CHAPTER 2

REVIEW OF LITERATURE

Review of literature

This chapter reviews the literature on reported studies performed on coconut milk, pineapple juice, and blended beverage, and also explores the effect of high-pressure homogenization and thermal pasteurization on the shelf life of juice. The role of nanocellulose synthesized from various sources in the stabilization of Pickering emulsion, and the bioaccessibility of curcumin encapsulated in emulsions are also reviewed.

2.1. Plant based milk and its health benefits

Functional beverages derived from plant sources are gaining popularity due to shifts in dietary habits, increased instances of endocrine disorders, lactose intolerance, allergies to cow milk, and skin issues, such as acne. Among the plant-based milk alternatives, five are frequently consumed: coconut milk, soy milk, almond milk, rice milk, and oat milk.

Plant-based milk substitutes vary greatly in terms of their nutrient density both across and within varieties. Their nutritional qualities are further influenced by the kind of raw material utilised, the techniques of processing, the addition of sugar and oil, and the fortification of vitamins and minerals. For those with milk protein allergies, plant-based protein sources can serve as substitutes (Walther et al., 2022). Compared to cow's milk, plant-based milks are often linked to reduced environmental effects (such as greenhouse gas emissions and water usage) (Ramsing et al., 2023).

2.2 Coconut milk and its use in different products

Coconut is economically important and used in many traditional foods especially in Asia as a source of dietary fat. There are generally two varieties of coconut: the tall and dwarf varieties. While whole milk contains more protein than coconut milk, which is equally creamy, coconut milk contains no lactose, so it poses no problem for those who are lactose intolerant. Those who are lactose intolerant may experience problems like cramps, gas accumulation, diarrhoea, and bloating when consuming cow’s milk (Boateng et al., 2023).

Coconut milk adds flavour and taste to products such as ice cream and biscuits (Kwao et al., 2023). The coconut milk or coconut skim milk is a major component of many different recipes (e.g. curry), desserts, and products such as coconut syrup coconut jam/spread, beverages, , coconut tofu, bakery products, (e.g. coco soy milk and pina colada) and coconut cheese (Seow and Gwee, 1997; Patil and Benjakul, 2018).

Table 2.1: Proximate composition of coconut milk

Constituent	Range (%)
Moisture	50-54.1
Ash	1.0-1.5
Protein	2.8-4.4
Fat	32.2-40.0
Carbohydrate	5.5-8.3

Source: (Seow et al., 1997)

2.3. The effect of fat content on coconut milk stability

The effect of fat content in coconut milk on stability and digestibility has been reported in various research articles. One study evaluated the emulsifying properties, stability, and digestibility of coconut milk with different fat contents, showing that as the fat content increased, the droplet size and viscosity also increased. In both raw and processed coconut milks, separation of the oil-in-water emulsion is typically regarded as an unacceptable physical fault (Simuang et al., 2004). Chiewchan et al. (2006) reported that temperature, fat dispersion, and particle size all have a major impact on the stability of foods high in fat, including milk, yoghurt, and cheese. To maintain the stability of the coconut milk emulsion, homogenization and the addition of appropriate emulsifiers are necessary before heat treatment in order to reduce fat globule size. The type and quality of homogenization and emulsifier used has an impact on coconut milk's stability. Research has also shown that coconut milk with fat content below 10% can withstand environmental factors such as storage, lipid oxidation, and freeze thaw (Chen et al., 2024).

2.4. Digestibility of coconut fat and protein

A study found that monosodium glutamate can increase the digestibility of proteins in coconut milk while inhibiting the digestion and absorption of fat (Wu et al., 2024). Another study found that coconut milk, with a high fat content of 27.69%, is fast digestible and more resistant to oxidation compared to dairy milk (Beegum et al., 2022). The fat content in coconut milk plays a significant role in its stability and digestibility, with higher fat content leading to increased droplet size, viscosity, and faster digestion. However, lower fat content can also provide stability and resistance to environmental factors. Benaissa et al. (2019) reported that there is better gastrointestinal digestion of the proteins in coconut milk than in cow milk.

2.5. Effect of different emulsifiers on stability of coconut milk

The effect of different stabilizers on the stabilization of coconut milk has been investigated by researchers. Some of the common stabilizers used to improve the stability of coconut milk includes protein, sorbitol esters, ethoxy esters, and sucrose esters. These are substances that help to stabilize the emulsion by reducing the interfacial tension between the oil and water phases (Ariyaprakai et al., 2013). Heating coconut milk above 80 °C can lead to the denaturation of proteins, resulting in the complete destabilization of the emulsion (Raghavendra & Raghavarao, 2010). Coconut protein, an amphiphilic molecule, can be adsorbed, unfolded, and rearranged at the oil–water interface, stabilizing the oil-in-water emulsion (Chen et al., 2023). The coconut milk emulsion can be separated by adjusting the pH between 3 and 5.6, and an increase in pH from 6 to 10 can also result in higher destabilization of the emulsion (Raghavendra & Raghavarao, 2010). Adding starch to coconut milk can increase its viscosity and improve emulsification (Arlai and Tananuwong, 2021). The interaction between CG (coconut globulin) and coffee polyphenols can change the lipophilicity of CG and facilitate the formation of a dense and thick interfacial film at the oil–water interface, leading to improved emulsion stability (Chen et al., 2023). These stabilizers can be used to improve the stability of coconut milk, which is essential for its use in various food applications. However, the choice of stabilizer depends on factors such as taste, flavour, and the specific application of the coconut milk product.

2.6. Extraction of coconut oil using different methods

Coconut oil is an edible oil called, also known as copra oil (CO), is produced from the flesh or kernel of mature coconuts that are obtained from the coconut palm (*Cocos nucifera*). It has various applications due to its high saturated fat content; it is slow to oxidize and, thus, resistant to rancidification lasting up to six months at 24°C without spoiling. However, if CO is not properly extracted, the nutritional and medical properties might be destroyed because the extraction method employed has a direct effect on both the quantity and quality of the oil produced (Famurewa et al., 2021). The extraction of coconut oil using different methods has been the extensively investigated. One study by Oseni et al. (2017) used six different techniques of coconut oil extraction, including enzymatic, chilling and thawing, centrifugation, natural-fermentation, and induced-fermentation processes. Ghani et al. (2018) also studied the effect of extraction methods on the quality and stability of coconut oil. In a comprehensive review by Ng et al. (2021), various extraction methods of coconut oil were summarized, including fermentation, refrigeration, centrifugation, and enzymatic separations. Fermentation is a low-cost process that does not require expensive equipment or materials, but it is time-consuming and requires minimal heat to preserve nutrients. The method maintains the natural coconut flavour, but it requires a longer time to extract the oil (Ng et al., 2021). Another study by Agarwal and Bosco (2017) discussed the extraction processes of virgin coconut oil (VCO), including cold and hot extraction methods. Cold extraction involves destabilizing coconut milk without heating, while hot extraction involves pressing clean, ground, and fresh coconut to yield coconut milk followed by heating at high temperatures. The extraction of coconut oil can be done through two primary methods: wet and dry methods. The wet method is generally considered more effective than the dry method, with a higher level of effectiveness reaching up to 73% compared to the dry method's 70%. In wet method, coconut milk is chilled at < 4°C and agitated for 15 min with a rotator. After removing the top layer of cream from the aqueous layer, it is taken out and allowed to defrost in a water bath set at 50°C. Centrifugation is then done for 45 min at 6000 rpm in order to further isolate the VCO from the aqueous layer (Ghani et al., 2018). However, the dry method is more commonly used due to its lower cost and ease of operation. In dry extraction process, the coconut kernel is heated in an oven in controlled condition or sun-dried to remove moisture content. The dried kernel is pressed mechanically to obtain coconut oil (Ghani et al., 2018). The wet method requires more equipment and labour, making it less practical for large-scale commercial production. The quality of coconut oil extracted through the wet and dry methods can vary depending on the processing conditions and equipment used (Nurma et al., 2022). VCO extracted through the wet method, for instance, is considered a high-quality product due to its natural freshness and lack of additives. VCO is suitable for human consumption in its natural state without refining and is known for its health benefits (Agarwal and Bosco, 2017).

2.7. Nutritional benefits of coconut milk

Abdul Rahim et al. (2020) reported that coconut milk is higher in medium-chain triglycerides like lauric acid (46–54%), caprylic acid (5–10%), capric acid (5–8%) and has a lower risk of clogging arteries compared to cow's milk (Jadhav and Annapure, 2023). Additionally, coconut milk contains soluble and insoluble fibers, antioxidants, and micronutrients such as vitamin C, vitamin B, iron, and phosphorus, making it a healthy alternative to cow's milk (Agdeppa and Zamora, 2022). In addition to its anti-viral, anti-microbial, and anti-carcinogenic properties, coconut milk is linked to fitness benefits. It is also abundant in minerals and nutrients, including iron, calcium, potassium, magnesium, and zinc (Tulashie et al., 2022). The antioxidant property of coconut milk that was measured using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging test and the ferric reducing power (FRAP) assay, showed that coconut milk has more antioxidant qualities than cow's milk. DPPH and 2,2-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium (ABTS) assays were also used to test the antioxidant properties of the coconut kernel methanolic extracts as a function of maturity. The antioxidant activities increased up to 190 days from the date of pollination and then decreased or remained unchanged (Karunasiri et al., 2020).

2.8. Biochemical and nutritional properties of pineapple juice

Pineapple juice promotes to healthy living because it is a excellent source of vitamins, phenols, organic acids, and carbohydrate. Its juice has 81.2–86.2% moisture, 13–19% total solids of which sucrose, glucose and fructose are the main sugars, 0.4% fibre, 0.89% crude protein, 0.50% ash, and 16.19% carbohydrate. The juice is a rich source of vitamin C with a content of 17.60 mg/100 ml (Kiin et al., 2016; Bamidele et al., 2017). It is also rich in vitamins A and B, besides containing several minerals such as calcium, phosphorus, and iron (Jiménez and Capron, 2018). It is a precious reservoir of polyphenolic compounds such as p-coumaric acid, caffeic acid, ferulic acid, sinapic acid, p-coumaroylquinic acid, feruloyl glucose, p-hydroxybenzoic acid, p-hydroxybenzaldehyde, and syringic acid, which have been revealed to have antioxidative, antimutagenic, and anticarcinogenic effects and have beneficial roles against cardiovascular diseases and cataracts (Wen and Wrolstad, 2002). It also contains bromelain enzyme that promotes digestion, and other components that contribute to various health benefits due to their anticancer, antidiabetic, and antihypertensive properties. Fresh pineapple juice contains the following important minerals: iron (0.2–0.31 mg/100 ml), manganese (0.3–0.99 mg/100 ml), phosphorus (3.1–8.0 mg/100 ml), magnesium (12–15.4 mg/100 ml), and potassium (124–130 mg/100 ml) (Khalid et al., 2016). Numerous advanced processing methods have been applied to reduce bacterial contamination, extend shelf life, and preserve antioxidants, vitamins, and minerals in pineapple juice that includes ultrafiltration, pasteurisation, freeze-drying, reverse osmosis, microwave treatment, supercritical carbon dioxide, ohmic heating, thermosonication, pulsed electric fields, high hydrostatic pressure, high-pressure homogenization, and UV irradiation (Leneveu et al., 2020).

