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Shilpa Krishnan PV
Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Dr. Shweta Sharma
Assistant Professor, Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Dr. Shweta Sharma
Assistant Professor, Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Health benefits of black carrot and different types of extracting techniques for bioactive compounds

Shilpa Krishnan PV and Dr. Shweta Sharma

Abstract
The black carrot (*Daucus carota* L. ssp. *sativus* var. *atrorubens*) is a popular root vegetable due to its high nutritional value and potential health advantages. Anthocyanins, which are strong antioxidants with anti-inflammatory, anti-cancer, and anti-diabetic activities, are abundant in black carrots. Furthermore, the root vegetable is high in fiber, vitamins, and minerals, all of which have been linked to a variety of health benefits such as improved digestive health, a decreased risk of acquiring chronic illnesses, and improved cognitive function. Studies show that eating black carrots may help treat and prevent various conditions, including diabetes, heart disease, and obesity. Black carrot has also been demonstrated to offer potential advantages for skin health and wound healing. This study covers the pharmacological advantages, nutritional benefits, health advantages, various bioactive component extraction methods, and microencapsulation of bioactive compounds present in black carrots.

Keywords: Black grape, black carrot, antioxidants, anthocyanins

Introduction
Black carrot, commonly known as *Daucus carota* subsp. *sativus* var. *atrorubens*, is a root vegetable that is native to Asia and Europe. Due to the presence of anthocyanins, a flavonoid pigment with several health advantages, it is distinguished by its unusual dark purple-black colour. Black carrots are a rich source of antioxidants, which help prevent cell damage and reduce the risk of chronic illnesses. Additionally, they contain dietary fiber, which aids in digestion and promotes regularity. In addition, black carrots are a great source of calcium, potassium, and vitamin A, all of which are essential for good health. (Alam *et al*., 2019) [52]. In the Eastern Region, carrots have been cultivated as ancient crops and used as a source of vegetable-based sustenance since at least 3000 years ago. Because many fruits and vegetables have a high concentration of anthocyanins, a type of flavonoid pigment that gives them their vibrant colours. black carrots have a distinctive reddish-purple colour. Additionally, the antioxidant qualities of these anthocyanins can aid in preventing oxidative damage to the body. About 488 mg/L of anthocyanins were detected in the juice of black carrots. The primary anthocyanins in black carrots were cyanidin-based, and it was discovered that they were acylated with different sugars including ferulic acid, sinapic acid, or coumaric acid (Baria *et al*. 2021a) [6].

The numerous phytochemicals and vital elements found in black carrots, which have a lot of health benefits, are a great source of nutrition. These phytochemicals include the provitamin A-producing carotenoids, phenolic compounds, ascorbic acid, tocopherol, vitamins D, K, B1, B6, biotin, and polyacetylenes, which act as antioxidants. Furthermore, carrots are 88% water, 1% protein, 7% carbohydrates, 0.2% fat, and 3% fibre. The nutritional value and bioavailability of these elements can both be impacted by cooking (Char *et al*., 2017) [53]. Carrots include fructose, sucrose, and glucose as their main sources of carbohydrates. The protein content, which is just about 1%, is also quite low. The cultivar of the carrot can also affect how much nutritional fibre and carbs are present. Up to 92% of dietary fibres are made up of cellulose and hemicellulose, with lignin at 4%. About 8% to 50% of the total fiber in carrots is soluble fiber, which is composed of fermentable hemicellulose and pectin.

Due to worries about the safety of synthetic dyes, some of which have been outlawed, there has been a recent trend towards the use of natural colorants. The demand for natural products among consumers also fuels this trend. Black carrots have become a well-liked natural source of culinary colouring. As a natural substitute for synthetic colourants, black carrot extracts are frequently employed in various foods and beverages, including juices, candies, ice cream, jams, and alcoholic beverages.

