REVIEW OF LITERATURE

CHAPTER 2

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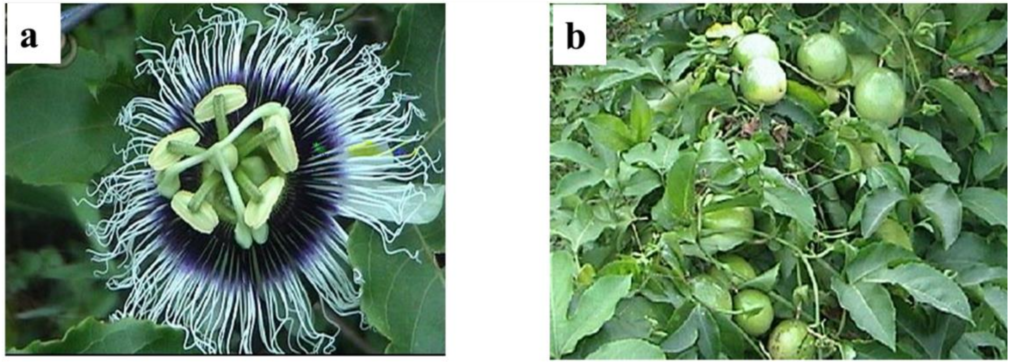
2.1. Passion fruit

Passion fruit is a delicious, underutilised exotic fruit that grows widely in tropical and subtropical regions of the world. India produced 123.94 thousand tonnes of passion fruit, with an estimated 19.01 thousand hectares land under cultivation [150]. The majority of the cultivation is restricted to the states of Kerala, Tamil Nadu, Karnataka, and North-East. Northeast India, particularly Manipur and Nagaland, contribute more than 70 percent of passion fruit to the nation [150]. This tropical fruit is primarily consumed fresh, is widely utilised in traditional medicine, and is also being employed by the food processing, pharmaceutical, and cosmetics sectors. This is because of the fruit's health-promoting qualities and intense, delicious, and distinctive aroma and flavour. [1,4,7].

According to its commercial production around the world, yellow or sour passion fruit is the most widely cultivated and industrially used edible variety, which accounts for over 95% of all fruit farms [35,122]. Due to its higher pulp content and acidic taste, its processing industries/markets are mainly focussed on pulp and juice industries [35]. However, other sweet-flavored edible species like orange and purple passion fruit are eaten fresh or juiced [122], but their production is limited. The purple-coloured fruit is smaller in size (40-90 mm in long and 35-70 mm in diameter) than the yellow passion fruit, measuring roughly 60-120 mm long and 40-70 cm in circumference with a powerful aroma [136].

As shown in **Table 2.1**, carbohydrates, vitamins, and minerals-nutrients necessary for sustaining daily life-can be found in abundance in passion fruits. As an exotic tropical fruit, passion fruit has a high nutraceutical value and is rich in bioactive substances like phenolic compounds, anthocyanins, carotenoids, and fibres etc., which show a variety of health benefits, including antimicrobial, antioxidant, anti-hypertensive, anti-inflammatory, hepatoprotective, sedative, and antidepressant abilities [35,60,110].

Fig. 2.1. presents the various parts as well as stages of passion fruit. As shown in **Fig. 2.1e.,** whole fruit is composed of three separate parts - mainly pulp/juice, seed, and peel. A significant issue in the passion fruit juice producing sector is the amount of waste produced, which primarily results from the discarding of peels and seeds, as this waste comprises more than half (about 60%) of the whole fruit weight [107].



Above **Fig. 2.1a** and **1b** is adopted from Passion Fruit -Technical Bulletin, ICAR Research Complex for NEH **[79]**

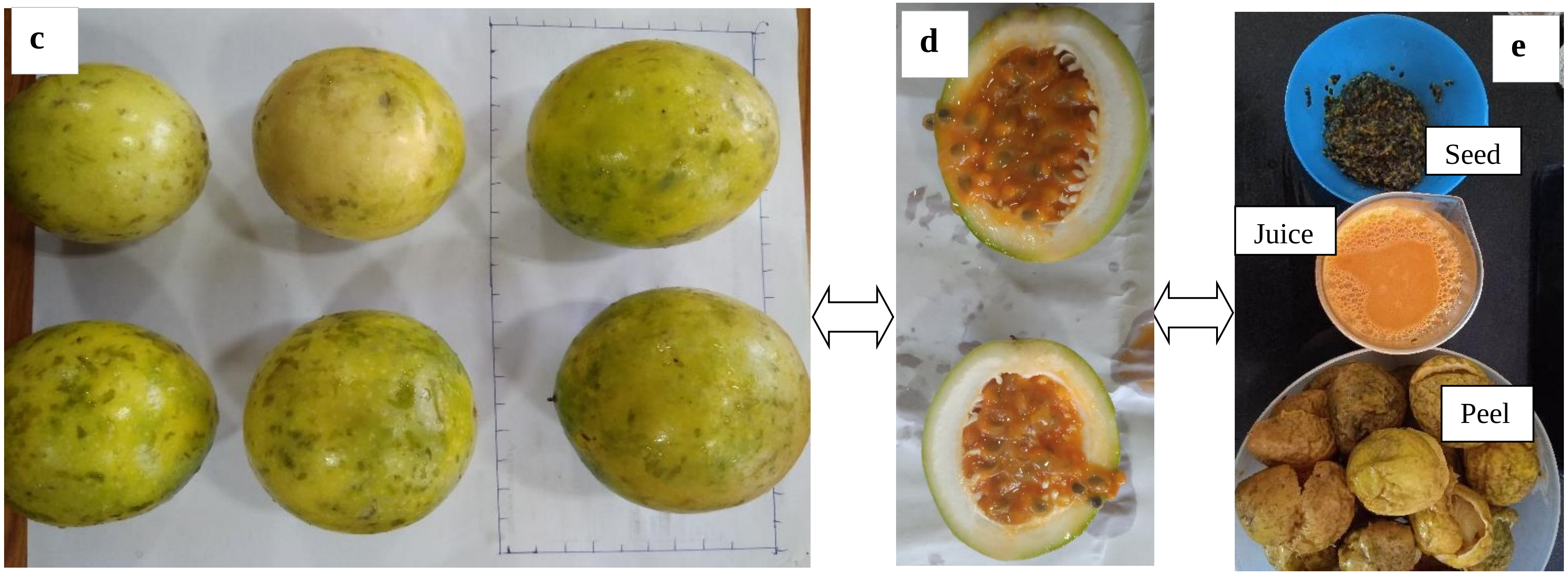


Fig. 2.1. Images of passion fruits (yellow) of (a) Flower **[79]**, (b) Tree & flower **[79]**, (c) Whole passion fruit, (d) Inside passion fruit (cut), (e) Different parts of passion fruit.

