. Critical reviews in Food Science and Nutrition. 1998;38(6):421-464.
24. Cosa P, Vlietinck AJ, Berghe DV, Maes L. Anti-infective potential of natural products: How to develop a stronger *in vitro* proof-of-concept. Journal of Ethnopharmacology. 2006;106:290-302.
25. Daintree LS, Kordikowski A, York P. Separation processes for organic molecules using SCF technologies. Advanced Drug Delivery Reviews. 2008;60(3):351-372.
26. Day L, Seymour RB, Pitts KF, Konczak I, Lundin L. Incorporation of functional ingredients into foods. Trends in Food Science and Technology. 2009;20(9):388-395.
27. Dewick PM. The mevalonate and deoxyxylulose phosphate pathways: terpenoids and steroids. In: Medicinal natural products: a biosynthetic approach, 2nd edn. Wiley, New York/Chichester. c2001. p. 167-289.
28. Dunford NT, Irmak S, Jonnala R. Pressurised solvent extraction of policosanol from wheat straw, germ and bran. Food Chemistry. 2010;119(3):1246-1249.
29. Eberhardt TL, Li X, Shupe TF, Hse CY. Chinese tallow tree (*Sapium Sebiferum*) utilization: Characterization of extractives and cell-wall chemistry. Wood and Fiber Science. 2007;39:319-324.
30. Eggeman T, Elander RT. Process economic analysis of pretreatment technologies. Bioresource Technology. 2005;96:2019-2025.
31. Elleuch M, Bedigian D, Roiseux O, Besbes S, Blecker C, Attia H, *et al*. Dietary fibre and fibre-rich by-products of food processing: characterisation, technological functionality and commercial applications: A review. Food Chemistry. 2011;124(2):411-421.
32. Esclapez MD, García-Pérez JV, Mulet A, Cárcel JA. Ultrasound-assisted extraction of natural products. Food Engineering Reviews. 2011;3(2):108-120.
33. Fernández-García E, Carvajal-Lérida I, Pérez-Gálvez A. *In vitro* bio accessibility assessment as a prediction tool of nutritional efficiency. Nutrition Research. 2009;29(11):751-760.
34. Ferreira-Santos P, Zanuso E, Genisheva Z, Rocha CMR, Teixeira JA. Green and sustainable valorization of bioactive phenolic compounds from pinus by-products. Molecules. 2020;25(12):2931. https://doi.org/10.3390/molecules25122931
35. Fincan M, Dejmek P. In situ visualization of the effect of a pulsed electric field on plant tissue. Journal of Food Engineering. 2002;55(3):223-230.
36. Flanagan JL, Simmons PA, Vehige J, Willcox MD, Garrett Q. Role of carnitine in disease. Nutrition & Metabolism. 2010;7:30.
37. Galanakis CM. Introduction. In: Galanakis CM (ed) Nutraceutical and functional food components. Effects of innovative processing techniques. Elsevier (Academic Press), London; c2017. p. 1-14.
38. Galanakis CM, Markouli E, Gekas V. Fractionation and recovery of different phenolic classes from winery sludge via membrane filtration. Separation and Purification Technology. 2013;107:245-251.
39. Ashwini G, *et al*. Betalains: Natural plant pigments with potential application in functional foods. LWT - Food Science and Technology. 2015;64(2):645-649.
40. Gorte O, Nazarova N, Papachristou I, Wustner R, Leber K, Syldatk C, *et al*. Pulsed electric feld treatment promotes lipid extraction on fresh oleaginous yeast Saitozyma podzolica DSM 27192. Frontiers in Bioengineering and Biotechnology; c2020. p. 8. https://doi.org/10.3389/fbioe.2020.575379
41. Gossell-Williams M, Benjamin J. Choline are our university students eating enough? West Indian Medical Journal. 2006;55(3):197-199.
42. Gruenwald J, Freder J, Armbruester N. Cinnamon and health. Critical Reviews in Food Science and Nutrition. 2010;50(9):822-834.
43. Hahn-Deinstrop E. Applied Thin Layer Chromatography: Best practice and avoidance of Mistakes. Wiley-VCH, Weinheim. Germany; c2000.

44. Hancock WS. High Performance Liquid Chromatography in Biotechnology. Wiley - Inter science, New Jersey, USA; c1990.
45. Hazra KM, Roy RN, Sen SK, Laska S. Isolation of antibacterial pentahydroxy flavones from the seeds of *Mimusops elengi* Linn. African Journal of Biotechnology. 2007;6(12):1446-1449.