Anthocyanins may also provide health advantages due to their color characteristics, including a decreased risk of coronary heart disease, a decreased risk of stroke, anticancer qualities, anti-inflammatory effects, and better cognitive function. (Sravani *et al*. 2017a) [43]

Studies on black carrot extracts have revealed potential benefits for treating menopausal symptoms, reducing the number of reactive oxygen species (ROS) in the digestive system, and preventing tissue degeneration and oxidative DNA damage. Researchers discovered in one study that the cyanidin and malvidin present in black carrot aqueous extracts fermented with Aspergillus Oryza can help avoid menopausal symptoms in estrogen-deficient rats with diet-induced obesity, including reduced energy. This shows that using black carrots as a natural treatment for menopausal symptoms may be possible. Reactive oxygen species (ROS) in the digestive system can be reduced by eating purple carrots, including black carrots, according to a different study. For instance, it was discovered that carrot extract at 1 mg/mL prevented intracellular ROS generation and decreased oxidative DNA damage. Additionally, it has been demonstrated that black carrot extract at doses of 400 mg/L or 800 mg/L reduces liver cell levels of 8-hydroxy-2'-491 deoxyguanosine (8OHdG) and tissue degeneration brought on by calcium poisoning. This shows that black carrot extract may have value as a homeopathic treatment for oxidative stress and tissue damage in the body. (Olejnik *et al*., 2016).

To separate pure components from a solid or liquid mixture, extraction is an appropriate procedure. Many different extraction methods exist, including the traditional heat reflux, soxhlet, boiling, agitating, soaking, and distilling as well as the emerging technologies of ultrasonic, microwave, pulsed electric fields, supercritical fluid, and high pressure. Modern extraction aid methods should hasten extraction, utilise less solvent, and increase extraction effectiveness in order to reduce costs and the environmental impact of the operation. The first stage in separating the desired component from the raw ingredients is extraction. The target chemical must be extracted after the plant material has been dried out and ground to enhance surface area and decrease particle size. For solvent extraction, solvent selection is a crucial step.

Table 1: Bioactive Components of Black Carrot

Main Group	Type of component	Reference
Anthocyanin	Malvidin-3-O-glucoside, delphinidin-3-O-glucoside, peonidin-3-O-glucoside, and cyanidin-3-O-glucoside	(Alezandro *et al*., 2013) [54].
Carotenoids	Lutein, zeaxanthin, lutein, beta-carotene, and alpha-carotene	(Baranski *et al*., 2012) [55]
Vitamin C	Ascorbic acid	(Sun *et al*., 2009) [44]
Phenolic acid	Hydroxybenzoic, protocatecuic, gallic, syringic, chlorogenic, caffeic, cumaric, ferulic	(Moustafa *et al*., 2016) [56]
Flavonoids	Quercetin, isorhamnetin, and kaempferol	(Algarra *et al*., 2014)
Minerals	Calcium, magnesium, phosphorus, potassium	(Olejnik *et al*.,2016)

Fig 1: Health benefits of black carrot

Metabolic syndrome and cancer prevention

Black carrots contain bioactive substances, notably anthocyanins, which may help prevent or treat the metabolic syndrome, according to studies. It has been demonstrated that antioxidant and anti-inflammatory capabilities exist in anthocyanins. They may also lessen blood pressure and enhance insulin sensitivity, both of which are significant metabolic syndrome risk factors. Purple carrots' bioactive ingredients offer protection from a number of diseases, including cancer, CVD, obesity, and diabetes. Due to their high nutritional value and effective storage capabilities, carrots play a vital role in the fibre and nutrition the body receives. By reducing inflammatory markers, anthocyanins and phenolic acids have been effectively proven to reduce metabolic changes and inflammation in animals (Ekinci *et al*., 2016) [57]. Additionally, polyacetylenes generated from plant extracts are recognised for supporting good health and have been demonstrated *in vitro* tests to have anti-inflammatory and anti-cancer effects. They also contain anti-inflammatory, anti-fungal, and anticoagulant activities, which are similar to this. Black carrots may help in the prevention of cancer and the metabolic syndrome. In animal tests, the anthocyanins in black carrots were found to have anti-cancer qualities by causing cancer cells to die and preventing tumour development and spread. According to Sevimli *et al*. (2013) [58], black carrots' antioxidant capabilities may have a preventive impact against some cancers, such as colon and breast cancer.