Bioactive compounds present in these fruits are not only in the edible pulp portion but also in the peel and seeds, occasionally even in greater quantities than the edible sections (**Table 2.1**) [35,102,122]. Many efforts have been made in recent years to use the appealing nutritional and functional qualities of passion fruit for the benefit of human health by mixing them into or developing a wide range of products, such as ice cream, cake, jam, yoghurt, tea, wine, vinegar, soup, sauces, and so on [5,6,7,21,25] as well as conventional medications and a moisturising agent for cosmetics [166]. Additionally, research has concentrated on examining trash recovery methods and new applications of the recovered compounds. Traditional medicine has also been manufactured and used in a range of pharmaceuticals based on components, in addition to being used as culinary ingredients [60,122].

2.2. Passion fruit juice and its processing

As the passion fruit is native to Brazil, according to Brazilian law, passion fruit juice (PFJ) is "a non-fermented and not diluted beverage obtained from the edible part of passion fruit (*Passiflora spp*.) through adequate technological process" [50]. It must present the fruit’s characteristic odour and flavor. It ranges in colour from yellow to orange. The following regulations are imposed by Brazilian legislature for PFJ: maximum natural total sugar content of 18.0 g/100 g, with minimum total acidity of 2.5 g/100 g in citric acid, and a minimum soluble solid (ºBrix at 20 ℃) of 11.0 °Brix [50].

Direct extraction of orange-coloured pulpy passion fruit juice (**Fig. 2.1e**) is possible from crushed passion fruit material [5]. The fruit juice shows a distinct flavour and taste, as well as superior nutritional and therapeutic qualities. Fruits have a healthy balance of sugars (reducing and non-reducing), as well as acids (**Table 2.1**). Fruits contain high amount of minerals including sodium, magnesium, sulphur, and chlorides as well as vitamins like vitamin C (30 -50 mg) and vitamin A (1300-2500 IU) in 100 g pulp [121]. To create fruit juice and concentrate, some kind of processing is needed.

The juice has a great flavour and is delectable. The rich aroma and nutrients of the passion fruit include more than 135 aromatic compounds as well as seven different types of organic acids such as ascorbic acid, citric acid, lactic acid, malic acid etc. [175]. Fe, Cu, Mn, Zn, Se, as well as another 21 types of trace elements and an additional 17 types of amino acids including histidine, arginine, and glutamic acid, among which glutamic acid content was the highest, were found in the passion fruit [39]. The passion fruit juice is used as a digestive aid and in stomach cancer treatment [155].

Table 2.1. Nutritional evaluation of passion fruit and its by-products (mean values).

Proximate	**Passion fruit Pulp** [126]		**Yellow passion fruit juice** [126]	**Fresh peel** [172]	**Peel flour** [86]	**Seed** [88]
	Purple	**Yellow**				
Moisture (g/100g)	72.93	85.62	84.21	87.64	7.42	10.8
Energy (Kcal/100g)	97	51	60	29.91	122.95	398.04
Protein (g/100g)	2.20	0.39	0.67	0.67	8.87	10.8
Fat (g/100g)	0.70	0.05	0.18	0.01	3.39	23.4
Carbohydrates (g/100g)	23.38	13.60	14.45	6.78	14.24	36.06
Total dietary fiber (g/100g)	10.4	0.2	0.2	4.33	60.08	17.48
Ash (g/100g)	0.80	0.34	0.49	0.57	6.00	1.46
Calcium (Ca) (mg/100g)	12	4	4	44.51		0.54
Iron (Fe) (mg/100g)	1.60	0.24	0.36	0.89		0.2
Magnesium(Mg)(mg/100g)	29	17	17	27.82		1.54
Phosphorus (P) (mg/100g)	38	13	25	-		1.25
Potassium (K) (mg/100g)	348	278	278	178.40		0.85
Sodium (Na) (mg/100g)	28	6	6	43.77		2.98
Zinc (Zn) (mg/100g)	0.10	0.05	0.06	0.32		0.055
Copper (Cu) (mg/100g)	0.086	0.053	0.05	0.04		0.013
Ascorbic acid (mg/100g)	30	29.8	18.2			
Riboflavin (mg/100g)	0.130	0.131	0.101			
Niacin (mg/100g)	1.5	2.46	2.24			
Folate (µg/100g)	14	7	8			
Choline ((µg/100g)	7.6	4	4			
Vit. A (µg/100g)	64	36	47			
β carotene (µg/100g)	743	419	525			

*Adapted from Corrêa et al., 2016 [35]

The PFJ is extensively used in confectionery and preparation of cakes, pies and ice cream [19]. Considering that passion fruit juice potentially contains a variety of bioactive chemicals that benefit human health, it offers tremendous potential for juice production [121]. Despite the abundance of various health-promoting chemicals, passion fruit pulp and juice's high acidity and astringency make them unpopular for direct consumption [5]. In order to balance the acidity and astringency, PFJ is frequently blended with juices of mango, ginger, pineapple, etc. [19]. The flavour of the final product is enhanced using appropriate material to liquid ratio, the amount of added sucrose, and pH as parameters of the developed blended beverages [175]. A passion fruit based blended beverage with optimized conditions of 1: 3 material to liquid ratio, pH 4.0, and sucrose addition of 8% was developed by Zhu et al. [175] that had red colour and rich flavor and pleasant taste. The yellow colour (commercial) passion fruit, which is used to make juice, has a fairly acidic flavour, thus sweeteners may be added to improve the flavour and Rocha and Bolini [125] found 9.4g/100 mL as equi-sweet concentration of sucrose. Passion fruit-based jam is generally prepared with various ratios of passion fruit skin pulp and juice, sugar, and sodium bicarbonate. Jena [65] developed jam of high overall acceptability using 1:1 ratio of PFJ to skin pulp.