46. Heaney RP. Factors influencing the measurement of bioavailability, taking calcium as a model. Journal of Nutrition. 2001;131(4):1344S-1348S.
47. Heftmann F. Chromatography: Fundamentals and Application of Chromatographic and Electrophoretic Techniques. 5th Ed. Elsevier, Amsterdam. The Netherlands; c1992.
48. Herrero M, Cifuentes A, Ibañez E. Sub-and supercritical fluid extraction of functional ingredients from different natural sources: Plants, food-by-products, algae and microalgae: A review. Food Chemistry. 2006;98(1):136-148.
49. Ibrahim A, Yaser AZ, Lamaming J. Synthesising tannin-based coagulants for water and wastewater application: A review. Journal of Environmental Chemical Engineering. 2021;9:1. https://doi.org/10.1016/j.jece.2020. 105007
50. Valerio I, *et al*. The effects of dietary flavonoids on the regulation of redox inflammatory networks. Frontiers in Bioscience. 2012;17:2396-2418.
51. Jain PK, Joshi H. Coumarin: chemical and pharmacological profile. Journal of Applied Pharmaceutical Science. 2012;02(06):236-240.
52. James CB, Uhl TL. A review of articular cartilage pathology and the use of glucosamine sulfate. Journal of Athletic Training. 2001;36(4):413-419.
53. Jeon YJ, Shahidi F, Kim SK. Preparation of chitin and chitosan oligomers and their applications in physiological functional foods. Food Reviews International. 2000;16(2):159-176.
54. Katz ED. High Performance Liquid Chromatography: Principle and Methods in Biotechnology (Separation science Series). John Wiley & sons, New Jersey. USA; c1995.
55. Vaibhav K. Centre, Biotechnology & Deshmukh, Panjabrao & Vidyapeeth, Krishi & Akola, & Maharashtra, & Mumbai, India & Ingle, Krishnananda & Deshmukh, Amit & Padole, Dipika & Dudhare, Mahendra. Phytochemicals: Extraction methods, identification and detection of bioactive compounds from plant extracts; c2017. p. 32-36.
56. Khoddami A, Wilkes MA, Roberts TH. Techniques for analysis of plant phenolic compounds. Molecules. 2013;18(2):2328-2375.
57. Kitts DD. Bioactive substances in food: identification and potential uses. Canadian Journal of Physiology and Pharmacology. 1994;72(4):423-434.
58. Kris-Etherton PM, Hecker KD, Bonanome A, Coval SM, Binkoski AE, Hilpert KF, *et al*. Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. American Journal of Medicine. 2002;113(9):71-88.
59. Kris-Etherton PM, *et al*. Bioactive compounds in nutrition and health-research methodologies for establishing biological function: The Antioxidant and Anti-Inflammatory Effects of Flavonoids on Atherosclerosis. Annual Review of Nutrition. 2004;24(1):511-538.
60. Kumar K, Yadav AN, Kumar V, Vyas P, Dhaliwal HS. Food waste: A potential bioresource for extraction of nutraceuticals and bioactive compounds. Bioresources and Bioprocessing. 2017;4(1):1-14.
61. Kumar B, Misra A, Srivastava S. Bioactive Phenolic Compounds from Indian Medicinal Plants for Pharmaceutical and Medical Aspects. Biochemistry; c2022. DOI: 10.5772/intechopen.99672
62. Leighton TG. What is ultrasound? Progress in Biophysics and Molecular Biology. 2007;93(1-3):3-83.
63. Emanuele L, *et al*. Carotenoid intake from natural sources and head and neck cancer: A Systematic Review and meta-analysis of epidemiological studies. Cancer Epidemiology, Bio-markers and Prevention. 2015;24(7):1003-1011.
64. Lesser S, Cermak R, Wolffram S. The fatty acid pattern of dietary fat influences the oral bioavailability of the flavonol quercetin in pigs. British Journal of Nutrition. 2006;96(6):1047-1052.
65. Littlewood AB. Gas Chromatography Principle, Techniques and Applications. Academic Press. London, UK; c1962.
66. Silvina L, Frei B. Consumption of flavonoid-rich foods and increased plasma antioxidant capacity in humans: Cause, consequence, or epiphenomenon? Free Radical Biology and Medicine. 2006;41(12):1727-1746.
67. Martı´nez MJA, Bermejo Benito P. Biological activity of quinones. Studies in Natural Products Chemistry. 2005;30:303-366.