Anti-Diabetic Potential of the black carrot

According to a recent hypothesis, the compounds present in purple carrots may have an effect on how glucose is metabolized. The enzymes -amylase, -glucosidase, and -dipeptidyl peptidase have been successfully inhibited by purple carrot anthocyanins, notably cyanidin 3-xylosyl galactosidase. Furthermore, it was shown that the glycosidic side of cyanidin chains had no appreciable influence on the inhibition of -glucosidase (mono glucoside has a comparable effect to glycoside). It was discovered that the acylated compounds had a significantly greater effect than anthocyanin-3-glycosides. Black carrots contain anthocyanins that are acylated to a degree of 58%. Another study that made use of animal models detailed and assessed the functions of the phenolic compounds in purple carrots in rat kidney and liver damage, glucose metabolism, and antioxidant defense.

Researchers show that blood triglyceride levels considerably dropped after eating purple carrot juice for 30 days, and superoxide dismutase activity dropped in a dose- and time-dependent manner. Consequently, blood glucose levels were not significantly affected, and the kidney and liver's ability to function were not negatively affected. (Badshah *et al*., 2013) [59]

Anti-Inflammatory and Anti-Cancer Potential

The protection of a wide range of diseases, such as cancer, aging, metabolic events, immunological problems, and neurological diseases, may depend heavily on the presence of antioxidant-active chemicals. According to certain studies, the bioactive components in black carrots may be able to decrease inflammation and combat cancer. The biological activity and antioxidant potential of pure anthocyanin from several anthocyanin-rich plants were investigated. The outcomes demonstrated biological and antioxidant activity in all of the pure anthocyanin samples tested, with anthocyanin contents ranging from 4.9 to 38.5 mg/g DW. (Poudyal *et al*., 2010) [61] Different anthocyanins displayed variable degrees of radical scavenging activity, and this was particularly prominent in samples containing non-acylated anthocyanins. As a result, pure anthocyanins decreased the synthesis of endothelial inflammatory antigens, indicating a possible benefit for cardiovascular protection. Structure differences also had an impact on that outcome. Non-acylated anthocyanins performed better than those that had been acylated with cinnamic acid derivatives. Purple carrots include elements that may act as anticancer agents, such as carotenoids, which are readily available when purple carrots are consumed. Oxidative stress in the human body is inversely correlated with high levels of carotenoids. (Wright *et al*., 2013) [62]

Anthocyanins from black carrots may have anticancer, antioxidant, and chemoprotective properties. The aqueous extract of purple carrot anthocyanins significantly reduced the development of the human colorectal cancer cell line (HT-29). Anthocyanins from purple carrots had more inhibitory effects than anthocyanins from radish or elderberry, and non-acylated anthocyanins were more efficient than acylated ones in killing different cancer cells in people. The IC50 values for the cell lines MCF-7, SK-BR-3, and neuro-2A were the lowest. Because they show low cytotoxicity in the healthy normal cell line VERO and do not kill typical, healthy cells, purple carrot phenolics seem to be a superior alternative. (Poudyal *et al*., 2010) [61].

Application of black carrot in the food industry

In addition to juices, smoothies, ice cream, confections, and baked goods, black carrot is utilized as a natural food colorant in many other culinary products. The plant's anthocyanin pigments are the source of the carrot's rich purple-to-black color. The flavor of the food product is unaffected by these pigments, which are stable under a variety of processing circumstances (Akhtar *et al*. 2017) [3]. Natural plant extracts have been widely used in the food industry in recent years as natural colorants, antioxidants, and antimicrobials due to consumer health concerns. Anthocyanins have seen an increase in demand in the food sector as a natural colorant, particularly during the past ten years, for items like jams, canned foods, dairy products, drinks, or confectioneries to restore or improve color (Montilla *et al*., 2011) [24]. black carrot anthocyanins are available at the market in both liquid and powdered form. Turkish plain yogurt was tinted by the inclusion of black carrot anthocyanins in capsule form. To replicate fruity yogurt products, whey protein capsules at four different quantities (5, 10, 15, and 20% w/w) were added to the yogurt and homogenized (Ultra-Turrax T25 basic IKA-WERKE) for 30 seconds at 11,200 rpm. Using a Hunter Colorflex, the CIE a* value, which represents the redness of yogurt samples, was determined. (Özen, Akbulut, and Artik 2011) [27]