Another concern with the juice is that it spoils easily due to the growth of yeast and bacteria. Normally, at normal temperature, raw PFJ goes through alcoholic fermentation by yeast and alcohol oxidation by bacteria [3]. Kaddumukasa et al. [69] suggested that, unpasteurized fresh juices stored at 24 and 4 ℃ could be safely ingested between one and two days, respectively, therefore some kind of treatments are needed to extend the shelf life. Juice preservation techniques have improved, making it possible to successfully feed large populations in nations with limited fruit production. Our diets have evolved into becoming more diversified and well-balanced as a result of the enhanced preservation and transportation techniques. Foods that spoil quickly are now available all year long. Preservative-I, such as sugar, and Preservative-II, such as benzoic acid, citric acid, etc., were employed to preserve the PFJ [5]. Akpan and Kovo [5] reported that passion fruit juice with 4% sugar preservative spoiled after three days, whereas 4% citric acid maintained the qualities for more than one week, but thereafter the aroma started to fade. Additionally, they discovered that 3% benzoic acid and 4% citric acid kept the juice's characteristics relatively intact for two to three weeks [5]. They also found that using 30% benzoic acid as a preservative allowed the juice to retain its colour, flavour, and scent for at least one month [5].

Consumers prefer high quality fruit juice that is nutritious (**Table 2.1**.), has minimal chemical preservatives, and maintains the natural characteristics while conforming to legislative requirements. Standard thermal treatments are typically used as an alternative to chemical preservation. Fernandes et al. [50] observed how the quality parameters of PFJ changes as a result of homogenization and thermal pasteurisation. They discovered that homogenization increased the retention of variables like vitamin C, anthocyanins, carotenoids, and colour, and that these variables were impacted during pasteurisation of passion fruit juice. Reis et al. [121] observed positive effects of pasteurization in orange PFJ because of the enhancement of bio-accessibility of several bioactive components. Janzantti et al. [64] were able to extend the shelf life of passion fruit pulp stored under refrigerated conditions for a minimum shelf-life period of 207 days after pasteurisation at 70 °C and 90 °C; for the fresh pulp, shelf-life obtained was 60 to 90 days, respectively. When pulp was heated at low temperature, researchers noticed more stable behaviour and higher sensory quality.

Despite the fact that traditional heat treatment extended the shelf life of PFJ, the delicate flavour is incredibly susceptible to thermal treatment [133]. Significantly lower concentrations of four naturally occurring volatile chemicals (hexyl butyrate, ethyl butyrate, hexyl caproate, and ethyl caproate) were found by Sandi et al. [133] in PFJ during storage following pasteurisation at 75 ℃ for 60 s compared to unpasteurized, with ethyl caproate showing the greatest decrease. Additionally, higher thermal treatment of PFJ produces toxic compounds like furfural [133] especially higher thermal treatment produced 5-hydroxymethyl-2- furfural [53,139].

Since most of the nutrients are present in the colloidal suspension, other treatments like clarifying processes are linked to decreased nutritional value [35]. So, novel nonthermal treatment such as ultrasonication, high pressure homogenization and natural antimicrobial- based technique may be added. Gómez-López et al. [53] treated PFJ with ultrasonication treatment (263 W, 20 kHz) for 8 min and reported that the juice remained microbiologically stable for up to 10 days at 4 °C without significantly changing the other examined parameters, suggesting that ultrasonication alone is insufficient for longer shelf life.

2.3. Passion fruit peel

Researchers have shown great interest for the utilization of peel of passion fruit (PFP), a co-product dumped in large quantities due to excessive cultivation and increased industrial processing. As shown in **Table 2.1.,** the peel can serve as a potential material for functional ingredients, like fibres, starch, protein, polysaccharides, pectin [175] and phytochemical substances such as alkaloids, flavonoids, carotenoids, tea polyphenols, etc. [1,58,175]. The peel has versatile uses for medical treatment (e.g., immunomodulators), mitigation of environmental risks (e.g., decaying solid wastes), and industrially useful value-added products (e.g., pectin substitutes) [1,65].

Based on the selected extraction conditions (40 % ethanol as solvent at 30 ℃ for 60 min of extraction), the total phenolic content and antioxidant properties of PFP extracts were 15.84 µg GAE/g and >500 µg/mL EC_{50} of DPPH and ABTS values [164]. Reis et al. [122] found 918.41 µg/100 g d.w., carotenoids content in yellow PFP and significant higher total phenolic content in PFP (orange and purple) than pulp (found approximately 5-6 times). They also reported that antioxidant activity (DPPH, *IC50 (g/100 mL)) of yellow PFP (1.69) was much higher than pulp (0.20) (**Table 1.1**) [122]. Similarly, passion fruit peels are a good source of fibres with approximately 42 % is cellulose, 25 % pectin, and 16 % hemicelluloses, which may be used as a feedstock in the fermentation process [23,100]. The *In-vitro* tests on passion fruit fibre showed that 80 % of the digestible glucose from the passion fruit peel was absorbed within 5 h, which was slower than the other by-products. It has been claimed that dietary fibre from yellow PFP can be used to make an alcohol-insoluble substance that may be useful for preventing diverticular disorders [81].

Purple PFP and its extract have been used in the recovery of several diseases and several authors reported the use of purple peel for recovery from wheeze, cough, shortness of breath in adults with asthma, hypertension, anxiety, insomnia, etc., and also have been used as folk medicine [163,164]. Oral administration of PFP extracts was also effective in elderly adults with osteoarthritis of the knee, lessening stiffness and pain, and alleviating hypertension [42,137,138]. The examined by-products have the potential to greatly reduce food waste and contribute to the development of a sustainable food system on being included into a variety of food items.

2.4. Passion fruit seed and its major parts

One of the predominant co-products of PFJ industry is passion fruit seeds (**Fig, 2.1e**), which contains approximately 22-30 % oil [115,120], which is enriched with several bioactive compounds like phenolic acids, phytosterols, and unsaturated fatty acids [120,124]. Passion fruit seed oil exhibits antimicrobial effects [68,73]. The seed oil contains approximately 570 mg/kg total phenolic compounds and possesses strong antioxidant activity (34 mg/mL) [128,133].