2.9. Blended beverages

Beverages are consumed for their refreshing effect, and thirst quenching and nutritional properties. However, in recent times, functional beverages have gained consumer liking for their ability to modulate or prevent diseases. Plants from different sources have been used for making plant based beverages, including the following groups: i) cereals (rice, oat, corn, spelt, rye, quinoa, kamut); ii) legumes (soy, peanut, lupin, cowpea), iii) nuts (almond, coconut, hazelnut, pistachio, walnut); iv) seeds (sesame, flax, sunflower, pumpkin, hemp); and v) pseudocereals (quinoa, teff, amaranth). As the sources used in these beverages vary, their nutritional composition also varies considerably (Munekata et al., 2020).

Consumption of blended vegetable and fruit juice boosts antioxidants, vitamins, and minerals level in the blood, lowers homocysteine levels (a risk factor for heart diseases), increases immunity, and reduces inflammatory indicators (Grau et al., 2023). Abedi et al. (2014) developed raspberry juice-milk, an acidic dairy drink having two main phases, milk phase (pH: 6.6–6.7) and raspberry juice phase (pH: 3.2±0.1). Due to the low pH in this beverage, the problem of milk protein sedimentation was encountered. The influence of pectin, carboxymethylcellulose (CMC) and kappa-carrageenan on the stability of the milk-raspberry juice drink and their synergistic effects were investigated. According to the results obtained, the most suitable samples were those comprising of a combination of pectin and CMC, exhibiting greater stability and viscosity as compared to samples consisting solely of pure CMC (Abedi et al., 2014). The milk–sour cherry juice mixture was stabilized using gum tragacanth and Persian gum as adsorbing and guar gum as nonadsorbing hydrocolloids along with inulin to enhance their stabilising properties. The combination of inulin and guar gum was able to better stabilise the mixture at certain ratios and concentrations. Guar gum played the main role in the stabilisation of the juice by increasing the viscosity and forming gel network (Teimouri et al., 2018). Food processors are more interested in natural fruit or vegetable juice–skim milk mixtures because fruits, vegetables, and milk are the main sources of various bioactive compounds, natural antioxidants, as well as macro- and micro-nutrients (Zulueta et al., 2007; Calligaris et al., 2004). The most common fruits used in ready to serve blended beverages include grapes, gooseberries, litchi, pineapple, orange, and mango. These fruits are valued for their nutritional content, refreshing quality, pleasant flavour, and medicinal properties. They are a source of vitamins, minerals, energy, and fiber, which can help reduce the risk of many diseases. They also provide antioxidants and antimicrobial properties, which can serve as a good appetizer. The development of functional beverages can boost their sensory properties and nourishing properties (Rathinasamy et al., 2021).

2.10. Effect of citric acid addition in low pH fruit juices

Fruit juices are suitable for consumption by persons of all ages. Many fruit juices are acidic (pH 2.5 - 3.8), which is harmful to most bacteria. Citric acid is traditionally added to juice to lower pH and inhibit browning. Citric acid (0.3%), potassium sorbate (0.025%), sodium benzoate (0.015%), and sugar (10%) were the preservatives that were utilized to extend the shelf life of sugar cane juice. The shelf life was extended to 15 days at room temperature (26 ± 2 °C) and 35 days at 10 °C because of the treatment (Mishra et al., 2011). The number of microorganisms was discovered to be below the detection limit throughout this time (Mishra et al., 2011). Citric acid concentration affects the pH of fruit juices. As the concentration of citric acid increases, the pH decreases, as citric acid is a weak triprotic acid. This decrease in pH can impact the quality and properties of the fruit juice (Fidaleo and Ventriglia, 2022) . The citric acid concentration impacts properties like pH, titratable acidity, and sensory characteristics of the final product (Tua et al., 2018). The low pH created by citric acid in fruit juices creates an environment that is less conducive to the growth of spoilage microorganisms, thereby prolonging the shelf life of the juice. Citric acid contributes to the stability of fruit juices by maintaining their quality attributes and sensory characteristics, thus ensuring a longer shelf life (Humayun et al., 2014) . Researchers have observed that citric (1–20% w/v) and lactic (0.3–4.0% v/v) acids inactivate *Yersinia enterocolitica* at various temperatures (4°, 20°, 40°, 8 °C). The duration, temperature, and acid concentration of exposure affects the inactivation impact of lactic and citric acids (Virto et al., 2005). Citric acid naturally exists in fruits and vegetables. However, it is not the naturally occurring citric acid, but the manufactured citric acid that is used extensively as a food and beverage additive (Sweis and Cressey, 2018). Addition of citric acid or ascorbic acid to pasteurized sugarcane juice restricted the degradation of total soluble solids, total sugars and reducing sugars during storage. Potassium metabisulphite further reduced changes in these parameters, likely due to suppressing microbial activity (Chauhan et al., 2002). Orange, lemon, ginger juice and honey are rich in citric acid and have been used as natural preservatives in fruit drinks and other fruit products. However, quality fruit juice needs to be safe for consumption for 3–9 months, which can be achieved by combining natural and synthetic preservatives like citric acid (Tiencheu et al., 2021). Fresh sugarcane juice spoils within 3–4 h at room temperature and 8 h during refrigerated storage. Adding citric acid, ascorbic acid, or potassium metabisulphite as preservatives significantly slowed the decrease in pH and increase in acidity during storage of sugar cane juice, with the effect being higher at room temperature (Chauhan et al., 2002).

2.11. Thermal treatment of juice

The most popular technique for extending the shelf life of liquid foods is thermal treatment, which inactivates microorganisms and enzymes. However, heat alters the antioxidant properties of the food, causes unfavourable changes in its physicochemical properties, and irreversibly loses nutritional compounds. Many juice processors have searched for alternatives to thermal pasteurisation in order to help preserve unstable nutrients (Zulueta et al., 2013). Mild pasteurization and minimal processing have received considerable attention due to the growing consumer awareness towards fresh-like, nutritive, and healthy products. The Food and Drug Administration (FDA) mandates at least a 5-log decrease of the microorganism of concern in order to accept processing conditions, as fruit juices have been linked to many outbreaks (Yildiz et al., 2019). Choo et al. (2022) reported the effects of thermal pasteurisation on microbiological, antioxidant, and nutritional qualities of noni juice. During the course of eight weeks of refrigeration (4 °C) storage, the level of microbiological counts in thermal pasteurized noni juice remained within a reasonable range, but other parameters like antioxidant and organic acid values in thermally pasteurised noni juice were lower than the fresh sample. He et al. (2016) reported that the effects of thermal treatment and high-pressure homogenization on the juices of apples, oranges, and grapes were favourable because they increased the phenolic and antioxidant content of the juices. These findings suggested that thermal treatment was superior to high pressure homogenization in terms of improving fruit juice functional qualities like enhanced antioxidants, vitamins, and minerals. Thermal treatment disrupts the cell walls; it promotes the release of bound phenolic compounds from fruit cells and increases their concentration in the juice. The high-pressure homogenization ruptures the fruit cellular structure, which initiates the oxidative degradation of phenolic compounds by cytoplasmic polyphenol oxidase (He et al., 2016).

2.12. High pressure homogenization of juice

A lot of research is being done on emerging technologies to provide food items with the fresh qualities that modern customers want. High pressure is one of the methods used primarily to inactivate microorganisms or enzymes that may modify or harm fresh food items. It can be utilised in static (high hydrostatic pressure, HHP) and dynamic (high-pressure homogenization, HPH) forms. Utilising these cutting-edge technologies has the benefit that some of them are also referred to as nonthermal technologies as the processing temperature never goes over 40 °C. As a result, research on the impact of high pressure on the sensory, microbiological, and enzymatic properties of food has been done. The heat-labile pectinesterase in orange and grapefruit juices was rendered inactive by high pressure (500–600 MPa). After processing orange juice for 10 min at pressures between 500 and 900 MPa, the hazy stability remained (Welti et al., 2009). Due to the comminution brought on by the intense fluid-mechanical stresses generated on the pressurised (up to 350 MPa) liquid when flowing at high velocity through a micrometric gap (homogenization valve), HPH can be profitably applied to reduce the particles and emulsion droplets dispersed in a liquid to finer dimensions. The numerous studies on HPH microbial inactivation attest to the fact that the comminution action of HPH may also be used to break the cell membranes of microorganisms floating in liquid. In this regard, HPH can be regarded as a nonthermal technology because, as demonstrated by numerous studies, microbial inactivation during HPH treatments is only weakly attributable to thermal effects, even with the temperature rise brought on by frictional heating in the homogenization valve (roughly 0.2°C/MPa) (Maresca et al., 2011). A patent from two decades ago stated that juice homogenised at high pressure (100 MPa) has a longer shelf life and less microbial activity than juice homogenised at regular pressures (Clark et al., 1993).

2.13. Serum separation in blended beverage

Fruit juices undergo fast sedimentation due to their natural composition. Juices do not contain substances that can stabilize the movement of particles. Sedimentation of juices may be considered a technological problem for the food industry. If the fruit juices are not homogeneous, the properties of the juice, such as viscosity and thermal conduction, may be different for all materials, damaging their processing. Also, sedimentation of juices may be a problem regarding the sensory (visual) acceptance of the consumer. During storage, these particles aggregate to form sediments due to the action of gravity (Silva et al., 2019). The physicochemical properties of foods depend on interactions of food components including proteins and polysaccharides. For many processed food products, proteins and polysaccharides serve as fundamental ingredients to improve stability, rheological properties, and mouth feel. Products like milk and soymilk mixed with fruit juice can be described as acidified liquid protein systems with physical stability and viscosity almost like natural milk. They are usually composed of a dairy based acidic fraction (fermented dairy base) or a neutral fraction (milk, soymilk, etc.), which are further acidified with an acidic medium (fruit juice, fruit pulp, fruit juice concentrate, etc.) where it can also contain some flavourings, sweeteners, and stabilizers (Abbasi and Mohammadi, 2013). If the protein and polysaccharide carry similar net charge, electrostatic repulsive forces occur, resulting in thermodynamic incompatibility between biopolymers, further leading to separation in protein- and polysaccharide-rich phases. The stability of casein-hydroxypropyl cellulose complexes was enhanced with the increasing homogenization pressure, especially for the complex containing high molecular weight hydroxypropyl cellulose. The apparent particle size of complexes was reduced from ~200 nm to ~130 nm when using 300 MPa, when compared to the non-homogenized controls (Ye and Harte, 2014). The effect of guar gum as stabilizer on physicochemical and organoleptic properties were determined at different concentrations in kiwi fruit-based ready to serve beverage incorporated with lemongrass. Study results revealed that increasing the guar gum concentration increases the total soluble solids, titratable acidity, and viscosity. Organoleptic properties viz. mouthfeel and flavour were also significantly affected (Bochare et al., 2020).