Different types of techniques for extracting bioactive compounds

The variety of primary and secondary metabolites found in plants and microorganisms in nature, as well as their many uses in a variety of sectors, call for the adoption of a wide range of extraction techniques that are optimized for each kind of metabolite (Zhang *et al*. 2018) [60]. Extraction is the procedure used to acquire an interesting product from a raw material. It may be roughly divided into conventional and non-traditional varieties. Maceration, decoction, and Soxhlet extraction are examples of conventional techniques. The majority of solvents used in industrial-scale extraction equipment, including hexane, are petrochemical industry by-products. High energy use and extensive use of these solvents have negative environmental effects.

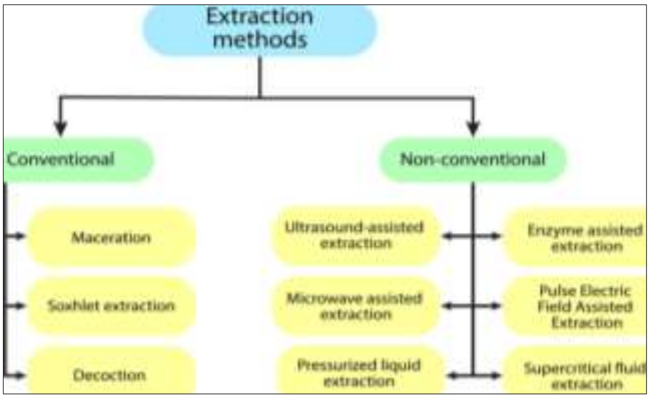

Fig 2: Novel extraction techniques

Pressurized liquid extraction (PLE)

The extraction of bioactive chemicals from plant materials is frequently accomplished using the pressurised liquid extraction (PLE) method. Response surface methodology (RSM) was used to optimise the PLE process for the extraction of anthocyanins from black carrots. On the extraction efficiency, the influences of pressure (10–20MPa), temperature (40–60 °C), and extraction time (10–30min) were assessed. With an extraction efficiency of 32.5 mg/g, 15 MPa, 50 °C, and 20 min were discovered to be the ideal PLE conditions. Using high-performance liquid chromatography (HPLC), the anthocyanin concentration of the black carrot extract was examined. The extract was discovered to include a total of 24.8 mg/g of the three principal anthocyanins cyanidin-3-O-rutinoside and peonidin-3-O-glucoside. The essential instrumental requirements for PLE are not particularly challenging that includes a pump, extraction cell, pressure valves, oven, and collecting vessel. The pump is necessary to inject the solvent into the extraction cell as well as to push the extract outside when the extraction is finished. This pump should be able to achieve the required pressure (often between 35 and 200 bar) throughout the extraction. The extraction solvents utilised should be oxygen-free in order to reduce the amount of oxidation of the bioactive and prevent cavitation in the pump. This is often done using helium purging or ultrasonic degassing. To always maintain the extraction's set pressure, the extraction cell has to have two on/off valves. (Agcam, Akyıldız, and Balasubramaniam 2017) [1]

The extraction cell is normally made of stainless steel and is capable of withstanding very high pressures. The extraction cell is housed inside an oven, which controls the applied temperature. About 200 C is the maximum operating temperature for the majority of instruments. A collection vessel is also required. More sophisticated instruments can be employed despite these essential instrumental requirements. If dynamic extraction rather than a static procedure is desired, for example, more accurate pumps may be needed to maintain a precise flow rate during the whole extraction process. To guarantee that the solvent enters the extraction cell at the proper temperature in this case, it is important to include a heating coil within the oven. In most PLE instruments, a system venting mechanism is also a typical feature. A nitrogen circuit can also be included to enable full system purging after extraction and to guarantee that all of the extracting solvents reach the collecting vial after extraction is complete (Kumar *et al*. 2022) [21].