Crude fat (24.5 g/100 g) and insoluble dietary fibre (64.1 g/100 g) are abundant in passion fruit seeds [28] (Table 2.1). The insoluble fibre-rich fractions (from 84.9 to 93.3 g/100 g), became the dominating component after the oil was extracted from the seeds. These fractions were mostly made of cellulose, pectic compounds, and hemicellulose [28]. The defatted component is typically wasted after oil extraction even though it has the potential to be used as functional ingredients to make foods with health advantages.

2.5. Dietary fibre and its extraction

Because total dietary fibre (DF) can be either completely or partially fermented in the large intestine but is resistant to absorption and digestion in the human small intestine, DF-rich foods and diets have become more and more popular as food items for their health benefitting affects, which has inspired food researchers/scientists to investigate for new uses of dietary fibre and to produce high-fibre enriched food products [18,40].

Numerous studies have shown that DF can support healthy intestine structure, function, health [29,116] and physicochemical and compositional characteristics affect the functional properties [28]. DFs from various agricultural processing by-products have been incorporated in various foods, particularly meat, morning cereals, bread, bakery products, and dairy goods [92]. Insoluble dietary fibre (IDF) and soluble dietary fibre (SDF) are two subcategories of DFs that can be separated depending on solubility.

For the application of plant DFs in foods, DFs have to be extracted and the extraction process is critical. Processing of DF changes its structure and composition, which can have both advantageous and unfavourable effects on its physico-chemical and functional properties [6]. To extract dietary fibre, a variety of extraction techniques, including chemical, biological, and physical procedures have been employed [45,160], which may affect extraction efficiency and quality differently [42]. But several of these techniques have a number of shortcomings and need to be applied according to their further application.

Generally, alkaline treatment is conventionally used to extract the dietary fibres from various plant matrices [173]. However, it has a number of drawbacks, such as prolonged chemical reaction durations, a high solvent need, requirements of higher temperature and the insertion of many ions throughout the reaction process, etc. [63,160]. Again, alkaline treatment is followed by acid neutralisation, which entails an additional step and additional expense. The food system cannot be directly integrated with chemical processes either [160].

The ultrasonic-assisted extraction (UAE) method is a quick and efficient way to remove fibres from a variety of food products. Cavitation of bubbles in UAE results in the disintegration of cell matrices, enhances the mass transfer of the extracted solvent, and promotes quicker release of desirable compounds from the solid plant matrix structure into the extraction liquid (solvent) [173]. UAE, in contrast to thermal, enzymatic, and chemical treatments, has recently attracted increased attention due to the benefits of high extraction efficiency, low energy consumption, and ease of usage [42]. It can marginally enhance the physicochemical properties of DF, including its ability to hold water and oil as well as swelling and rheological properties [90]. DFs functional qualities were linked to its particle size. In general, smaller particles have more surface area and yield more bioactive DF [24].

Instead of the conventional alkaline treatment, which requires more time to extract the dietary fibres from various plant matrices, alkali extraction combined with ultrasonication treatment has been applied for improved extraction efficiency [42,173]. And recently, many reports have discussed the use of UAE-alkaline in the extraction of fibres from different plant matrices, such as papaya peel [173], *Nannochloropsis oceanica* [42] and *Akebia trifoliata* (Thunb.) Koidz. seeds [66], wood [31], defatted coconut flour [45], sisal fibre [80]. Also, alkaline extraction combined with homogenization, and microwave have shown better extraction [24,66].

2.6. Novel nonthermal preservative technique for juices

High pressure, ultrasonication, radiation of UV, Gamma, electron beam, ozonization, pulsed electric field, pulse light technology etc. have been applied to preserve fruit juice [4,41], but among them, high pressure and ultrasonication are most widely used due to their low cost and feasibility.

2.6.1. Ultrasonication (US)

One of the fast-developing non-thermal methods for improving quality and ensuring safety, particularly with regard to food with thermolabile nutrients, functional, and sensory characteristics, is ultrasonication [43]. US is an innovative preservation technique in food processing where a power range between 10 to 1000 W/cm^2 , and low frequency (20–100 kHz) or high intensity [26] are used. The Food and Drug Administration (USFDA), has identified ultrasound as a promising method to achieve their criterion of a 5 log reduction of microbial load in fruit juices [151]. Cavitation is a phenomenon caused by ultrasound that includes the formation **(Fig. 2.2),** expansion, and explosion/collapse of bubbles on the surface, which can cause a jet of liquid or vapour to be directed at the surface and rupture a cell. Cavitation that occurs close to the cellular surface is likely to collect dissolved gases inside the cell into a vacuole, which can then suddenly expand due to rarefaction after bubble collapse and rupture the cell [74,109]. The diffusion process mainly internal and eddy of the biomass are accelerated by the cavitation bubbles' implosion because it causes collision of particles at high kinetics energy causing micro-turbulence, and alterations to its tiny porous particles [11]. The collapse of bubbles generates high temperature (about 5000 K), pressure (1000 atm) and, rate of heating and cooling above 10^{10} K/s [52,109,151].

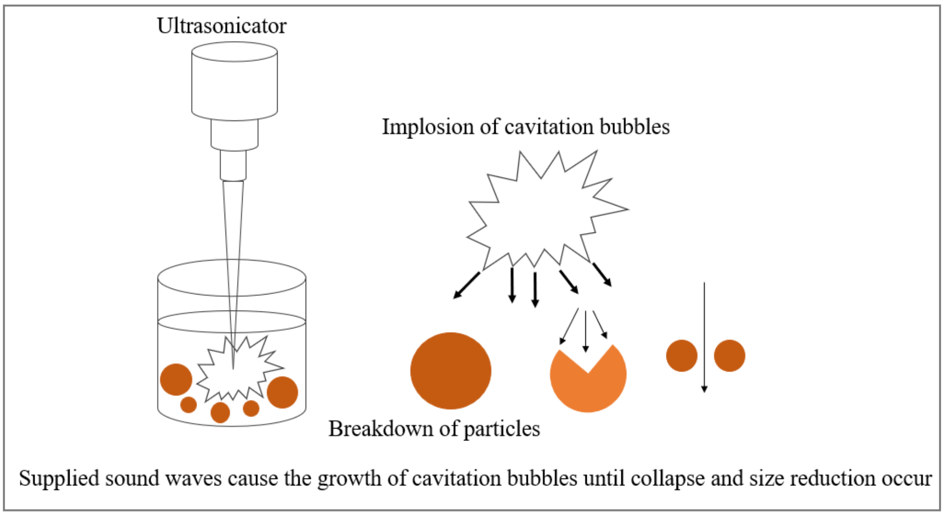


Fig. 2.2. A schematic image of size reduction by ultrasonication (probe).