68. Meisel H. Biochemical properties of peptides encrypted in bovine milk proteins. Current Medicinal Chemistry. 2005;12(16):1905-1919.
69. Meyer BJ, Mann NJ, Lewis JL, Milligan GC, Sinclair AJ, Howe PRC. Dietary intakes and food sources of omega-6 and omega-3 polyunsaturated fatty acids. Lipids. 2003;38(4):391-398.
70. Miron TL, Plaza M, Bahrim G, Ibáñez E, Herrero M. Chemical composition of bioactive pressurized extracts of Romanian aromatic plants. Journal of Chromatography A. 2011;1218(30):4918-4927.
71. Mugge RL, Salerno JL, Hamdan LJ. Microbial functional responses in marine biofilms exposed to deepwater horizon spill contaminants. Frontiers in Microbiology. 2021;12:636054. https://doi.org/10.3389/fmicb. 2021.636054
72. Nath D, Ghangrekar MM. Plant secondary metabolites induced electron fux in microbial fuel cell: investigation from laboratory-to-feld scale. Scientific Reports. 2020;10:1. https://doi.org/10.1038/ s41598-020-74092-y
73. Nigam PS. Production of bioactive secondary metabolites. In: Nigam PS, Pandey A (ed) Biotechnology for agro-industrial residues utilisation. Springer, The Netherlands; c2009. p. 129-145.
74. Online Etymology Dictionary (website): http://www.etymonline.com; 2013.
75. Pandey A. Solid-state fermentation. Biochemical Engineering Journal. 2003;13(2-3):81-84.
76. Plaza M, Santoyo S, Jaime L, Reina GGB, Herrero M, Señoráns FJ, *et al*. Screening for bioactive compounds from algae. Journal of Pharmaceutical and Biomedical Analysis. 2010;51(2):450-455.

77. Pogorzelska-Nowicka E, Atanasov AG, Horbańczuk J, Wierzbicka A. Bioactive compounds in functional meat products. Molecules. 2018;23(2):307. https://doi.org/10.3390/molecules23020307
78. Parisa R, *et al*. Betalains, the nature-inspired pigments, in health and diseases. Critical Reviews in Food Science and Nutrition; c2018. p. 1-30.
79. Ivana R, *et al*. Glucosinolates and their potential role in plant. Periodicum Biologoru. 2008;110(4):297-309.
80. Routray W, Orsat V. Microwave-assisted extraction of flavonoids: A review. Food and Bioprocess Technology. 2012;5(2):409-424.
81. Ruxton CHS, Reed SC, Simpson MJA, Millington KJ. The health benefits of omega- 3 polyunsaturated fatty acids: A review of the evidence. Journal of Human Nutrition and Dietetics. 2004;17:449-459.
82. Saldarriaga-Hernandez S, Hernandez-Vargas G, Iqbal HM, Barcelo D, Parra-Saldívar R. Bioremediation potential of *Sargassum* sp. biomass to tackle pollution in coastal ecosystems: Circular economy approach. Science of the Total Environment. 2020;715:136978. https://doi.org/10.1016/j.scitotenv.2020.136978
83. Frank S, Ross C. Plant Physiology. 4th Ed. Belmont, California: Wadsworth Publishing; c1991. p. 325-326.
84. Sanders LM, Zeisel SH. Choline: dietary requirements and role in brain development. Nutrition Today. 2007;42(4):181-186.
85. Santos-Buelga C, Scalbert A. Proanthocyanidins and tannin-like compounds - nature, occurrence, dietary intake and effects on nutrition and health. Journal of the Science of Food and Agriculture. 2000;80(7):1094-117.
86. Sasidharan S, Chen Y, Saravanan D, Sundram KM, Latha LY. Extraction, isolation and characterization of bioactive compounds from plants' extracts. African Journal of Traditional, Complementary and Alternative Medicines. 2011;8(1):1-10.
87. Sasidharan S, Chen Y, Saravanan D, Sundram KM, Yoga Latha L. Extraction, isolation and characterization of bioactive compounds from plants' extracts. African Journal of Traditional, Complementary and Alternative Medicines. 2011;8(1):1-10.
88. Schmid A, Collomb M, Sieber R, Bee G. Conjugated linoleic acid in meat and meat products: A review. Meat Science. 2006;73:29-41.