Microwave Assisted Extraction (MAE)

A few advantages of the MAE approach are its minimal solvent use, great repeatability, ease of manipulation, and quick extraction times, temperatures, and energy input. When MAE uses microwave energy to create molecular dipole rotation, the solvent temperature rises quickly, breaking down the plant cell wall and promoting component extraction. Microwave-assisted extraction method uses microwave radiation that moves polar molecules and spins dipoles to heat liquids in order to promote the transfer of target compounds from the sample matrix into the solvent. Microwaves are non-ionizing electromagnetic waves with a frequency in the range of 300 MHz to 300 GHz (between radio frequency and infrared at the higher frequency). Domestic microwave ovens often utilize the 2450 MHz frequency for extraction and other uses. In MAE, the sample is heated for a brief period of time using microwaves with the usual energies of 700W. Microwave extraction provides for shorter extraction periods than standard extraction methods, which considerably reduces the quantity of solvent required. (Guldiken, Boyacioglu, and Capanoglu 2016) [14]

In the extraction of MAE, the solvent is crucial. Typically, materials are homogenized, mixed with a solvent, and the suspension is temporarily irradiated at a frequency greater than 2000 MHz for MAE. To avoid boiling, heating is often done numerous times with cooling intervals in between. The efficiency of this method is comparable to that of traditional Soxhlet extraction, although it may be completed considerably more quickly. There are two methods for applying microwave energy: the crude, but labor-intensive, selective heating of the target components (Sadilova, Carle, and Stintzing 2007) [38]. The crude method involves simply heating a combination in its whole using absorbent containers and solvents (oven-type apparatus with samples under closed-vessel conditions). According to the results of the current study, microwave-assisted extraction is a more effective approach than other traditional extraction techniques, including ultrasonication, for the extraction of bioactive substances including total phenolics, anthocyanins, and other antioxidants. Therefore, it may surely succeed as a cost-effective and environmentally acceptable method of extracting polyphenolic compounds for use in medicine from black carrot pomace and other food sector by-products.

Enzyme Assisted Extraction (EAE)

In comparison to non-enzymatic approaches, recent research on EAE has revealed greater recovery, quicker extraction, less energy use, and reduced solvent usage. Macromolecules like proteins and polysaccharides make up the micelles that make up the cell wall and cell membrane. The primary challenges of extraction in natural products are the denaturation and coagulation of proteins at high temperatures (Q.W. Zhang 2018 *et al*.,). Enzymes are extremely specific, regioselective, and often catalyze reactions under moderate circumstances, which further encourages the recovery of bioactive molecules. Thus, cellulases, hemicelluloses, pectinases, or combinations of them, are used based on the substance to be extracted. As a result, the cell walls' structural integrity is actually compromised and their porosity is enhanced, making it easier to remove the desired components EAE will boost the extraction efficiency because enzymes have a hydrolytic impact on the cell membrane, cell wall, and macromolecules inside the cell, which increases the extraction of certain compounds. The function of the enzyme in the rupturing and dissolution of a cell wall structure and extraction of target compounds can be impacted by a number of significant aspects. (Manzoor *et al*. 2019a) [22]

Due to its natural coloring, antioxidant, and medicinal characteristics, anthocyanins are often employed in the food, cosmetics, and pharmaceutical sectors. To extract the greatest amount of water-soluble bioactive components from black carrots, isozyme-assisted extraction was optimized. The recovery of total soluble components and anthocyanins yield increased with minimal browning parameters at the ideal circumstances (enzyme/substrate: 0.2% v/w, 50 C, 58.4 min) for VAE. Viscozyme's multi-catalytic activity on the black carrot's cell wall components led to the effective extraction of bioactive with strong antioxidant activity. With the ability to protect these organic hues from thermal deterioration and enzymatic degradation, this extraction method can be used as an effective, environmentally friendly, and economically viable method for the extraction of anthocyanins from black carrots and other fruits and vegetables in food processing industries.(Kamiloglu *et al*. 2015a) [16]

Ultrasound-Assisted Extraction (UAE)

UAE employs sonic cavitation to break down cell walls, reduce particle size, and improve the interaction between the solvent and the target substance. Due to the ability to use a variety of solvents with various polarities, it is particularly adaptable. Furthermore, it enables quick extraction, which is essential for preventing the deterioration of labile chemicals. The creation of UAE procedures may thus mark a turning point in sustainable development because they are economical and consume less solvent. The Ultrasound assisted extraction technique is a method (Manzoor *et al*., 2019) [22] that allows for the efficient extraction of large amounts of flavonoids in a cost-effective manner. It also helps to improve the release of the targeted molecule while also enhancing solvent penetration inside the cell walls.