Due to its ability to inactivate harmful and pathogenic microorganisms in fruit juice and improving the beneficial component composition, ultrasound-assisted processing has been shown to be a possible replacement for heat pasteurisation of fruit juices [53,54,105]. In addition, ultrasound is reliable, safe for the environment, and simple to scale up, indicating that it is more practical to use on a commercial scale than other pricey non-thermal approaches [27]. Ultrasound is increasingly studied for the processing of fruit juice and puree, such as passion fruit [53,54], bayberry [26], prebiotic-rich strawberry juices [27], strawberry juice [152,170], cherry [105], orange [151], fruit and vegetables juices [74], etc. Thermosonication (TS), also known as the combination of ultrasonication and controlled temperature, has demonstrated a synergistic effect on the food safety and quality attributes of various juices and has attracted significant attention for its ability to enhance the retention of phytochemicals and extend the shelf life of liquid foods such as fruit and vegetables juice [12], hazelnut milk [13], spinach [95], almond milk [96], pineapple juice [93], etc.

2.6.2. High pressure homogenization (HPH)

HPH is among the minimal processed food technologies that has come to be used by researchers for processing of juices. HPH can be categorised as one of these developing technologies because research has recently focused on novel food processing techniques that can ensure safety and improve shelf life without sacrificing qualities [89].

At the inlet and outlet of the high-pressure chamber, velocity gradients, turbulence, shearing, cavitation, impingement, and other effects are created as the fluid under pressure is forced to pass through a tiny hole (micron-level) in order to destroy the cell, achieve inactivation of microbes and change the fluid's properties [72,89] (**Fig. 2.3**).

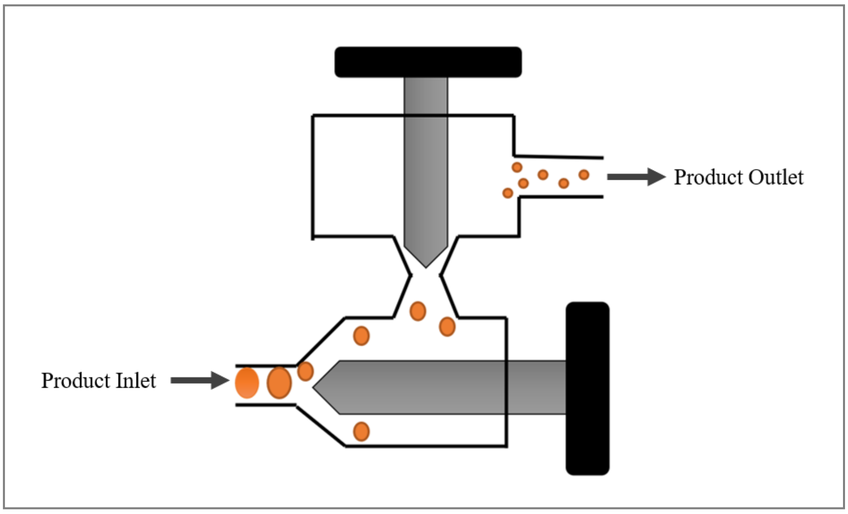


Fig. 2.3. A schematic image of size reduction by high pressure homogenization (Two stage).

Although HPH is employed in a number of processes, including microbial reduction, the creation of nano-emulsions, product quality enhancement, size reduction, and the production of homogenous solutions, this "cold" treatment method is also utilised in the processing of fruit juice [20,56,89,112]. In the dairy business, homogenizers have been employed to create stable emulsions, but they are insufficient to cause microorganism inactivation [44].

As a result of many mechanisms, including velocity gradients, spatial pressure, shear stress, cavitation, and turbulence that take place in the liquid phase throughout the HPH treatment, it is believed that the HPH treatment triggers a microbial inactivation mechanism by the mechanical loss of cell integrity [56,89]. Additionally, these physical events might cause the cell membrane to burst or become more permeable, which would kill the cell [89]. During the two stage HPH treatment, temperature of the samples was also increased as Velázquez-Estrada et al. [157] observed that in the two-stage homogenization system, when 209.8 MPa pressure was applied in HPH system, the juice sample with inlet temperature 19 ℃ increased before the second homogenization valve to 72.1 ℃, but final outlet temperature again drop to 23.8 ℃ [157]. Additionally, the physical characteristics of the cell membrane can change with temperature that weakens hydrogen and hydrophobic interactions and decreases the resistance of bacterial membranes to high temperatures [56,157]. In addition, during HPH treatment, when a rise in inlet temperature resulted in a decrease in viscosity, the fluid flow pattern showed greater turbulence, which improved microbial inactivation due to an increase in fluid cavitation [56]. In the HPH system, inactivation effect significantly depends on pressure, inlet temperature, number of passes, type of microorganisms, type of liquid, and stage of microbial inactivation [56].

Numerous research works on the use of HPH have shown a decrease in microbial loads in various food matrices such as pear juice [89], water melon juice [87], kiwifruit juice [111], mulberry Juice [176], mango nectar [153], orange juice [156], commercial fruit juices (orange, red orange, pineapple) [98], phosphate buffered saline (PBS) buffer [44], milk [9,44], apple juice [44,143], apricot juice [113], annurca apple juice [98], and mango juice [56]. Guanet al. [56] achieved 100% inactivation of moulds and yeasts with 1 and 3 passes at 190 MPa and 60 °C, and total plate count was below 2.0 log10 CFU/mL in mango juice, whereas Dong et al. [44] observed reduction of 3.19 and 3.67 $\log_{10}$ CFU/mL of *E.coli* present in apple juice and milk, respectively when treated with 200 MPa at 40 ℃ inlet temperature. In addition, Tahiri et al. [145] observed that 5 passes of HPH at 200 MPa and 25 ℃ resulted in significantly larger reduction in *E. coli* O157:H7 to around 6.0 $\log_{10}$ CFU/mL. Further research revealed that HPH treatment might enhance the colour, antioxidant activity, and essential phytochemicals of fruit juice in contrast to heat treatment [56]. Marszałek et al. [99] found that shelf life of concentrate juices can be prolonged up to several weeks (up to 28 weeks of cold storage) by high pressure treatment. Thus, HPH has the potential to be used as a preservation technique in fruit juice industry.