2.14. Bioaccessibility and stability of blended beverages

Due to an increased interest in blended beverage, researchers have studied the in vitro gastrointestinal digestion of fruit juice (pineapple, orange, and kiwi) blended with soya milk and reported that water-fruit juice beverages favoured the bioaccessibility of phenolic compounds and hydrophilic antioxidants. Islam et al. (2021) developed a blended beverage of whey and pineapple juice, and shelf life of the blended beverage was investigated for sensory attributes, phase separation, acidity, and probiotic cell viability. The results revealed that the probiotic whey-pineapple beverage could be preserved for 42–56 days at 4°C with satisfactory acceptability and quality. Fruits contain several useful substances including antioxidants. Biological antioxidants have been defined as “compounds that protect biological systems against the potentially harmful effects of processes or reactions that cause extensive oxidations. It must be noted that various processing methods applied to food materials may have significant effects on their antioxidant potential and phytochemical bioaccessibility. For instance, the bioaccessibility and bioavailability of phenolic compounds could be affected by interaction with other macromolecules present such as proteins, carbohydrates, and lipids. The bioaccessibility of total phenolic compounds ranged from 13.52–26.49% and of flavonoids between 24.25–67.00%. The pomegranate juice and the juice of black grapes and aloe vera kept 58.12 and 50.36% of their initial anthocyanins content, while for the other samples less than 1.10% was established. As a result, a maximum of 30% remaining antioxidant activity was measured for some of the samples, but for most this was less than 10% (Mihaylova et al., 2021). A study found that the presence of biopolymers, such as gum Arabic, can enhance the bioaccessibility of bioactive compounds in freeze-dried orange juice (García et al., 2023). Fermentation was found to increase the bioaccessibility of polyphenols and carotenoids in mango cultivar juices, which in turn enhanced their antioxidant activity (Cele et al., 2022). The effect of in vitro gastrointestinal digestion on the bioaccessibility of phenolic compounds from fruit juices was studied. The study found that the bioavailability of phenolic compounds can be affected by the digestive process, with some phenolic acids showing increased liberation in digested samples (Mihaylova et al., 2021). Researchers investigated the ability of iron from almond and coconut beverages to be taken up by Caco-2 cells, which are a model of the human intestinal epithelium. The study found that both almond and coconut beverages significantly increased ferritin induction when iron sulfate was added, suggesting that these beverages could either contribute directly to iron supply or indirectly by enhancing iron absorption (Silva et al., 2022).

2.15. Bioactive properties and bioavailability of curcumin

Curcumin [1,7-bis(4-hydroxy-3-methoxyphenyl)-1, 6-heptadiene-3, 5-dione], a low molecular weight hydrophobic polyphenol derived from turmeric rhizomes (*Curcuma longa* Linn.), is used as a spice in many foods and as a colouring agent (Ma et al., 2019). Curcumin is the main bioactive ingredient in turmeric. *Curcuma longa* contains 3-5% curcuminoids with four primary forms, curcumin (77%), demethoxycurcumin (17%), bisdemethoxycurcumin (3%), and cyclocurcumin (Araiza et al., 2018). The hydroxyl groups of the benzene rings, double bonds in the alkene parts and the central β- diketone moiety in curcumin are responsible for many chemical/biochemical reactions such as free radical scavenging, antimicrobial and antioxidant activities (Rao et al., 2016). Curcumin is one of the well-studied nutraceuticals with health benefits and researchers are interested in developing curcumin-based functional foods. The studies related to absorption, distribution, metabolism, and excretion of curcumin have revealed that curcumin has low solubility in gastrointestinal fluids (Ngwabebhoh et al., 2018). The bioavailability of curcuminoids, unfortunately, is low, mainly due to their water insolubility and rapid metabolism. It has been shown that bisdemethoxycurcumin (BD-Cur) and demethoxycurcumin (D-Cur) have similar bioactivities as curcumin (Yu and Huang, 2012). Various nanocarriers have been developed to increase the oral bioavailability of curcumin (Ma et al., 2019). The in vivo pharmacokinetics revealed that curcumin-encapsulated nanoparticles demonstrate at least 9-fold enhance in oral bioavailability when contrasted with curcumin regulated with piperine (Rincon et al., 2020). Permeation experiments on Caco-2 cell monolayers suggested that digestion-diffusion was the major absorption mechanism of curcumin within nanoemulsion (Yu and Huang, 2012).

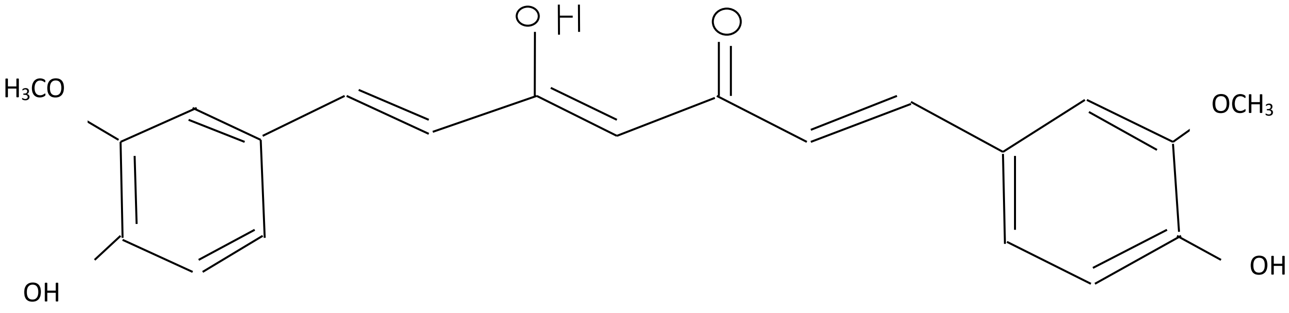

Fig 2.1: Structure of curcumin (Zhai et al., 2020).

2.16. Solubility of curcumin

One of the key areas of interest when it comes to curcumin dissolution is solubility enhancement. There are two primary approaches to consider: using substances to improve curcumin dispersibility and reducing the size of the particles to increase the surface area. The popular and effective strategies among them include inclusion complex creation, hydrophobic carriers, and surfactants (Tabanelli et al., 2021). Previous researchers have indicated that curcumin's low solubility and wettability result in poor dissolution, which in turn leads to poor bioavailability. A drug's solubility and/or dissolving rate determine its oral bioavailability, and dissolution may be a rate-determining step for the onset of a medicinal effect. For this reason, it is sometimes necessary to make attempts to improve the dissolution of drugs with poor water solubility (Modasiya and Patel, 2012). Luo et al. (2022) reported about the possibility of increasing curcumin absorption by excipient emulsions. Three distinct types of oils were used to create oil-in-water excipient emulsions: medium chain triglycerides (MCT), maize oil, and olive oil. Excipient emulsions can decrease cellular metabolism and increase trans-enterocyte absorption of curcumin, hence boosting its bioavailability. O/W emulsions were made with fish, flaxseed, coconut, sunflower, or maize oils. The solubility of curcumin increased with temperature at 100 °C (190–200 µg/ml) than at 30 °C (30–36 µg/ml) (Zou et al. 2016). Joung et al. (2016) reported that the solubility of curcumin was much higher in MCT oil (45% capric acid and 55% caprylic acid) as compared to coconut oil and olive oil. The solubility of curcumin in coconut oil, olive oil, and MCT oil was 0.1 mg/ml, 0.08 mg/ml and 0.25mg/ml, respectively.

2.17. Antimicrobial activity of curcumin

The traditional medical practices of Pakistan, Bangladesh, and Afghanistan, as well as the Ayurvedic and Unani systems, and traditional Chinese medicine, have all made extensive use of this rhizome. In the past, people have used turmeric as an antiseptic, antibacterial, anti-inflammatory, choleretic, and carminative agent to treat burns and wounds, liver and gastrointestinal issues, respiratory conditions (such as sinusitis, asthma, coughing, and runny nose), anorexia, and rheumatism (Adamczak et al., 2020). Research has shown that curcumin has strain-specific activity, with a stronger effect against Gram-positive bacteria compared to Gram-negative bacteria. Studies have demonstrated that curcumin inhibits the growth of both Gram-positive and Gram-negative bacteria, with minimum inhibitory concentrations ranging from 31.25 to 5000 µg/ml. Notably curcumin has been found to be more effective against Gram-positive bacteria like *Staphylococcus aureus* and *Staphylococcus epidermidis*

(Adamczak et al., 2020). When combined with antibacterial drugs, curcumin has shown a synergistic relationship, enhancing the antibacterial effect against certain pathogens. Additionally, curcumin-based photodynamic treatment has been explored for its antibacterial efficacy, showing promising results in inactivating *Staphylococcus aureus* in juices, which can potentially be utilized to extend the shelf life of beverages. These findings highlight the potential of curcumin as a natural antimicrobial agent with diverse applications in combating bacterial infections and foodborne pathogens (Dai et al., 2022; Górski et al., 2022; Hussain et al., 2022).

2.18. Curcumin nanoemulsion

Curcumin nanoemulsions were developed with different surfactant concentrations followed by high pressure homogenization and finally incorporated in a milk system (Joung et al., 2016). Two immiscible liquids (oil and water) combined with emulsifiers, thickeners, jelly agents, and a host of additional food-grade substances stabilised the mixture to generate emulsions and nanoemulsions. Their sizes varied between 10 and 100 nm for nanoemulsions and between 100 nm and 100 µm for emulsions, therefore their primary differences were in size (Tabanelli et al., 2021). Curcumin nanoemulsion-fortified milk showed lower lipid oxidation than unfortified milk. Curcumin nanoemulsion dissolved in coconut oil, sunflower oil or linseed oil were fed to weaning rats for 60 days (Sugasini and Lokesh, 2017). The rat fed with curcumin in linseed oil showed high level of curcumin in serum, heart, liver and brain. Solubility of curcumin in oil is low and it is also known that much larger amount of curcumin is dissolved in heated oil that remains soluble for long period of time. Therefore, Yu and Huang (2012) studied the metastable (120 h) solubility of curcumin in four different oils. About 1 mg/ml curcumin was dissolved in MCT oil, canola, coconut, and corn oil and percentage bioaccessibility of curcuminoids was determined after in vitro lipolysis in both fed and fasted states. The results showed that the metastable solubility and lipolysis of MCT oil generated the highest percentage of bioaccessibility (72.1±6.4% and 72.2±10.1%, respectively) followed by coconut oil and then canola and corn oils. Curcumin release was 10% from nanoemulsion developed using ultrasound during gastric digestion and 23% under intestinal conditions, indicating its slow release and increased bioavailability. Curcumin stability in traditional emulsion was shown to be somewhat higher after comparing curcumin oil-in-water nanoemulsion and emulsion; however, nanoemulsions demonstrated superior stability (Tabanelli et al., 2021). The pure curcumin is very susceptible to chemical degradation in alkaline aqueous solutions (pH ≥7.0) and tends to crystallise out of aqueous acidic solutions.

These effects were attributed to modifications in curcumin's molecular structure at various pH values. The resulting curcumin crystals were comparatively big (10−50 μm). It caused them to sediment quickly. Curcumin increases the water dispersibility and chemical stability of O/W emulsions. After a month of incubation at 37 °C, emulsions maintained in an acidic environment (pH <7) were able to keep >85% of the curcumin, while emulsions placed in an alkaline environment having pH 7.0, 7.4, and 8.0 were able to retain 62, 60, and 53% of the curcumin, respectively (Kharat et al., 2017).