In the Ultrasound assisted extraction, only a small portion of the ultrasound spectrum-primarily power ultrasounds-is used. It is well known that processes like cleaning, degassing, solubilization, homogenization, emulsification, sieving, filtering, and crystallization are significantly sped up by power ultrasounds, which have frequencies between 20 kHz and 100 MHz. Power ultrasound involves the mechanical and chemical effects of cavitation. When subjected to ultrasound, microbubbles swiftly form, grow, and oscillate in a liquid; if the acoustic pressure is high enough, they may eventually rupture violently. Close to a solid surface, these collapses produce shock waves and micro-jets that clean, erode, and fracture the surface. Non-destructive analysis use low-intensity ultrasound to collect information on the physicochemical properties of fruits, including their firmness, ripeness, sugar content, and acidity. High-intensity ultrasound, on the other hand, can alter the chemical or physical properties of food. It offers a wide range of high power (10-1000W/cm2) and low frequency (16-100 kHz). High-intensity ultrasound has a variety of uses, including accelerating and enhancing the effectiveness of extraction.

Surface tension, viscosity, and vapor pressure are three physical properties that might influence cavitation intensity in a liquid phase and should be considered while selecting the best extraction solvent for the UAE. Although cavities are more easily formed in solvents with high vapour pressure, low viscosity, and low surface tension, cavitation intensity increases in solvents with low vapour pressure, high viscosity, and high surface tension. High surface tension, density, and viscosity solvents often have a greater cavitation threshold but harsher conditions once cavitation begins. The use of ultrasound in extraction procedures requires two fundamental prerequisites: a liquid medium (at least 5% of the total medium must be liquid) and a source of high-energy vibrations (ultrasounds) (Vardanega *et al*. 2014) [63]. The UAE of bioactive compounds is becoming increasingly adept at translating knowledge into technology for corporate gain. Analytes may be extracted in a concentrated condition with minimal to no contamination or artefacts with this novel approach. The benefits of the UAE in terms of yield, selectivity, operating time, energy input, and even thermolabile material preservation are well demonstrated by recent improvements.

Supercritical fluid extraction

The fundamental tenet of this method is the increase of the target molecule's temperature and pressure over its critical value. Some of the benefits of using super-critical solvents are often employed. By altering the temperature and pressure, these solvents may modify their density. Using solvents at pressures and temperatures over their critical points is the foundation of SFE. Supercritical fluids' physical characteristics fall in the range between a gas and a liquid. For example, a supercritical fluid's diffusivity is halfway between that of a gas and a liquid, whereas the fluid's viscosity is halfway between that of a gas and a liquid. With large values close to the critical point, supercritical fluids' thermal conductivity is comparatively high. The use of harmful organic solvents is drastically decreased (often to nothing) by SFE, which is one of its most advantageous features. In this regard, SFE employing green solvents has been recommended as a safe substitute for risky procedures, and as a result, SFE has discovered an expanding niche. Here, the most popular solvent for removing bioactives from natural sources is carbon dioxide. In reality, CO_2 possesses a number of intriguing qualities for the extraction of bioactive. (Chatterjee *et al*. 2021) [7]

CO_2 has a high diffusivity in supercritical circumstances, but the strength and density of its solvent may be easily changed by adjusting the temperature and pressure used. The ability to produce solvent-free extracts with this method and supercritical CO_2 is another crucial feature. The system is depressurized when the extraction process is finished to allow the CO_2 to exit the matrix as gas, leaving the chemicals that were extracted from the matrix and solubilized in the CO_2 at high pressures behind in the collecting vessel. The extended use of supercritical CO_2 for bioactive chemical extraction can be attributed to these features. On both solid and liquid matrices, SFE is possible. An extraction vessel with a predetermined internal capacity for solid materials makes up the equipment. (Zadernowski *et al*. n.d.-a) [48]

Table 2: Novel extraction techniques and their main principles with affecting parameters:

Techniques	Principles	Parameters	References
SFE (supercritical fluid extraction)	Bioactive chemicals are extracted using supercritical fluids.	Physical parameters: pressure, temperature, flow rate, co-solvent, density	Chia *et al*., 2015 [64]
UAE (ultrasound Assisted extraction)	1. Acoustic cavitation 2. Increased mass transfer by turbulence and acoustic streaming. 3. Disruption of cellular matrix by shock waves and microjets. 4. Reduction in particle size to increase surface area	Physical parameters: Frequency (Intensity/power/ amplitude)	Pandey and Shrivastava, 2018 [65]
EA (enzyme Assisted extraction)	1. Degradation and disruption of cell walls 2. Breakdown of large macromolecules 3. Release of bound target bioactive from macromolecules	Enzyme specificity, concentration, pH and temperature specific for the enzyme	(Rao, 2010 *et al*.,) [66].
MAE (microwave Assisted extraction)	1. uses microwave energy to extract bioactive compounds 2. Rapidly increase the local temperature and pressure	Physical parameters: Frequency such as microwave power Reactor parameters: Stirring, refluxing, temperature and pressure control	Kumar *et al*., 2016 [67]

Microencapsulation of bioactive compounds

The bioactive compounds in black carrots are susceptible to degradation and loss of potency during processing and storage. Microencapsulation is a promising technique to protect and deliver the health-promoting compounds in black carrot-based products. The process of coating microscopic solid, liquid, and gaseous particles with a continuous layer of synthetic or natural polymer, known as microencapsulation, protects them from the environment while allowing for a controlled release of particles at the appropriate time, pace, dosage, and location of the action (Jyothi *et al*., 2010) [68]. Microparticles (microcapsules, microspheres, and microemulsions) are the name given to the resulting structure. There are many different sizes, compositions, and uses for microparticles. Several technical difficulties are involved in creating functional meals by adding bioactive ingredients. Probiotics, minerals, vitamins, phytosterols, lutein, fatty acids, lycopene, and antioxidants are among the bioactive substances that can be better delivered into food by microencapsulation. The food industry has developed a number of microencapsulation technologies that hold promise for the creation of functional meals.

Additionally, these technologies could facilitate the efficient transport of bioactive substances to the digestive system. Future studies are likely to concentrate on delivery-related issues and the potential application of co-encapsulation methodologies, which combine two or more bioactive ingredients to produce a synergistic effect. The food and pharmaceutical sectors have exploited bioactive chemicals derived from various plant sections as health-promoting agents. They may be easily acquired from plant extracts made by solvent extraction from plant components. Bioactive substances have been shown in the pharmaceutical sector to be successful in treating cancer, obesity, infection, and cardiovascular problems. Additionally, their benefits for animal health are being researched. (Yousuf *et al*., 2016) [69].

Table 3: Type of Encapsulation

Sr no	Type of Encapsulation	Principle	Materials Used	Advantages	Disadvantages	Reference
1	Spray drying	A spray dryer is fed with homogenized core and wall material, which is then atomized using a nozzle using the appropriate solvents. Due to the high temperature, water evaporation occurs, and capsules also precipitate at the bottom.	Polysaccharides (Maltodextrin, gum Arabic), proteins (whey protein isolate), alginate	• Used for hydrophobic and hydrophilic polymers • Suitable for heat labile and highly viscous solutions (300mpa)	• Loss of product. • Degradation of heat-sensitive products • For limited wall materials • Fiber formation is sometimes achieved	(Cruz *et al*., 2012) [70]
2	Freeze-drying/ lyophilization	The homogenized material is frozen by lowering the pressure in the area and applying enough heat to the frozen water. This allows the water to transition straight from the solid phase to the gas phase.	Dextran, chitosan, polyvinyl alcohol, gelatin, carrageenan, gum arabica, soy protein, guar gum	For thermosensitive compounds (water-soluble natural aromas and essence, drugs)	Expensive and Time Consuming	(Kandansamy & Somasundaram, 2012) [71]
3	Coacervation	Phase separation of two or more polymers in a solution, where one polymer forms the wall of the capsule and other is the core material	Polymers (gelatin, chitosan, alginate)	• Low cost, easy to handle • High encapsulation efficiency	• Limited control over particle size, cross-linking between bioactive compounds and encapsulating material can occur	(Jyothi *et al*., 2010) [68]
4	Emulsification	Two immiscible liquids that are either utilised directly as liquids or dried into powder form are used to create an emulsion mixture.	Oil and Water system	Both hydrophilic and hydrophobic food compounds can be encapsulated	• Droplets are bigger in size and need separation • Always coupled with another encapsulation method	(Alric *et al*., 2013)
5	Liposomes	Phospholipid bilayers are scattered across the core, encapsulation, and aqueous environment.	Cholesterol and natural and/ or synthetic phospholipids	• Site targeted and efficient • controlled drug delivery • Both hydrophilic and hydrophobic compounds can be encapsulated • Stable and easy production	• Issues with sterilization and stability • Expensive	