2.6.3. Emulsion

A colloidal system called an emulsion is a combination of two or more immiscible liquids. In an emulsion, an interfacial boundary separates one liquid, commonly well known as dispersed phase, from another liquid, usually term as continuous phase [106,167]. Emulsions are classified into three categories, oil in water (O/W) example milk, water in oil (W/O) example butter [20,167] and bi-continuous [59]. Emulsions can also be broken down into subcategories like micro, macro, and nano based on size. Emulsions are excellent delivery systems for bioactive chemicals because they increase the permeability of substances in the stomach and through epidermal barriers, increasing their bioavailability [59,137,159].

In comparison to typical emulsions, nanoemulsions have a number of benefits, including increased kinetic stability, no flocculation or creaming, more encapsulation of lipophilic bioactive chemicals, and optical clarity [59]. Today's market offers a variety of foods produced with nanoemulsions, such as sweets, milks, beverages, butter, creams, mayonnaise, dressings, sauces, dips, margarine etc. Although there are many advantages to nanoemulsion, there are also some disadvantages, including high manufacturing costs and a higher risk of thermodynamic instability because of coalescence, flocculation, Ostwald ripening, phase inversion, oxidation, creaming and hydrolysis [106]. The stability of an emulsion is influenced by various factors, including the production process, types of emulsifiers and its concentration, processing pH, time, temperature, particle size, methodology, and other factors [38,59]. Among these parameters, types of emulsifiers and production techniques are the most crucial parameters.

Surfactants are described as molecules with different chemical properties that can be positioned at the interface because they include both hydrophobic and hydrophilic groups [38]. Adsorbed surfactant produces electrostatic repulsion and steric stabilisation, which prevent phase separation and stabilise the solution [167]. A suitable emulsifier must successfully reduce the interfacial tension of dispersed and continuous phases and immediately adsorb onto the surface of lipophilic phase **(Fig. 2.4**) in order to assist the disruption of droplets during treatments like homogenization, ultrasonication, etc. [36]. With prolonged use, most chemical surfactants result in health issues and may have harmful side effects for users [38], so usage of most of the chemical surfactants in food has been restricted because of their toxicity, safety, non-food grade and supersedance nature.

According to their molecular size, biosurfactants can be categorised into two groups: (1) High-molecular-weight biosurfactants: proteins and polysaccharides, which are frequently referred to as "bioemulsifiers," have high emulsifying properties but are unable to significantly reduce surface tension [38,144,146]; (2) Small droplet size emulsions: they are usually produced by adding low or micromolecular-weight biosurfactants, like saponins, glycoproteins, and phospholipids, which are effective at reducing the interfacial tension between oil and water [38,144,146]. High-molecular-weight biosurfactants can be more stable than small-molecular surfactants, but the emulsions that are nanosized require a high emulsifier-to-oil ratio [144]. Emulsions can be employed as a protective carrier for bioactive substances, to increase bioaccessibility and bioavailability, to manage the distribution of target compounds or drugs, and to improve product quality, such as texture and shelf life [7,84].

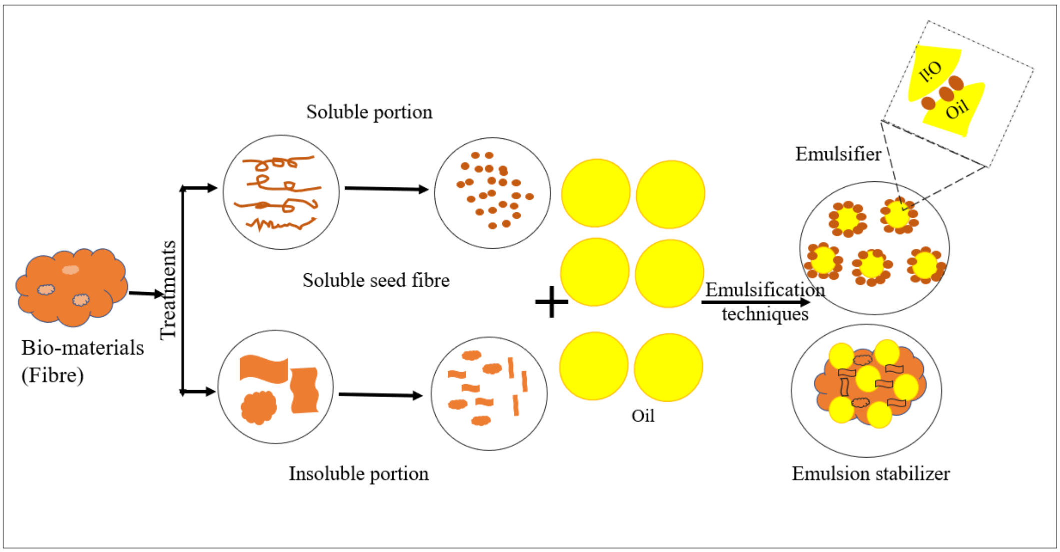


Fig. 2.4. A schematic image of nanoemulsion development using biomaterials (Fibre) as emulsifier/stabilizer.

Along with acting as a protective carrier for lipophilic carriers of bioactive chemicals and as a method to promote bioavailability, food nanoemulsions are also utilised to improve the texture of food [7,84]. For instance, pork patties were found to have better texture and softness when 3.5% Tween 80 and 1% lecithin stabilised canola oil-in-water nanoemulsions were added [84]. Additionally, nanoemulsions have been utilised for the shelf-life enhancement of foods by encapsulating antimicrobial compounds like essential oils in foods such as whey cheese [32], chicken [129], butter [25], and fruits [154], liquid food [91], etc. Sagar et al. [129] noticed that the samples coated with nanoemulsions had a significantly longer shelf life of 20 days and higher level of sensory acceptability. Similarly, Long et al. [91] developed emulsion using garlic oil with antifungal activity, which enhanced the shelf life of liquid food with health benefiting properties. Emulsions, therefore, can be used as a shelf-life improver as well as a quality enhancer.