2.19. Processing conditions for nanoemulsions

Emulsions are created when a shearing mechanical force splits the dispersed phase into tiny droplets, exposing two immiscible phases to one another. Two types of sources of shear force are used to create emulsions: high energy sources use a device to apply the shear force, and low energy sources understand how the system's thermal or chemical energy changes to produce the desired surfactants and each liquid phase's physical properties (emulsion formation). A two-step procedure is needed to create nanoemulsions: first, coarse emulsions must be generated, and then the large droplets must be broken down into nano-size using high-pressure homogenization or ultrasonication (Wilson et al., 2022). Ultrasonication involves the use of ultrasonic waves to disrupt droplets into smaller sizes, while high-pressure homogenization utilizes mechanical devices like high-pressure valve homogenizers to create nanoemulsions. These methods are crucial for achieving small droplet sizes, enhancing stability, and improving functional properties of nanoemulsions. Additionally, the preparation of nanoemulsions can be categorized into low-energy and high-energy methods, with each method offering distinct advantages in terms of efficiency and droplet size control (Ashaolu, 2021; Aswathanarayan and Vittal, 2019; Çınar, 2017). Microfluidization is another method used to manufacture nanoemulsion. This instrument operates using a high-pressure displacement pump (500–20,000 psi) that forces materials through a chamber with many microchannels. The materials flow through the microchannels to an impingement location where they are transformed into minuscule particles. Other methods used are emulsion inversion point (EIP) method and phase inversion temperature (PIT) method. The EIP approach involves spontaneous emulsification using low energy, whereas PIT involves raising the emulsion system's temperature to alter the surfactant's solubilization pattern from hydrophilic to lipophilic. This results in the formation of bicontinuous microemulsions, which are then followed by emulsion inversion (Sutradhar and Amin, 2013).

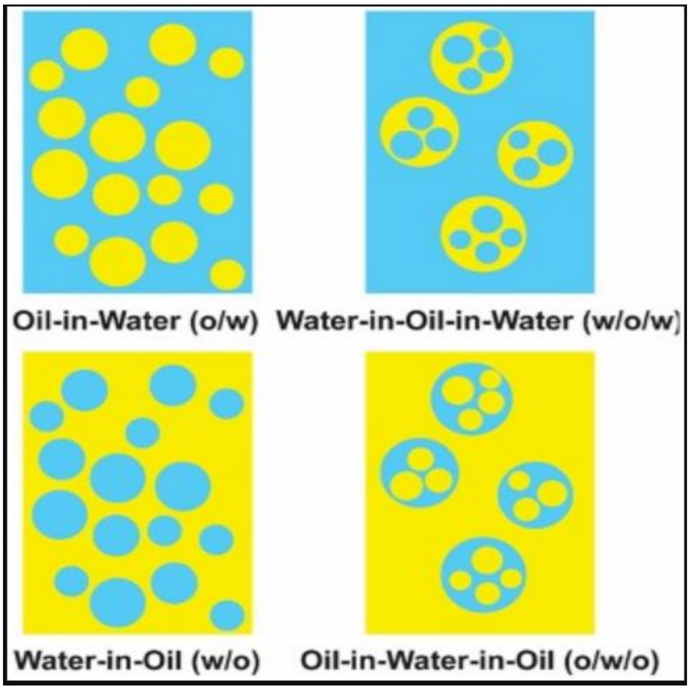

Fig 2.2: Different types of emulsion that are categorised by their continuous and dispersed phases (Wilson et al., 2022).

2.20. Nanoemulsion destabilizing mechanisms

When the oil and water phases of a nanoemulsion have different densities, the droplets in the nanoemulsion migrate as a result of gravitational forces, leading to gravitational separation. Depending on the relative densities of the phases, this can cause either sedimentation (movement below) or creaming (movement upward). There are several parameters that affect the rate of gravitational separation, including the viscosity of the continuous phase, droplet size, and density differential. Enhancing the viscosity of the aqueous phase and decreasing the particle size and density contrast can contribute to improving the stability of nanoemulsions (McClements et al., 2021).

The process by which two or more droplets combine to create clusters is known as flocculation. Repulsion forces like steric and electrostatic contacts may be outweighed by attractive forces like van der Waals, hydrophobic, depletion, and bridging attraction, causing this to happen. Larger droplets may develop as a result of flocculation, which can also occur before coalescence. While flocculation in concentrated nanoemulsions can hinder gravitational separation and cause the production of a semi-solid texture owing to Ostwald ripening, it can also speed up creaming or sedimentation in weak nanoemulsions (Liu et al., 2019). Depending on the nature of the forces, droplet aggregation can occur via coalescence or flocculation. Smaller droplets combine to form larger ones in the process of coalescence. Flocculation occurs as two or more droplets cluster together. Flocculation facilitates coalescence by allowing droplets to remain in close proximity for extended durations. Due to droplet aggregation particle size increases, and it typically speeds up creaming or sedimentation. Oiling off, or the creation of an independent layer of oil on top of the nanoemulsion, can happen as a result of the attraction interactions between droplets. Several variables, including the type of forces at play and the makeup of the emulsifier being utilised, might affect coalescence (McClements et al., 2021). The process "oiling-off" occurs when individual layers of oil separate from the aqueous phase of a nanoemulsion. This is frequently observed in diluted nanoemulsions and might be caused by coalescence. By employing emulsifiers that improve stability and raising the aqueous phase viscosity, oiling-off can be minimised coalescence (McClements et al., 2021). Smaller droplets dissolve during the Ostwald ripening process, and the dispersed oil molecules spread to bigger droplets, enlarging them. This process, which is impacted by variables including the interfacial tension and oil molecule concentration, can result in a net increase in droplet size. Using an oil phase with limited water solubility or adding ripening inhibitors can prevent Ostwald ripening (Liu et al., 2019). In mixed colloidal dispersions with small and big droplets, the rate of Ostwald ripening may also be accelerated. Ostwald ripening is primarily caused by differences in particle sizes, hence emulsions with varying droplet sizes may experience an acceleration of this process. Furthermore, by reducing the diffusion path, direct contact between flocculated oil droplets may accelerate Oswald ripening in emulsions (Salvia and McClements 2016).

2.21. Coconut oil nanoemulsion

Coconut oil is used in nanoemulsions due to its advantages over conventional emulsions. Nanoemulsions have a high bioavailability, enhanced long-term stability, and high optical clarity. The small droplet sizes in the range of 20-200 nm allow for better dispersion and improved solubility of the oil phase (Hasan et al., 2015; Wuttikul and Sainakham, 2022). Piriyaprasarth et al. (2012) made nanoemulsion formulations via conventional homogenization (13,500 rpm, 10 min) method using various surfactants and oil phase that consisted of 20–40% weight/weight concentrations of coconut oil, sunflower oil, and castor oil. The formulations containing coconut oil in the range of 20-40% w/w and the ratio of polysorbate 80 to sorbitan monooleate of 2:1 and 3:1 provided stable nanosized emulsions (100-500 nm). The results indicated that a decrease in the concentration of surfactant and an increase in the concentration of oil affected the stability of nanoemulsions (Piriyaprasarth et al., 2012). The nanoemulsions containing extract of mangosteen (*Garcinia mangostana* L.) rind were prepared using both high-energy and low-energy emulsification methods, with VCO as the oil phase, Tween 80 and Span 80 as the oil-in-water surfactants, and distilled water as the aqueous phase. Results revealed that the VCO-based nanoemulsion was a promising carrier of mangosteen extract for topical formulation (Mulia et al., 2018). Coconut oil-based nanoemulsions have been studied for their potential in food applications, such as improving the compatibility, solubility, stability, and physicochemical equilibrium of various ingredients. For example, a coconut oil-based resveratrol nanoemulsion was optimized for use in food products. The optimization process involved using response surface methodology to study the effect of formulation and ultrasonication process factors on the globule size, polydispersity index (PDI), and zeta potential of the nanoemulsion (Kotta et al., 2021).

2.22. Effect of particle size on nanoemulsion stability

Ostwald ripening has an impact on micro and nanoemulsion stability. Adding a stabilizer, or a combination of them, can lower Ostwald ripening. It has been demonstrated that mixtures of costabilizers, both short and long chain, are effective in halting the deterioration of micro and nanoemulsions (Reyes et al., 2021). Food-grade Tween 80 and Span 80 were used as emulsifiers for the system based on the screening of previous experiments and the consideration of easiness. As the amount of Tween 80 increased, the particle size decreased. The effect of the difference in surfactant combination on particle size can be attributed to the change in HLB (hydrophilic-lipophilic balance of surfactant) values. HLB value indicates the affinity of the surfactant for the aqueous or oil phase and plays an important role in the phase transition of the low energy methods. Tween and Span are used as surfactants; while Tween has hydrophilic characteristics having HLB value >10, Span has hydrophobic characteristics with HLB value <10 (Fang et al., 2022). The precise size of the oil droplets within an O/W emulsion depends on the type and concentration of emulsifier and oil used, as well as on the homogenization method employed. When an emulsion contains droplets with a mean diameter greater than 200 nm, it is usually categorized as a conventional emulsion (Choi and McClements, 2020). Different authors have given different maximum mean diameter of an emulsion; the highest limit has been suggested to be 100 nm (Dasgupta and Ranjan, 2018; Zhou et al., 2018), 200 nm (Mason et al., 2006; McClements and Rao, 2011), 500 nm (Gupta et al., 2016), or 1000 nm (Abramovits et al., 2010). This misconception is understandable given that crossing one of these particle size limitations does not significantly alter any of the physicochemical or functional characteristics of emulsions, such as optical qualities, creaming rate, rheology, or bioavailability. Rather, for various qualities, there usually is a rather slow shift that takes place at different particle sizes. When the droplets are smaller than around 50 nm in diameter, a nanoemulsion may become nearly optically transparent; but, when the droplet size is less than 100 nm, the nanoemulsion becomes very stable against creaming. Products that must be optically clear, such as soft drinks and fortified waters, can employ this kind of nanoemulsion (McClements, 2011).

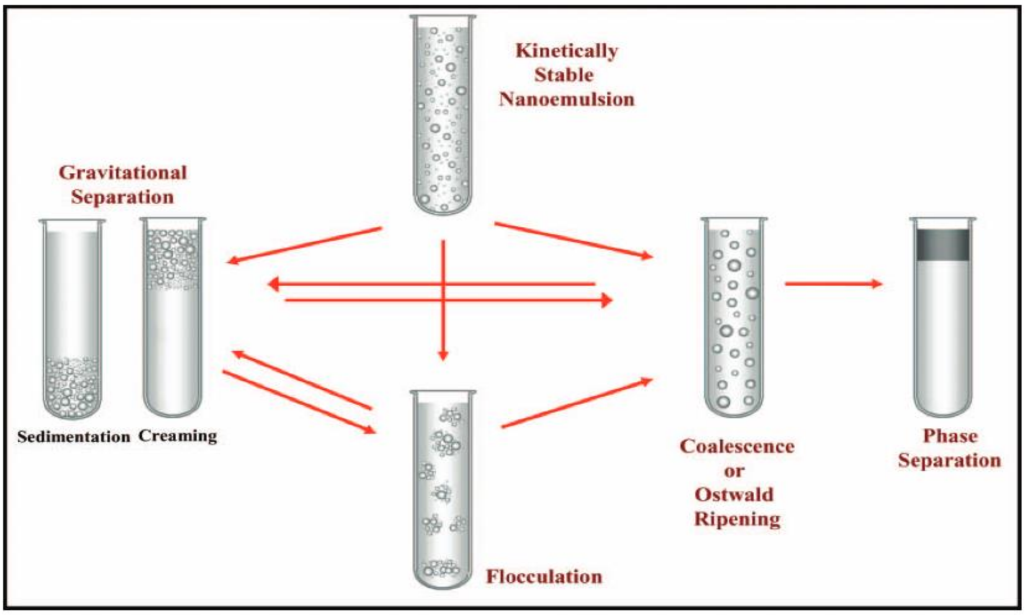

Fig 2.3: Nanoemulsions may breakdown numerous distinct physicochemical processes, including gravitational separation, flocculation, coalescence, Ostwald ripening, and oiling-off (McClements and Rao, 2011).