Applications

Many companies, particularly the food and pharmaceutical sectors, employ microencapsulation technology because it may boost solubility, improve stability, and improve the substances with controlled release capabilities, including medicines, enzymes, essential oils, and antioxidants. As a result, the emphasis of this section is on how microencapsulation is used in various sectors.

Functional additives are used in the food business to enhance flavour, colour, and texture qualities as well as to lengthen product shelf lives. Additionally, substances with functional health advantages, such probiotics and antioxidants, are highly sought-after (Borgogna *et al*., 2010) [72]. The majority of these compounds, however, have limited stability and are quickly broken down by the environment. Therefore, it is crucial to develop high-stability bioactive molecules. One approach to solving these problems is microencapsulation. Numerous studies on the creation of high-efficiency microcapsules and their uses in the food sector have been conducted recently. Increasing stability, disguising flavour, and controlling drug release are all possible with the help of the microencapsulation method, which has been widely employed in the pharmaceutical sector (Mendanha *et al*., 2009) [73].

When delivering a water-soluble peptide medication to the colon, investigated the utilization of microcapsule formulations. Peptides often have minimal membrane permeability and are heat-sensitive. Thus, this work aimed to maintain the permeability needed for a delayed-release profile of macromolecular medications while maintaining the stability of heat-sensitive pharmaceuticals. The findings demonstrated that poly (EA/MMA/HEMA) with a molar ratio of 95:85:40 had good film-formability at 40 °C. For the administration of water-soluble medicines in colon-specific delayed-release microcapsules, these circumstances could be suggested as an acceptable preparation method. It appears that the growth of functional foods is a long-term trend with significant commercial potential. As a result, the food business has adopted new technologies (Santiago and Castro, 2016). One of the inventions that are now attracting attention is microencapsulation. Furthermore, by utilizing microencapsulation methods, several researchers are creating unique elements for application in food items as functional additives, preservatives, colorants, and tastes.

The pharmaceutical industry has a lot of promise for using drug microencapsulation since it allows for the controlled and extended release of drugs for a variety of therapeutic applications. Encapsulated medications still can't be delivered to specific organs, though. It's difficult to get microencapsulated pharmaceuticals with excellent repeatability.

Conclusion

In light of their abundance of nutrients, bioactive compounds, and enzymes, this review came to the conclusion that incorporating black carrots in food products may be beneficial. Under a range of processing conditions, polyphenol anthocyanins from black carrots are remarkably stable. The biological actions of some of the phytochemicals found in carrots, such as phenolic compounds (particularly chlorogenic acid), carotenoids, polyacetylenes, and ascorbic acid (vitamin C), have demonstrated that they have the potential to improve human health through their anticancer, antioxidant, anti-inflammatory, antibacterial, plasma lipid modification, and serotonin reuptake actions. The concentration and makeup of phytochemicals are affected by a number of factors, including carrot genotype (color variations), environmental conditions, and the processing and storage of carrot products. Black carrots are particularly high in other polyphenols, which are thought to protect against a number of degenerative diseases, in addition to having an extraordinary anthocyanin profile. Despite being incredibly nutritious, black carrot is largely ignored in India. Despite being quite affordable, only a small amount is consumed. This vegetable has to get greater acceptance if we are to utilize it to the fullest.

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