2.7. Different extraction techniques

The valuable compounds from plant food matrices have typically been extracted and recovered using conventional extraction (CE) methods with common petrochemical solvents, but this technique results in high energy consumption and higher input costs. Additionally, use of petrochemical solvent in this extraction process has several drawbacks, including the need for prolonged exposure time, unwanted thermal effect, and generation of hazardous volatile organic compounds [140,168]. Around 100 billion dollars worth of chemical compounds were sold on the global market in 2009, however only 3% of these substances were derived from renewable resources. As a result, the usage of these common solvents is subject to various restrictions from governmental organisations [168].

Due to their rapid rate of extraction, high extraction yield, minimal negative impact on the extracted compounds, higher extraction of thermosensitive bioactive compounds, lower processing temperatures, and lack of hazardous volatile residuals, green chemistry principle-based high-energy extraction techniques are currently gaining a lot of interest and have become a novel and interesting topic in the field of extraction of phytochemicals [55,85]. Many innovative methods have recently been researched and applied into practise to increase the effectiveness of bioactive chemical extraction while also addressing challenges encountered during CE. Due to their affordability, ease of use, accessibility of equipment, and high extraction efficiency, microwave-assisted extraction (MAE) and UAE have been identified as the two most practical new techniques that can be applied in a variety of food processing industries [34,162].

2.8. Vegetable oils as green solvents

Vegetable oils are considered green solvents in the extraction process and are considered to be bio-based. These solvents have benefits for the environment and human health and can be utilised as alternatives to conventional solvents for the extraction of hydrophobic chemicals because of their solubility [46,55,85], Moreover, there was little to no loss or degradation of hydrophobic compounds, particularly carotenoids, during the extraction procedure [168]. Several authors experimented on the extraction of bioactive compounds using vegetable oils. The extractability of carotenoids from shrimp wastes was examined by Sachindra and Mahendrakar [127] using soy oil, sunflower oil, coconut oil, mustard oil, groundnut oil, rice bran oil and gingelly oil. Damechki et al. [37] increased the total polar phenol content in olive oil by 3.5 and 1.7 times after the treatment with oregano and rosemary gourmet oils, respectively with respect to that of the control sample.

Similarly, other authors used oil for extraction of bioactive compounds such as using soy oil [55,71,127], corn oil [71,135], sunflower oil [55,127,138], olive oil [11,37,71], mustard oil [127], groundnut oil [127], grape seed oil [71], gingelly oil [127], coconut oil [127], flax seed oil [46] and, and rice bran oil [127], etc.

2.9. Green extraction

Although vegetable oils are considered green solvents in the extraction process with several benefits such as environment friendly nature, less requirement of energy, and contaminants-free non-denatured extract [85,109,168], efficient extraction is hampered due to oil's relatively high viscosity that results in poor diffusivity (effective) and, ultimately low extraction yield. This is a major drawback in employing vegetable oil directly in a simple extraction process [55]. If high temperatures are employed for extended periods of time, the viscosity may be reduced diffusivity gets enhanced but it causes degradation of bioactive chemicals [142].

UAE primarily involves acoustic and hydrodynamic cavitation and generally works together to increase the extraction efficiency of targeted compounds from the solid particles [55,85,118]. UAE has been used to improve the extraction process of diosgenin from fenugreek seed and fenugreek-supplemented cookies [162], bioactive compounds/phytocompounds from different foods products such as carotenoids, polypehnols and antioxidants from pumpkin peel and pulp[135], antioxidants from peach [114], oils from different seeds [30,108,148], etc.

MAE is another extraction technique frequently used in food processing. Dipolar rotation and ionic conduction are primarily responsible for the extraction of phytochemicals from the matrix in MAE method. Ionic conduction and dipole rotation generates friction force, activates molecules, and generates heat energy. During this process, it is possible for the cell walls to weaken or break, and thereby the phlegm to spread [34,46,114]. Several studies have been investigated to extract different phytochemicals from food materials, for example diosgenin from fenugreek seed and fenugreek-supplemented cookies [162], bioactive compouds from different foods material [46,83,128], flavonoids from *Terminalia bellerica* [169], carotenoids from different sources [8,46], etc.

2.10. Carotenoids and their extraction

The majority of tetraterpene pigments in nature, known as carotenoids, are found in plants, algae, photosynthetic bacteria, some species of archaea and fungus, and animals. They exhibit the red, yellow, purple, and orange colors [97]. Their fundamental structures generally feature an end group at either end of a polyene chain with nine conjugated double bonds. Carotenoids are broadly divided into two groups as carotenes and xanthophylls based on the functional group: Carotenes are hydrocarbons, including lycopene, β-carotene, γ-carotene, and α-carotene. In nature, carotenes are found in around 50 different varieties [22, 97], whereas, xanthophylls are carotenoids that include oxygen atoms as carbonyl, carboxylic, hydroxyl, aldehyde, furan oxide, and epoxide groups in these molecules. Examples are- lutein, β-cryptoxanthin, astaxanthin, zeaxanthin, peridinin, and fucoxanthin [22,97].

The important functions of carotenoids in animals are: (i) Ornamentation (such as in salmon and flamingos); (ii) Act as powerful antioxidant, which are mediated by oxidising the superoxide radical anion, and provide protection against head, lung neck, and prostate cancer; (iii) Modulation of the growth factors, immune system, and signalling pathways of cellular system; (iv) Control of cell cycle, apoptosis, and cell differentiation; (v) Photoprotection especially against UV light; and (vi) Act as precursors of Vitamin A [130, 131].

There have been focused efforts over the past few decades to improve carotenoids extraction techniques. However, recovery from complex food matrices is still poor because the food matrix contains a number of physical and chemical barriers that inhibit the mass transfer of carotenoids during extraction. It is particularly challenging to extract multiple carotenoids simultaneously since different groups of them have different degrees of polarity. Carotenoids' ability to oxidise also restricts their susceptibility to extremes in temperature, light, acidity, and extraction times. Carotenoids are often extracted using organic solvents since they are hydrophobic. Typically, non-polar solvents are a great option for extracting non-polar carotenes, such as tetrahydrofuran, petroleum ether, or hexane [130], which are associated with adverse health and environmental issues. The scientific community is therefore, showing interest in green solvents like vegetable oils.