2.23. Pickering emulsions stabilized with various shapes of food grade particles

Food grade particles in various forms have drawn the attention of researchers in recent years (Zhang et al., 2021). The importance of the shape of particles in stabilizing Pickering emulsions, as well as the potential advantages of using non-spherical particles for this purpose were explored. Anisotropic particles with different geometrical shapes can generate stronger capillary forces and interfacial layers, leading to more stable emulsion systems (Li et al., 2022). Recent research has explored the use of various food-grade particles to stabilize Pickering emulsions, including polysaccharides, proteins, and inorganic particles. However, many of these particles do not naturally have the required dual wettability, so physical and chemical modification methods are needed. Particles can provide a space barrier between the two immiscible phases to prevent droplets' coalescence (Dickinson, 2012) and Ostwald ripening in Pickering emulsions. Compared to spherical particles, non-spherical particles like rods, discs, and fibers can potentially form more stable Pickering emulsions. This is because their anisotropic shapes can generate stronger capillary forces at the interface (Li et al., 2022b). The particles with different shapes which have various particle densities, desorption energy, and capillary forces between adjacent particles largely affect the stabilization with different principles and application of emulsions. Particle shapes can be divided into regular spherical and irregular shapes with anisotropic morphology (Low et al., 2020). It was found that the principle of stable Pickering emulsion of rod-shaped particles was different from that of regular spherical particles.

2.24. Food applications of Pickering emulsions

Pickering emulsions have been the subject of academic interest in recent years due to their unique properties and potential applications in food systems. These emulsions are more physically and chemically stable than traditional emulsions, and they can offer a wide range of potential applications. They are made using a variety of techniques and can be stabilized by both organic and inorganic particles. While organic particles have a large molecular weight, inorganic particles are constrained by their indigestibility and lack of biodegradability. The stability of Pickering emulsions is influenced by factors such as wettability, particle shape, and size, and they can be used as stabilizers in food systems. The use of Pickering emulsions in food systems will improve the biological activity of food products (Potoroko et al., 2023). Pickering emulsions are more physically and chemically stable than traditional emulsions, which can be attributed to the solid particles that adsorb at the oil-water interface and form a dense film to prevent droplet aggregation (Chen et al., 2020; Potoroko et al., 2023). Pickering emulsions have a wide range of applications in food systems, including dairy and meat products, mayonnaises, and other food products (Potoroko et al., 2023). Pickering emulsions are more environmentally friendly than traditional emulsions, as they do not rely on synthetic emulsifiers (Klojdová and Stathopoulos, 2022). Pickering emulsions can be made using biodegradable particles, which can be beneficial for food systems (Yang et al., 2017). Nanocellulose-stabilized Pickering emulsions have potential health benefits in food and beverage products due to their excellent stability and biocompatibility. These emulsions can be used in various food-related applications, such as delivery systems, food packaging materials, and fat substitutes. The unique properties of nanocellulose, including its nanosize, amphiphilicity, and biodegradability make it a suitable stabilizer for Pickering emulsions. The preparation processes are facile and easy to handle, as they are conducted in aqueous solutions where nanocelluloses are well dispersed and do not require any time-consuming solvent exchanging process (Fujisawa et al., 2017; Ji and Wang, 2023; Perrin et al., 2020). Pickering emulsions can be used for the encapsulation and delivery of biologically active substances, which can improve the functionality of food products (Chen et al., 2020; Klojdová and Stathopoulos, 2022). However, there are technical challenges in using Pickering emulsions in food applications, such as the need for a proper choice of particle type and the requirement for particles to stabilize the emulsion (Linke and Drusch, 2018).

2.25. Plant-based emulsifier to reduce Tween level in emulsion

The research article by Phakthawat et al. (2023) discusses the use of hydrolysed rice glutelin as a plant-based emulsifier to reduce the need for synthetic emulsifiers like Tween in emulsion-based products, such as coconut milk. The study found that hydrolysed rice glutelin, a protein extracted from rice, can improve its emulsifying properties when partially unfolded by trypsin hydrolysis, leading to increased solubility and surface hydrophobicity. This improved emulsifying property can potentially replace Tween in emulsion-facing process stresses, making the emulsion more natural and environment friendly. Plant-based emulsifiers have gained significant attention in recent years due to their potential to enhance the functionality of food emulsions and contribution to sustainability. These emulsifiers, derived from natural sources such as plants, have been found to improve the stability, bioaccessibility, and oral bioavailability of encapsulated bioactive compounds in food emulsion. One study confirmed that plant-based ingredients, particularly saponins and lecithin, effectively produce stable O/W emulsions with flaxseed oil, offering opportunities for creating natural ingredient-based food emulsions (McClements et al., 2021). Another research article reviewed the use of natural emulsifiers in the design of emulsion-based delivery systems to protect bioactive compounds, discussing the properties and functionality of these systems (Teixé et al., 2023). In addition, plant-based emulsifiers have been found to be effective in improving the physicochemical properties of food emulsions, such as physical stability, microstructural characteristics, and rheological properties (Quezada et al., 2024). Soy lecithin, Quillaja saponin, vicilin and legumin, pea, lentil, faba bean proteins and methylcellulose films loaded with clove bud oil are some of the examples of plant-based emulsifiers for emulsion production (Deng, 2021; McClements et al., 2021; Quezada et al., 2024).

2.26. Nanocellulose

Nanocellulose is a natural and unique material extracted from native cellulose and has gained much attention due to its use as a biomedical material. Nanocelluloses are of three different types: cellulose nanocrystals (CNCs), cellulose nanofibrils (CNFs), and bacterial cellulose nanofibrils (BCNFs) (Benaissa et al., 2019). Nanocellulose, in the form of nanofibers and nanocrystals, can be obtained from various lignocellulosic waste materials like palm residues and agave bagasse. This makes it a sustainable and eco-friendly option for food applications (Franco et al., 2023). Nanocellulose has a high surface area, aspect ratio, and water absorption ability, which contribute to its effectiveness as a stabilizing agent in food products. It can be used to modify the rheological behaviour of food systems (Perumal et al., 2022). CNCs and CNFs are both known to stabilize oil-water interface, forming the so-called Pickering emulsion which are surfactant free and highly stable (Jiménez and Capron, 2018). Pickering emulsion using medium chain triglycerides and Tween 80 and aminated nanocellulose particles with average particle size of ≤150 nm was obtained by Ngwabebhoh et al. (2018). CNCs, CNFs, and BCNFs have emerged as sustainable stabilizers/emulsifiers in food-related Pickering emulsions due to their favourable properties such as renewability, low toxicity, amphiphilicity, biocompatibility, and high aspect ratio (Ji and Wang, 2023). Some specific applications of nanocellulose in food stabilization include its use as an additive, food supplement, or in packaging materials. It can help improve the texture, stability, and shelf-life of various food products (Franco et al., 2023).

Since cellulose microfibrils are firmly attached in hemicellulose and lignin matrixes, it takes a lot of energy and chemicals to isolate pure cellulose. By hydrolysing rice straw holocellulose with sulfuric acid, amphiphilic holocellulose nanocrystals are produced. The yield of holocellulose (holoCNC) and α-cellulose isolated from rice straw using dewaxing-delignification method and alkaline treatment was 36.4 and 75.4%, respectively (Jiang and Hsieh, 2015). Both CNCs and holoCNCs could make O/W Pickering emulsions; however, the emulsion produced by the holoCNCs was 30% more emulsified and had emulsion droplets twice the size of those produced by the CNCs. HoloCNCs' distinct surface activity, amphiphilicity, and reduced self-assembling qualities provide desired traits that previously was only achievable through extra, frequently complex surface modification of CNCs (Jiang and Hsieh, 2015). Lei et al. (2022) reported that Pickering emulsion was successfully fabricated using bamboo shoot nanocellulose. With an average width of 56.37 nm and height of 7.44 nm, the nanocellulose that was isolated from bamboo shoots had significant promise as an emulsifier in the Pickering emulsions. Pomelo peels were used to create CNFs and CNCs using an easy method that involved sulfuric acid treatment and TEMPO oxidation. The longer fibrils in CNFs cause a gel structure to develop, because of which the stability of CNF-based Pickering emulsions was higher than that of emulsions stabilised with CNCs. The viscoelasticity of Pickering emulsions based on CNF was improved by higher oil fractions. Due to the bigger droplet size and higher viscoelasticity of the emulsion, the in vitro digestion data indicated that increased oil fractions lowered the degree of lipolysis.

Table 2.2: Extraction of nanocellulose using different samples and processing conditions

Nanocellulose samples	Type of nanocellulose	Processing conditions	References
Cotton linters	Nanocellulose crystals	acid hydrolysis	Morais et al. (2013)
Sisal fiber	Cellulose nanofibers	acid hydrolysis	Morán et al. (2008)
Husks of rice grains	Cellulose nanowhiskers	acid hydrolysis	Rashid and Dutta (2020)
Apple stem	Nanocellulose whiskers	acid hydrolysis	Phanthong et al. (2015)
Yerba mate sticks	Cellulose nanofibers	acid hydrolysis	Júnior et al. (2019)
Palm residues	Cellulose nanocrystal	acid hydrolysis	Mehanny et al. (2021)
Kenaf bast	Nanocrystalline cellulose	Microwave treatment and acid hydrolysis	Song et al. (2018)
Rice husk	Cellulose nanofibers and cellulose nanocrystals	High-pressure homogenization, acid hydrolysis and Combination of high-pressure homogenization along with acid hydrolysis	Samsalee et al. (2023)
Pineapple leaf fibers	Cellulose nanofiber	High-shear homogenization and ultrasonication	Mahardika et al. (2018)

Lycopene release exhibited a tendency like that of free fatty acid release, indicating that increased oil fractions were advantageous for regulating lycopene release during gastrointestinal digestion (Gao et al., 2023). After acid hydrolysis, HPH was employed as a post-treatment to modify the morphology and physical characteristics of the cellulose found in ginkgo seed shells. The resultant nanocellulose was then added to stabilise O/W Pickering emulsions. Small quantities of nanocellulose processed at 50 MPa was used to create emulsions with an oil phase ranging from 10 to 70% (v/v). Furthermore, the emulsions demonstrated benign stability under a variety of pH, ionic strength, and temperature conditions (Ni et al., 2020).