89. Shahi KS, Didar Z, Hesarinejad MA, Vazifedoost M. Optimized pulsed electric Feld-assisted extraction of biosurfactants from Chubak (*Acanthophyllum squarrosum*) root and application in ice cream. Journal of the Science of Food and Agriculture. 2021;101(9):3693-3706. https://doi.org/ 10.1002/jsfa.11000
90. Shahidi F. Nutraceuticals and functional foods: whole versus processed foods. Trends in Food Science and Technology. 2009;20(9):376-387.
91. Shahidi F, Naczk M. Phenolics in food and nutraceuticals. CRC Press, Boca Raton; c2003.
92. Shahidi F, Naczk M. Contribution of phenolic compounds to flavor and color characteristics of foods. In: Phenolics in food and nutraceuticals. CRC Press, Boca Raton; c2004 p. 443-463.
93. Silva LV, Nelson DL, Drummond MFB, Dufossé L, Glória MBA. Comparison of hydrodistillation methods for the deodorization of turmeric. Food Research International. 2005;38(8-9):1087-1096.
94. Smith RM. Before the injection-modern methods of sample preparation for separation techniques. Journal of Chromatography A. 2003;1000(1-2):3-27.
95. da Costa Pereira SN, *et al*. Anticancer properties of carotenoids in prostate cancer: A review. Histology and Histopathology. 2015;30(10):1143-54.
96. Soria AC, Villamiel M. Effect of ultrasound on the technological properties and bioactivity of food: A review. Trends in Food Science and Technology. 2010;21(7):323-331.
97. Srilakshami B. Food Science. 7th Ed. New Delhi: New Age International Publishers; c2018.
98. Stahl E. Thin Layer Chromatography. Springer-verlag, Berlin; c1965.
99. Swain PK. Utilisation of agriculture waste products for production of biofuels: A novel study. Mater Today: Proc. 2017;4(11):11959-11967. https://doi.org/10.1016/j.matpr.2017.09.117
100. Talekar S, Patti AF, Singh R, Vijayraghavan R, Arora A. From waste to wealth: High recovery of nutraceuticals from pomegranate seed waste using a green extraction process. Industrial Crops and Products. 2018;112:790-802. https://doi.org/10.1016/j.indcrop.2017.12.023
101. Tang W, Zhu X, Ba Z. Bioactive substances of microbial origin 32. In: Cheung PCK, Mehta BM (ed) Handbook of food chemistry. Springer, Berlin Heidelberg; c2015. p. 1035-1060.
102. Trautwein Elke A, *et al*. LDL-Cholesterol Lowering of Plant Sterols and Stanols-Which Factors Influence Their Efficacy? Nutrients. 2018;10(9):1262-1276.
103. Filippos V. Biotechnology of flavonoids and other phenylpropanoid- derived natural products. Part I: Chemical diversity, impacts on plant biology and human health. Biotechnology Journal. 2007;2(10):1214-1234.
104. Vieira AR, *et al*. Fruits, vegetables and lung cancer risk: a systematic review and meta-analysis". Annals of Oncology. 2016;27(1):81-96.
105. Weiss J, wesiss T. Handbook of Ion Chromatography. Wiley-VCH, Weinheim, Germany; c2004.
106. Wink M, Schmeller T, Latz-Br€uning B. Modes of action of allelochemical alkaloids: interaction with neuroreceptors, DNA, and other molecular targets. Journal of Chemical Ecology. 1998;24(11):1881-1937.
107. Zerrif SEA, el Khallouf F, Oudra B, Vasconcelos V. Seaweed bioactive compounds against pathogens and microalgae: Potential uses on pharmacology and harmful algae bloom control. Marine Drugs. 2018;16(2): 55. https://doi.org/10.3390/md16020055
108. Zhang X, Chen F, Wang M. Bioactive substances of animal origin 31. In: Cheung PCK, Mehta BM (Ed) Handbook of food chemistry. Springer. Berlin Heidelberg; c2015. p. 1009-1034.
109. Zhao Y, Wu Y, Wang M. Bioactive substances of plant origin 30. In: Cheung PCK, Mehta BM (Ed) Handbook of food chemistry. Springer. Berlin Heidelberg; c2015. p. 967-1008.
110. Bhatnagar S, Sutton RS, Ghavamzadeh M, Lee M. Natural actor–critic algorithms. Automatica. 2009;45(11):2471-82.
111. Bhatnagar A, Sillanpää M. Applications of chitin-and chitosan-derivatives for the detoxification of water and wastewater: A short review. Advances in colloid and Interface science. 2009;152(1-2):26-38.