Recently, different techniques such as ultrasonication and microwave have been implemented to extract carotenoids from the food matrices. In recent decades, various authors have investigated the extraction of carotenoids using UAE process from various food plant matrices and their co-products, such as carrots [138], tomato [171], pomegranate [55], fresh carrots [85], peach plum fruits [109], sea buckthorn [30], auyama, cabbage, and lettuce wastes [8], gac peels [34], pumpkin [135], etc. Similarly, use of MAE to extract the carotenoids from plant foods are also reported, such as carrots [46,62], gac peel [34], pumpkin [135], citrus clementina peels [70], and agro-industries [8].

Combination of green solvent and novel extraction techniques have been used for better extraction of bioactive compounds, specially the hydrophobic ones, such as carotenoids from pumpkin peels and pulp using corn oil as solvent, and MAE and UAE as techniques [135], carotenoids from the waste portion of carrot juice processing with flaxseed oil as a solvent and MAE technique [46], etc.

2.11. Mathematical kinetics modelling in food technology

Simply, mathematical models are equations showing the relationship between two or more variables theory, and understanding the mechanisms and principles and the relationships among the variables [104]. To better understand the food processing system, one can model the kinetics of the various food processes [123]. Food technology typically uses empirical models. Dimensional analysis and Response Surface Methodology (RSM) are two forms of empirical models that are frequently used in the food processing industry. Generally, in food processing, five modeling techniques [149] are used, and they are modeling of (i) kinetic, (ii) continuum theory-based transport, (iii) regression (iv) artificial neural network, and (v) computational fluid dynamic modeling [149].

There are several advantages associated with mathematical modelling [48,104] such as:

a. Modelling decreases the seeming complexity of some situations and aiding a resolution.
b. Has the ability to lower experimental costs by lowering the number of tests required evaluating a specific issue, experimental design and prediction.
c. Models can be used to understand the untraversed or untraversable area.
d. Enables the consideration of options that could be challenging or expensive to test.
e. Makes it possible to study the susceptibility of a process to factors and the creation of the best techniques.

But modelling of food processing has some problems as mentioned below: (a) While giving a thermal treatment (heating or cooling), both temperature change and biochemical change have equal weightage to be understood; (b) When the food has continuous gain or loss of moisture; (c) The basic properties (density, thermal properties, diffusivity, permeability etc) are functions of internal as well as external factors, such as structure, composition, moisture content, and temperature; etc. which keeps on changing, and changing behaviour needs to be understood thoroughly; (d) The changes in physical boundary (shrinkage, swelling etc.) can bring continuous changes in the food structure; (e) Irregular space inside the food materials is another problem; (f) Sometimes changes of internal and external parameters such as temperature, moisture content, phase etc. are often interlinked with each other [82].

Because of the distinctive characteristics of foods, it is challenging to simulate the dynamics of chemical and physical systems. Simulations of biological materials also experience challenges brought on by the inherent multiscale and stochastic nature [123]. So, proper utilization of models is required. Many mathematics models have been recently studied on mathematical modeling in food processing [16,82] such as microbial growth/predictive modeling [10,67,77], extraction kinetics of bioactive compounds/materials [118,141,158,161], multiphase model to explain food processing [57,82], baking [103], drying [21,117,174], flowing [76], pasteurization/sterilization [94], etc.

2.12. Optimization

Finding the optimum answer, or, more generally, the best compromise between numerous competing objectives, is what it means to optimise. To select the greatest option among all feasible ones in an effective and methodical manner would be a more formal description [17]. About optimisation, there are a few frequent misunderstandings. First, even though the aforementioned definition is widely accepted, there are several misconceptions regarding this concept. It is frequently used incorrectly to refer to finding a better answer rather than the best one. Second, a method for optimization must be effective and methodical; hence, wasteful techniques like one-variable analysis (at a time), trial and error methods, and exhaustive search, are not considered to as optimization [17].

Review articles on optimization strategies for the food processing area, such as traditional optimization methods, multi-objective optimization techniques, computational fluid dynamics, and artificial intelligence-genetic algorithms are available [47]. The parameters involved in optimization must be properly designed. Experimental design is essential when deciding which important parameters to add to the model and optimisation system. Factorial design, Box-Benkhan design, central composite design, Doehlert matrix, artificial intelligence etc. are frequently utilized for experimental design purpose due to their capacity to identify relationships between factors in the design's columns [53,152]. Among the optimization techniques, RSM is most widely used due to low cost and availability. Using RSM, the modelling and optimization process is typically carried out in phases. Although various levels or stages are described in literature, all the processes are similar or share certain characteristics. In general, the steps are as follows [15,75]: (1) determining the input parameters and their levels; (2) choosing the appropriate experimental design; (3) choosing a regression model and predicting and verifying the model equation; (4) presenting the model equation graphically; and (5) predicting and figuring out the ideal operating conditions [15,75].

Recently various optimization techniques such as RSM optimization [3,101,161], bio-inspired optimization techniques [134], artificial neural network-genetic algorithm [3], hybrid RSM-artificial neural network-genetic algorithm [14], fuzzy logic for sensory optimization [33,66] have been used by researchers.

2.13. Bio-accessibility of carotenoids

The term "bio-accessibility" describes the percentage of ingested lipophilic compounds (carotenoids) that are liberated from the matrices of foods and integrated into the digestive tract in the form of micelles, making it accessible for absorption in the intestine. Whereas, the term "bioavailability" describes the percentage of a carotenoid that is ingested by the body, circulates throughout it, and then is made available for use in the body's normal physiological processes or for cellular storage [131].

Carotenoids are absorbed through a variety of mechanisms, including release from the food matrices, diffusion of carotenoids into lipid emulsion, formation of mixed micelles through solubilization of carotenoids in bile salts and pancreatic lipases, diffusion through microvilli, absorbed by intestinal mucosal cells, incorporation of carotenoids into chylomicrons, entry into the lymphatic process, and circulation and on average, our body system do not allow for the absorption of more than 5–30% of the ingested amount [165] of carotenoids.

Carotenoids can be added to the oil phase (lipophilic phase) of oil-in-water emulsions to boost their bio-accessibility [78], which are worthy for incorporation into a variety of food systems, enhancing the end product's colour, flavour, and nutritional content [78]. Also, other treatments such as size reduction [61]., other techniques such ultrasonication, homogenization [132], and cooking [61], changes in the matrix/ tissue microstructure [132], presence of digestible lipids [78]; addition of other compounds such as pectin [147], protecting the structure, etc. are useful.

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