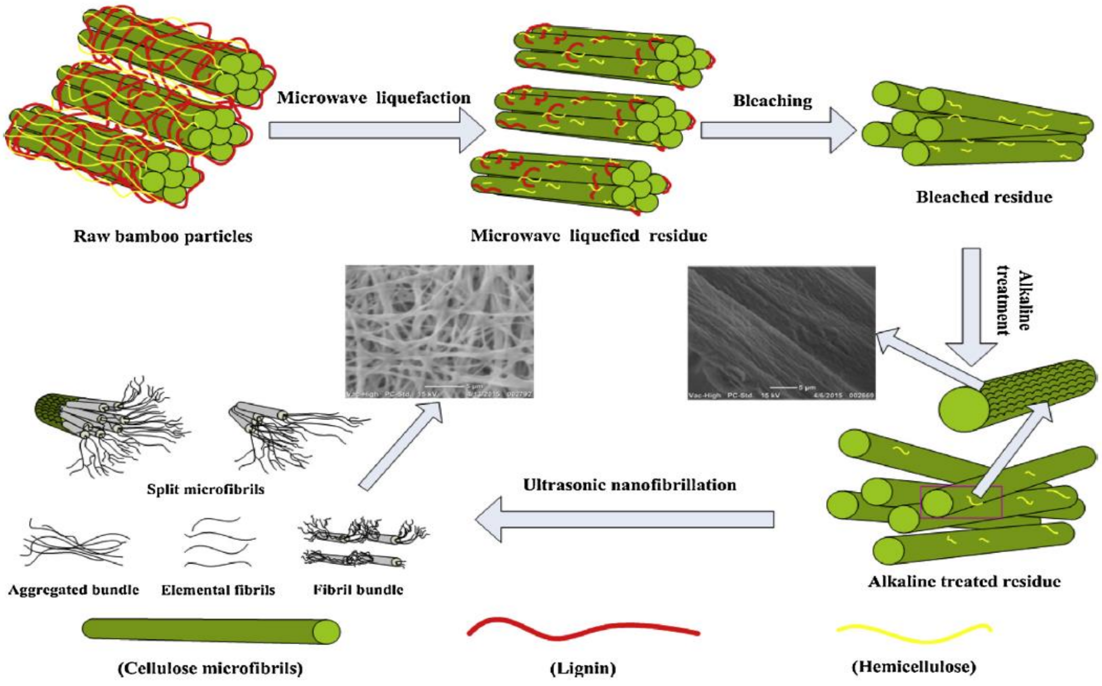

Fig 2.4: Graphical representation showing the formation mechanism of nanofibrils using combination of microwave and ultrasonication (Xie et al., 2016).

Bibliography

Abbasi, S., and Mohammadi, S. (2013). Stabilization of milk–orange juice mixture using Persian gum: Efficiency and mechanism. *Food Bioscience*, 2:53–60.

Abdul Rahim, A.R., Johari, K., Saman, N., Mat, H. (2021). Sustainable conversion of coconut wastes into useful adsorbents. In: Kharissova, O.V., Torres-Martínez, L.M., Kharisov, B.I. (eds) Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications. Springer, Cham

Abedi, F., Sani, A. M., and Karazhiyan, H. (2014). Effect of some hydrocolloids blend on viscosity and sensory properties of raspberry juice-milk. *Journal of Food Science and Technology*, 51(9):2246–2250.

Abramovits, W., Granowski, P., and Arrazola, P. (2010). Applications of nanomedicine in dermatology: use of nanoparticles in various therapies and imaging. *Journal of Cosmetic Dermatology*, *9*(2):154–159.

Adamczak, A., Ożarowski, M., and Karpiński, T. M. (2020). Curcumin, a natural antimicrobial agent with strain-specific activity. *Pharmaceuticals*, *13*(7):153.

Agarwal, R. K., and Bosco, S. J. D. (2017a). Extraction processes of virgin coconut oil. *MOJ Food Processing & Technology*, *4*(2):00087.

Agdeppa, I. A., and Zamora, J. A. T. (2022). The Effects of Coconut Skim Milk and Coco-Dairy Milk Blend on the Nutritional Status of Schoolchildren. *Journal of Nutrition and Metabolism*, 10:1155.

Araiza-Calahorra, A., Akhtar, M., and Sarkar, A. (2018). Recent advances in emulsion-based delivery approaches for curcumin: From encapsulation to bioaccessibility. In *Trends in Food Science and Technology*, 71:155–169.

Ariyaprakai, S., Limpachoti, T., and Pradipasena, P. (2013). Interfacial and emulsifying properties of sucrose ester in coconut milk emulsions in comparison with Tween. *Food Hydrocolloids*, *30*(1):358–367.

Arlai, A., and Tananuwong, K. (2021). Quality of chilled and frozen starch gels as affected by starch type, highly concentrated sucrose and coconut milk. *LWT-Food Science and Technology*, 147:111534.

Ashaolu, T. J. (2021b). Nanoemulsions for health, food, and cosmetics: a review. *Environmental Chemistry Letters*, *19*(4):3381–3395.

Aswathanarayan, J. B., and Vittal, R. R. (2019). Nanoemulsions and their potential applications in food industry. *Frontiers in Sustainable Food Systems*, 3:95.

Bamidele, O. P., and Fasogbon, M. B. (2017). Chemical and antioxidant properties of snake tomato (Trichosanthes cucumerina) juice and Pineapple (Ananas comosus) juice blends and their changes during storage. *Food Chemistry*, 220:184–189.

Beegum, P. P. S., Nair, J. P., Manikantan, M. R., Pandiselvam, R., Shill, S., Neenu, S., and Hebbar, K. B. (2022). Effect of coconut milk, tender coconut and coconut sugar on the physico-chemical and sensory attributes in ice cream. *Journal of Food Science and Technology*, *59*(7): 2605–2616.

Benaissa, Y., Addou, S., Dib, W., Benhatchi, S., Mehidi, A., Kheroua, O., and Saidi, D. (2019). Effect of in vitro hydrolysis on coconut milk digestibility. *Revue Francaise d'Allergologie*, 59(5):380–384.

Bochare, S., Kshirsagar, R., Sawate, A., Agarkar, B., and Patil, B. (2020). Studies on effect of guar gum as stabilizer on kiwi fruit ready to serve beverage incorporated with lemongrass. *The Pharma Innovation Journal*, *9*(3):109–111.

Calligaris, S., Manzocco, L., Anese, M., and Nicoli, M. C. (2004). Effect of heat-treatment on the antioxidant and pro-oxidant activity of milk. *International Dairy Journal*, 14(5):421–427.

Cele, N. P., Akinola, S. A., Shoko, T., Manhevi, V. E., Remize, F., and Sivakumar, D. (2022). The bioaccessibility and antioxidant activities of fermented mango cultivar juices after simulated in vitro digestion. *Foods*, 11(17):2702.

Chauhan, O. P., Singh, D., Tyagi, S. M., and Balyan, D. K. (2002). Studies on preservation of sugarcane juice. *International Journal of Food Properties*, *5*(1):217–229.

Chen, L., Ao, F., Ge, X., and Shen, W. (2020). Food-grade Pickering emulsions: Preparation, stabilization and applications. *Molecules*, *25*(14):3202.

Chen, Y., Chen, Y., Jiang, L., Huang, Z., Zhang, W., and Yun, Y. (2023). Improvement of emulsifying stability of coconut globulin by noncovalent interactions with coffee polyphenols. *Food Chemistry,* 20:100954.

Chen, Y., Zhang, Z., Chen, Y., Li, T., and Zhang, W. (2024). The role of fat content in coconut milk: Stability and digestive properties. *Food Chemistry*, 138900.

Chiewchan, N., Phungamngoen, C., and Siriwattanayothin, S. (2006). Effect of homogenizing pressure and sterilizing condition on quality of canned high fat coconut milk. *Journal of Food Engineering*, *73*(1):38–44.

Choi, S. J., and McClements, D. J. (2020). Nanoemulsions as delivery systems for lipophilic nutraceuticals: Strategies for improving their formulation, stability, functionality and bioavailability. *Food Science and Biotechnology*, *29*:149–168.

Choo, Y. X., Teh, L. K., and Tan, C. X. (2022). Effects of sonication and thermal pasteurization on the nutritional, antioxidant, and microbial properties of noni juice. *Molecules*, *28*(1):313.

Çınar, K. (2017). A review on nanoemulsions: preparation methods and stability. *Trakya Üniversitesi Mühendislik Bilimleri Dergisi*, *Journal of Engineering Sciences*, 18(1):73–83

Clark, A. V., Rejimbal Jr, T. R., and Gomez, C. M. (1993). Washington, DC: U.S. Patent and Trademark Office. *US Patent,* 5:232–726.

Dai, C., Lin, J., Li, H., Shen, Z., Wang, Y., Velkov, T., and Shen, J. (2022). The natural product curcumin as an antibacterial agent: Current achievements and problems. *Antioxidants*, *11*(3): 459.

Dasgupta, N., and Ranjan, S. (2018). *An introduction to food grade nanoemulsions*, Vol. 13, pages. 2–14. Singapore: Springer.

Deng, L. (2021). Current progress in the utilization of soy-based emulsifiers in food applications—A Review. *Foods*, *10*(6):1354.

Dickinson, E. (2012). Use of nanoparticles and microparticles in the formation and stabilization of food emulsions. *Trends in Food Science & Technology*, *24*(1):4–12.

Famurewa, J. A. V, Jaiyeoba, K. F., Ogunlade, C. A., and Ayeni, O. B. (2021). Effect of extraction methods on yield and some quality characteristics of coconut (Cocos nucifera L) oil. *Agricultural Engineering International: CIGR Journal*, *23*(3).

Fang, Q., Zhao, X., Li, S., Qiu, Z., Wang, Z., and Geng, Q. (2022). Effect of surfactants with different hydrophilic–lipophilic balance on the cohesive force between cyclopentane hydrate particles. *Journal of Marine Science and Engineering*, *10*(9):1255.

Fidaleo, M., and Ventriglia, G. (2022). Application of Design of Experiments to the Analysis of Fruit Juice Deacidification Using Electrodialysis with Monopolar Membranes. *Foods*, *11*(12):1770.

Franco, T. S., de Muniz, G. B., Lomelí-Ramírez, M. G., Rangel, B. S., Jiménez-Amezcua, R. M., Mijares, E. M., García-Enríquez, S., and Rentería-Urquiza, M. (2023). Nanocellulose and Its Application in the Food Industry. *Biology and Life Sciences Forum*, *28*(1):2.

Fujisawa, S., Togawa, E., and Kuroda, K. (2017). Nanocellulose-stabilized Pickering emulsions and their applications. *Science and Technology of Advanced Materials*, *18*(1):959–971.

Gao, J., Qiu, Y., Chen, F., Zhang, L., Wei, W., An, X., and Zhu, Q. (2023). Pomelo peel derived nanocellulose as Pickering stabilizers: Fabrication of Pickering emulsions and their potential as sustained-release delivery systems for lycopene. *Food Chemistry*, *415*:135742.

García-Martínez, E., Camacho, M. del M., and Martínez-Navarrete, N. (2023). In vitro bioaccessibility of bioactive compounds of freeze-dried orange juice co-product formulated with gum Arabic and modified starch. *Molecules*, *28*(2):810.

Ghani, N. A. A., Channip, A. A., Chok Hwee Hwa, P., Ja'afar, F., Yasin, H. M., and Usman, A. (2018). Physicochemical properties, antioxidant capacities, and metal contents of virgin coconut oil produced by wet and dry processes. *Food Science & Nutrition*, *6*(5):1298–1306.

Górski, M., Niedźwiadek, J., and Magryś, A. (2022). Antibacterial activity of curcumin–a natural phenylpropanoid dimer from the rhizomes of Curcuma longa L. and its synergy with antibiotics. *Annals of Agricultural and Environmental Medicine*, *29*(3):394.

Grau-Fuentes, E., Rodrigo, D., Garzón, R., and Rosell, C. M. (2023). Understanding the marketed plant-based beverages: From ingredients technological function to their nutritional value. *Journal of Functional Foods*, 106:105609.

Gupta, A., Eral, H. B., Hatton, T. A., and Doyle, P. S. (2016). Nanoemulsions: formation, properties and applications. *Soft Matter*, *12*(11):2826–2841.

Hasan, H. M., Leanpolchareanchai, J., and Jintapattanakit, A. (2015). Preparation of virgin coconut oil nanoemulsions by phase inversion temperature method. *Advanced Materials Research*, *1060*:99–102.

He, Z., Tao, Y., Zeng, M., Zhang, S., Tao, G., Qin, F., and Chen, J. (2016). High pressure homogenization processing, thermal treatment and milk matrix affect in vitro bioaccessibility of phenolics in apple, grape and orange juice to different extents. *Food Chemistry*, *200*:107–116.

Humayun, A., Gautam, C. K., Madhav, M., Sourav, S., and Ramalingam, C. (2014). Effect of citric and malic acid on shelf life and sensory characteristics of orange juice. *International Journal of Pharmacy and Pharmaceutical Science*, *6*:117–119.

Hussain, Y., Alam, W., Ullah, H., Dacrema, M., Daglia, M., Khan, H., and Arciola, C. R. (2022). Antimicrobial potential of curcumin: therapeutic potential and challenges to clinical applications. *Antibiotics*, *11*(3):322.

Islam, M. Z., Tabassum, S., Harun Rashid, M., Vegarud, G. E., Alam, M. S., and Islam, M. A. (2021). Development of probiotic beverage using whey and pineapple (*Ananas comosus*) juice: Sensory and physico-chemical properties and probiotic survivability during in-vitro gastrointestinal digestion. *Journal of Agriculture and Food Research*, 4:100144

Jadhav, H. B., and Annapure, U. S. (2023). Triglycerides of medium-chain fatty acids: A concise review. *Journal of Food Science and Technology*, *60*(8):2143–2152.

Ji, C., and Wang, Y. (2023). Nanocellulose-stabilized Pickering emulsions: Fabrication, stabilization, and food applications. *Advances in Colloid and Interface Science*, 102970.

Jiang, F., and Hsieh, Y. L. (2015). Holocellulose nanocrystals: amphiphilicity, oil/water emulsion, and self-assembly. *Biomacromolecules*, *16*(4):1433–1441.

Jiménez Saelices, C., and Capron, I. (2018). Design of Pickering Micro- and Nanoemulsions Based on the Structural Characteristics of Nanocelluloses. *Biomacromolecules*, 19(2):460–469.

Joung, H. J., Choi, M. J., Kim, J. T., Park, S. H., Park, H. J., and Shin, G. H. (2016). Development of Food-Grade Curcumin Nanoemulsion and its Potential Application to Food Beverage System: Antioxidant Property and In Vitro Digestion. *Journal of Food Science*, 81(3):745–N753.

Júnior, M. A. D., Borsoi, C., Hansen, B., and Catto, A. L. (2019). Evaluation of different methods for extraction of nanocellulose from yerba mate residues. *Carbohydrate Polymers*, *218*:78–86.

Karunasiri, A. N., Gunawardane, M., Senanayake, C. M., Jayathilaka, N., and Seneviratne, K. N. (2020). Antioxidant and nutritional properties of domestic and commercial coconut milk preparations. *International Journal of Food Science*, *2020*.

Khalid, N., Suleria, H. A. R., and Ahmed, I. (2016). Pineapple juice. *Handbook of Functional Beverages and Human Health*, 1:489–498. Taylor & Francis.

Kharat, M., Du, Z., Zhang, G., and McClements, D. J. (2017). Physical and chemical stability of curcumin in aqueous solutions and emulsions: impact of pH, temperature, and molecular environment. *Journal of Agricultural and Food Chemistry*, *65*(8):1525–1532.

Klojdová, I., and Stathopoulos, C. (2022). The potential application of Pickering multiple emulsions in food. *Foods*, *11*(11):1558.

Kotta, S., Aldawsari, H. M., Badr-Eldin, S. M., Alhakamy, N. A., and Md, S. (2021). Coconut oil-based resveratrol nanoemulsion: Optimization using response surface methodology, stability assessment and pharmacokinetic evaluation. *Food Chemistry*, *357*:129721.

Kwao-Boateng, E., Agyei-Boamah, M., Nyadjor, I., Agyemang, A., and Hanson, M. (2023). Assessing coconut milk as an alternative to cow milk in Ghanaian cuisines. *Journal of the Ghana Institution of Engineering*, *23*(2):44–50.

Leneveu-Jenvrin, C., Quentin, B., Assemat, S., and Remize, F. (2020). Maintaining physicochemical, microbiological, and sensory quality of pineapple juice (Ananas comosus, Var.'Queen Victoria') through mild heat treatment. *Processes*, *8*(9):1186.

Lei, Y., Zhang, X., Li, J., Chen, Y., Liang, H., Li, Y., and Liu, S. (2022). Nanocellulose from bamboo shoots as perfect Pickering stabilizer: Effect of the emulsification process on the interfacial and emulsifying properties. *Food Bioscience*, 46:101596.

Li, W., Jiao, B., Li, S., Faisal, S., Shi, A., Fu, W., Chen, Y., and Wang, Q. (2022). Recent advances on Pickering emulsions stabilized by diverse edible particles: Stability mechanism and applications. *Frontiers in Nutrition*, 9:864943.

Liu, Q., Huang, H., Chen, H., Lin, J., and Wang, Q. (2019). Food-grade nanoemulsions: preparation, stability and application in encapsulation of bioactive compounds. *Molecules*, 24(23):4242.

Linke, C., and Drusch, S. (2018). Pickering emulsions in foods-opportunities and limitations. *Critical Reviews in Food Science and Nutrition*, 58(12):1971–1985.

Luo, H., Li, Z., Yao, M., McClements, D. J., and Xiao, H. (2022). Impact of excipient emulsions made from different types of oils on the bioavailability and metabolism of curcumin in gastrointestinal tract. *Food Chemistry*, 370:130980.

Low, L. E., Siva, S. P., Ho, Y. K., Chan, E. S., and Tey, B. T. (2020). Recent advances of characterization techniques for the formation, physical properties and stability of Pickering emulsion. *Advances in Colloid and Interface Science*, 277:102117.

Ma, Z., Wang, N., He, H., and Tang, X. (2019). Pharmaceutical strategies of improving oral systemic bioavailability of curcumin for clinical application. In *Journal of Controlled Release*, Vol. 316:359–380.

Mahardika, M., Abral, H., Kasim, A., Arief, S., and Asrofi, M. (2018). Production of nanocellulose from pineapple leaf fibers via high-shear homogenization and ultrasonication. *Fibers*, *6*(2):28.

Maresca, P., Donsì, F., and Ferrari, G. (2011). Application of a multi-pass high-pressure homogenization treatment for the pasteurization of fruit juices. *Journal of Food Engineering*, 104(3):364–372.

Mason, T. G., Wilking, J. N., Meleson, K., Chang, C. B., and Graves, S. M. (2006). Nanoemulsions: formation, structure, and physical properties. *Journal of Physics: Condensed Matter*, *18*(41):635

McClements, D. J., and Rao, J. (2011). Food-grade nanoemulsions: formulation, fabrication, properties, performance, biological fate, and potential toxicity. *Critical reviews in Food Science and Nutrition*, 51(4):285–330.

McClements, D. J., Das, A. K., Dhar, P., Nanda, P. K., and Chatterjee, N. (2021). Nanoemulsion-based technologies for delivering natural plant-based antimicrobials in foods. *Frontiers in Sustainable Food Systems*, 5:643208.

Mehanny, S., Abu-El Magd, E. E., Ibrahim, M., Farag, M., Gil-San-Millan, R., Navarro, J., and El-Kashif, E. (2021). Extraction and characterization of nanocellulose from three types of palm residues. *Journal of Materials Research and Technology*, 10:526–537.

Mihaylova, D., Desseva, I., Stoyanova, M., Petkova, N., Terzyiska, M., and Lante, A. (2021). Impact of in vitro gastrointestinal digestion on the bioaccessibility of phytochemical compounds from eight fruit juices. *Molecules*, 26(4)–1187.

Mishra, B. B., Gautam, S., & Sharma, A. (2011). Shelf-life extension of sugarcane juice using preservatives and gamma radiation processing. *Journal of Food Science*, *76*(8):M573–M578.

Modasiya, M. K., and Patel, V. M. (2012). Studies on solubility of curcumin. *International Journal of Pharmaceutical and Life Science,* 3(3):1490–1497.

Morais, J. P. S., de Freitas Rosa, M., Nascimento, L. D., Do Nascimento, D. M., and Cassales, A. R. (2013). Extraction and characterization of nanocellulose structures from raw cotton linter. *Carbohydrate Polymers*, *91*(1):229–235.

Morán, J. I., Alvarez, V. A., Cyras, V. P., and Vázquez, A. (2008). Extraction of cellulose and preparation of nanocellulose from sisal fibers. *Cellulose*, *15*:149–159.

Mulia, K., Putri, G. A., and Krisanti, E. (2018). Encapsulation of mangosteen extract in virgin coconut oil based nanoemulsions: Preparation and characterization for topical formulation. *Materials Science Forum*, *929*:234–242.

Munekata, P. E., Domínguez, R., Budaraju, S., Roselló-Soto, E., Barba, F. J., Mallikarjunan, K., and Lorenzo, J. M. (2020). Effect of innovative food processing technologies on the physicochemical and nutritional properties and quality of non-dairy plant-based beverages. *Foods*, 9(3):288.

Ng, Y. J., Tham, P. E., Khoo, K. S., Cheng, C. K., Chew, K. W., and Show, P. L. (2021). A comprehensive review on the techniques for coconut oil extraction and its application. *Bioprocess and Biosystems Engineering*, *44*(9):1807–1818.

Ngwabebhoh, F. A., Erdagi, S. I., and Yildiz, U. (2018). Pickering emulsions stabilized nanocellulosic-based nanoparticles for coumarin and curcumin nanoencapsulations: In vitro release, anticancer and antimicrobial activities. *Carbohydrate Polymers*, 201:317–328.

Ni, Y., Li, J., and Fan, L. (2020). Production of nanocellulose with different length from ginkgo seed shells and applications for oil in water Pickering emulsions. *International Journal of Biological Macromolecules*, *149*:617–626.

Nurma, H., Nurhayati, N., Wibowo, Y., and Rahmanto, D. E. (2022). *Ethnobotany Production of Coconut Oil using Wet and Dry Methods*. In Proceedings of the 6th Food Ingredient Asia Conference- Food Science, Nutrition and Health, 75-78, Bogor- Indonesia.

Oseni, N. T., Fernando, W. M., Coorey, R., Gold, I., and Jayasena, V. (2017). Effect of extraction techniques on the quality of coconut oil. *African Journal of Food Science*, 58–66.

Patil, U., and Benjakul, S. (2018). Coconut milk and coconut oil: their manufacture associated with protein functionality. *Journal of Food Science*, *83*(8):2019–2027.

Perrin, L., Gillet, G., Gressin, L., and Desobry, S. (2020). Interest of pickering emulsions for sustainable micro/nanocellulose in food and cosmetic applications. *Polymers*, *12*(10):2385.

Perumal, A. B., Nambiar, R. B., Moses, J. A., and Anandharamakrishnan, C. (2022). Nanocellulose: Recent trends and applications in the food industry. *Food Hydrocolloids*, 127:107484.

Phanthong, P., Ma, Y., Guan, G., and Abudula, A. (2015). Extraction of nanocellulose from raw apple stem. *Journal of the Japan Institute of Energy*, *94*(8):787–793.

Phakthawat, K., Shen, P., Ranathunga, A., Klinkesorn, U., and Suwannaporn, P. (2023). Hydrolyzed rice glutelin as plant-based emulsifier to reduce tween in emulsion facing process stresses and its application in coconut milk. *Food Hydrocolloids*, *145*:109070.

Piriyaprasarth, S., Sriamornsak, P., Chansiri, G., Promboot, W., Imerb, U., and Sumpoung, D. (2012). Effect of coconut oil and surfactants on stability of nanoemulsions. *Advanced Materials Research*, *506*:429–432.

Potoroko, I., Kadi, A., Paymulina, A., Albadran, Z., and Ramadhan, A. J. (2023). Possibilities of Applying Pickering Emulsions in Food Systems. *Latin American Journal of Pharmacy*, 42:405–408.

Quezada, C., Urra, M., Mella, C., Zúñiga, R. N., and Troncoso, E. (2024a). Plant-Based Oil-in-Water Food Emulsions: Exploring the Influence of Different Formulations on Their Physicochemical Properties. *Foods*, *13*(4):513.

Raghavendra, S. N., and Raghavarao, K. (2010). Effect of different treatments for the destabilization of coconut milk emulsion. *Journal of Food Engineering*, *97*(3):341–347.

Ramsing, R., Santo, R., Kim, B. F., Altema-Johnson, D., Wooden, A., Chang, K. B., Semba, R. D., and Love, D. C. (2023). Dairy and plant-based milks: Implications for nutrition and planetary health. *Current Environmental Health Reports*, *10*(3):291–302.

Rao, P. J., and Khanum, H. A. (2016). Green chemistry approach for nanoencapsulation of bioactive compound - Curcumin. *LWT- Food Science and Technology*, 65:695–702,

Rashid, S., and Dutta, H. (2020). Characterization of nanocellulose extracted from short, medium and long grain rice husks. *Industrial Crops and Products*, *154*:112627.

Rathinasamy, M., Ayyasamy, S., Velusamy, S., and Suresh, A. (2021). Natural fruits based ready to serve (RTS) beverages: a review. *Journal of Food Science and Technology*, 1–7.

Reyes, Y., Hamzehlou, S., and Leiza, J. R. (2021). Ostwald ripening in nano/miniemulsions in the presence of two costabilizers as revealed by molecular dynamics simulations. *Journal of Molecular Liquids*, *335*:116152.

Rincon, L., Braz Assunção Botelho, R., and de Alencar, E. R. (2020). Development of novel plant-based milk based on chickpea and coconut. *LWT- Food Science and Technology*, 128:109479

Salvia-Trujillo, L., and McClements, D. J. (2016). Influence of nanoemulsion addition on the stability of conventional emulsions. *Food Biophysics*, 11:1–9.

Samsalee, N., Meerasri, J., and Sothornvit, R. (2023). Rice husk nanocellulose: Extraction by high-pressure homogenization, chemical treatments and characterization. *Carbohydrate Polymer Technologies and Applications*, *6*:100353.

Seow, C. C., and Gwee, C. N. (1997). Coconut milk: chemistry and technology. *International journal of Food Science & Technology*, *32*(3):189–201.

Silva, L. F. R., Gomes, A. D. S., Castro, D. R. G., Souza, F. D. C. D. A., Mar, J. M., da Silva, L. S., and Campelo, P. H. (2019). Ultrasound-assisted homogenization and gum Arabic combined to physicochemical quality of cupuaçu juice. *Journal of Food Processing and Preservation*, *43*(9): e14072.

Silva, J. G. S., Feitosa, S., Pallone, J. A. L., Greiner, R., and Briviba, K. (2022). Iron cellular uptake from almond and coconut beverages using an in vitro intestinal cell model. *Discover Food*, *2*(1):22.

Song, Y., Jiang, W., Zhang, Y., Wang, H., Zou, F., Yu, K., and Han, G. (2018). A novel process of nanocellulose extraction from kenaf bast. *Materials Research Express*, *5*(8):085032.

Sugasini, D., and Lokesh, B. R. (2017). Curcumin and linseed oil co-delivered in phospholipid nanoemulsions enhances the levels of docosahexaenoic acid in serum and tissue lipids of rats. *Prostaglandins Leukotrienes and Essential Fatty Acids*, 119:45–52.

Sutradhar, K. B., and Amin, M. L. (2013). Nanoemulsions: increasing possibilities in drug delivery. *European Journal of Nanomedicine*, *5*(2):97–110.

Sweis, I. E., and Cressey, B. C. (2018). Potential role of the common food additive manufactured citric acid in eliciting significant inflammatory reactions contributing to serious disease states: A series of four case reports. *Toxicology Reports*, *5*:808–812.

Tabanelli, R., Brogi, S., and Calderone, V. (2021). Improving curcumin bioavailability: Current strategies and future perspectives. *Pharmaceutics*, *13*(10):1715.

Teimouri, S., Abbasi, S., and Scanlon, M. G. (2018). Stabilisation mechanism of various inulins and hydrocolloids: Milk–sour cherry juice mixture. *International Journal of Dairy Technology*, *71*(1):208–215.

Teixé-Roig, J., Oms-Oliu, G., Odriozola-Serrano, I., and Martín-Belloso, O. (2023). Emulsion-based delivery systems to enhance the functionality of bioactive compounds: Towards the use of ingredients from natural, sustainable sources. *Foods*, *12*(7):1502.

Thorning, T. K., Raben, A., Tholstrup, T., Soedamah-Muthu, S. S., Givens, I., and Astrup, A. (n.d.). Milk and dairy 1354 products: Good or bad for human health? An assessment of the totality of scientific evidence. *Food and Nutrition Research*, 60(1):32527.

Tiencheu, B., Nji, D. N., Achidi, A. U., Egbe, A. C., Tenyang, N., Ngongang, E. F. T., Djikeng, F. T., and Fossi, B. T. (2021). Nutritional, sensory, physico-chemical, phytochemical, microbiological and shelf-life studies of natural fruit juice formulated from orange (Citrus sinensis), lemon (Citrus limon), Honey and Ginger (Zingiber officinale). *Heliyon*, *7*(6).

Tua, S. M., Apul, S., Restuana, S. D., Rosa, T., Maruba, P., Posman, S., Delima, P., Sisilia, Y., and Oktavia, T. D. (2018). Effect of citric acid and sucrose concentration on the quality of passion fruit jelly with dutch eggplant. *IOP Conference Series: Earth and Environmental Science*, *205*(1):012050.

Tulashie, S. K., Amenakpor, J., Atisey, S., Odai, R., and Akpari, E. E. A. (2022). Production of coconut milk: A sustainable alternative plant-based milk. *Case Studies in Chemical and Environmental Engineering*, *6*:100206.

Velangi, M., and Savla, M. (n.d.). Role of Plant Based Milk Alternatives as a Functional Beverage: A Review. *International Journal of Health Sciences and Research*, 12:11.

Virto, R., Sanz, D., Alvarez, I., and Raso, J. (2005). Inactivation kinetics of Yersinia enterocolitica by citric and lactic acid at different temperatures. *International Journal of Food Microbiology*, *103*(3):251–257.

Walther, B., Guggisberg, D., Badertscher, R., Egger, L., Portmann, R., Dubois, S., Haldimann, M., Kopf-Bolanz, K., Rhyn, P., and Zoller, O. (2022). Comparison of nutritional composition between plant-based drinks and cow's milk. *Frontiers in Nutrition*, *9*:988707.

Wen, L., and Wrolstad, R. E. (2002). Phenolic composition of authentic pineapple juice. *Journal of Food Science*, *67*(1):155–161.

Wilson, R. J., Li, Y., Yang, G., and Zhao, C.-X. (2022). Nanoemulsions for drug delivery. *Particuology*, *64*:85–97.

Wu, J., Tang, Y., Zhang, M., Chen, W., Chen, H., Zhong, Q., Pei, J., He, R., and Chen, W. (2024). Mechanism for improving the in vitro digestive properties of coconut milk by modifying the structure and properties of coconut proteins with monosodium glutamate. *Food Research International*, *185*:114288.

Wuttikul, K., and Sainakham, M. (2022). In vitro bioactivities and preparation of nanoemulsion from coconut oil loaded Curcuma aromatica extracts for cosmeceutical delivery systems. *Saudi Journal of Biological Sciences*, *29*(12):103435.

Xie, J., Hse, C.-Y., Cornelis, F., Hu, T., Qi, J., and Shupe, T. F. (2016). Isolation and characterization of cellulose nanofibers from bamboo using microwave liquefaction combined with chemical treatment and ultrasonication. *Carbohydrate Polymers*, *151*:725–734.

Yang, Y., Fang, Z., Chen, X., Zhang, W., Xie, Y., Chen, Y., Liu, Z., and Yuan, W. (2017). An overview of Pickering emulsions: solid-particle materials, classification, morphology, and applications. *Frontiers in Pharmacology*, *8*:235054.

Ye, R., and Harte, F. (2014). High pressure homogenization to improve the stability of casein–hydroxypropyl cellulose aqueous systems. *Food Hydrocolloids*, *35*:670-677.

Yildiz, S., Pokhrel, P. R., Unluturk, S., and Barbosa-Cánovas, G. V. (2019). Identification of equivalent processing conditions for pasteurization of strawberry juice by high pressure, ultrasound, and pulsed electric fields processing. *Innovative Food Science & Emerging Technologies*, *57*:102195.

Yu, H., and Huang, Q. (2012). Improving the oral bioavailability of curcumin using novel organogel-based nanoemulsions. *Journal of Agricultural and Food Chemistry*, 60(21):5373–5379.

Zhai, K., Brockmüller, A., Kubatka, P., Shakibaei, M., and Büsselberg, D. (2020). Curcumin's beneficial effects on neuroblastoma: mechanisms, challenges, and potential solutions. *Biomolecules*, *10*(11):1469.

Zhang, L., Han, C., Liu, M., Yang, H., Zhang, F., Liu, B., and Meng, X. (2020). The formation, stability of DHA/EPA nanoemulsion prepared by emulsion phase inversion method and its application in apple juice. *Food Research International*, 133:109132.

Zhang, T., Xu, J., Chen, J., Wang, Z., Wang, X., and Zhong, J. (2021). Protein nanoparticles for Pickering emulsions: A comprehensive review on their shapes, preparation methods, and modification methods. *Trends in Food Science & Technology*, *113*:26–41.

Zhou, X., Hao, Y., Yuan, L., Pradhan, S., Shrestha, K., Pradhan, O., and Li, W. (2018). Nano-formulations for transdermal drug delivery: A review. *Chinese Chemical Letters*, *29*(12):1713–1724.

Zou, L., Zheng, B., Zhang, R., Zhang, Z., Liu, W., Liu, C., and McClements, D. J. (2016). Influence of lipid phase composition of excipient emulsions on curcumin solubility, stability, and bioaccessibility. *Food Biophysics*, *11*:213–225.

Zulueta, A., Barba, F. J., Esteve, M. J., and Frígola, A. (2013). Changes in Quality and Nutritional Parameters During Refrigerated Storage of an Orange Juice-Milk Beverage Treated by Equivalent Thermal and Non-thermal Processes for Mild Pasteurization. *Food and Bioprocess Technology*, 6(8):2018–2030.

Zulueta, A., Esteve, M. J., Frasquet, I., and Frígola, A. (2007). Vitamin C, vitamin A, phenolic compounds and total antioxidant capacity of new fruit juice and skim milk mixture beverages marketed in Spain. *Food Chemistry*, *103*(4):1365–1374.