CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the previous research works carried out by research workers, scientists and students. Review related to jamun and its composition, therapeutic values, processing of jamun, juice extraction methods, ultrasound assisted juice extraction, spray drying technology, microencapsulation, carrier materials, operating parameters of spray drying, storage studies and cost economics are included in this chapter.

2.1 JAMUN

Syzygium cumini L. is a botanical name of jamun. It is also known as Indian blackberry. Jamun comes under the family of Myrtaceae and it is cultivated worldwide in regions of the tropical and subtropical. It has a wide range of applications due to its nutritional benefits. Each part of the plant such as bark, leaf, fruit, and seed are used for both culinary and non-food purposes. The fruits are round to oblong in shape and have a purple to bluish colour and pinkish pulp (Jagetia, 2017). The fruits are primarily eaten fresh and are considered seasonal treats. Jamun has many value-added products such as wine, juice, jam, powder, jelly, nectars, squash, and so on. (Kumar *et al.,* 2023)

According to Agarwala *et al.* (2019), jamun is an emerging crop because of its high nutritional significance. It is also referred as "the fruit of the future" (Madani *et al*., 2021). High nutraceutical properties of jamun gives the commercial importance which could reduce and helpful for the malnutrition. Jamun can adopt a wide range of climatic conditions. It can tolerate the flood as well as drought (Sarvade *et al*., 2016). Jamun tree yields 80 to 100 kg fruit per year. The fruit is categorized by its shape, it can be oblong or ovoid. The lower weight of seed, high fruit flesh portion and medium pectin content is observed in oblong varieties (Rasheed, 2024).

Jamun prefers the well-drained laterite soils found in the western coastal areas of India. It also does well in sandy loam and black cotton soils. It can also be found in ravines and wastelands, and on such lands where the water table is found at shallow depths (Singh *et al.,* 2011). It flourishes well in semi-arid regions, where there is an annual precipitation estimate of around 500 mm. Jamun needs a dry period weather during flowering and setting of fruits (Singh *et al*., 2019 and Singh *et al*., 2006). In subtropical regions, it is believed that early rains are good for enhancing fruiting and colour streaking.

Qamar *et al.* (2022) summarized that jamun has been used for the treatment of diabetes and dysentery traditionally. The different parts of the plant exhibit the properties of antioxidant, anticancer, anti-inflammatory, antipyretic, antimalarial, analgesic, and antidiabetic activities. The presence of primary and secondary metabolites is the reason for these properties. They may be proteins, carbohydrates, phenolics, flavonoids, and anthocyanins.

2.1.1 Origin, distribution and production of jamun

India or East India, Pakistan, Indonesia and Sri Lanka are the original home of jamun. Originating in India and Indonesia, it is widely distributed across Southern Asia (Periyathambi, 2007). It is found scattered in the regions of tropical and subtropical. It occurs in Himalayas up to an elevation of 1300 meters and 1600 meters in Kumaon hills. Thailand, Madagascar, Philippines and some other countries are having this fruit tree. Across the world, jamun was introduced in many places. It was introduced to Florida, USA in 1911 by the USDA. California, Israel, Florida, Algeria are the places where jamun has been introduced successfully. This tree is often planted in the Islands of the Pacific and the propagation of the species is widespread.

2.1.2 Fruit composition

Jamun is a nutritious fruit with wide range of use (Fig 2.1). The fruit weight, length and pulp percentage of individual one ranged from 10.10 to 22.50 g, 1.99 to 3.24 cm and 73.66 to 85.68%. Based on the different varieties, a wide variation in chemical characteristics occurs in jamun. The characteristics like total soluble solids, total sugar and vitamin C varies from 10.30 to 12.34%, 8.58 to 9.13% and 32.12 to 46.37 mg/100g (Table 2.1) (Anon, 2007).

Table 2.1 Nutritional composition of Jamun

Components	**Average concentration (per 100g of edible portion)**
Fat	0.15%
Crude fibre	0.6-1.2%
Mineral matter	0.4%
Pectin	2.3-3.7%
TSS	9-17.4%
Anthocyanin	115.38-210.76
Tannins	201.50-386.25 mg
Flavonoids	0.50-1.54 mg
Carotenoid	12.38-22.34 mg
Vitamin C	10.70-29.52 mg
Calcium	8.3-15 mg
Iron	0.8-1.2 mg
Magnesium	4-35 mg
Phosphorus	15-30 mg
Sodium	26.2-34.1 mg
Potassium	50-55 mg

Source: (Bose *et al.,* 2001 and Anon, 2007).

Fig 2.1 Jamun fruit

The flowers are known to be a rich source of honey collected by *Apis dorsata*, especially in the northern states of India (Singh *et al.,* 2019). Three triterpenoids have been reported in the flowers: acetyl oleanolic acid, eugeniatriterpenoid A, eugenia-tritetrapeniod B. Ellagic acid, accompanied with the following flavonoids is also present in Jamun flowers: isoquercitrin, quercetin, kaempferol, and myricetin (Adelia *et al.,* 2011).Jamun fruits are reported to be rich in certain minerals (Ca, K), vitamins (B-complex and C) and amino acids (alanine, arginine, aspergine). Delphinidin and petunidin were reported as the major anthocyanins, while malvidine peonidin and cyanidin were seen in minor concentrations (Singh *et al.,* 2011).

Ramya *et al.* (2012) evaluated the different properties of jamun pulp and observed that the pulp contained anthocyanin, malvidin-diglucosides, delphinidin and petunidin which gave the purple colour. Fruits had rich amount of glucose, fructose, raffinose, citric acid, gallic acid and malic acid. Iron, zinc, sodium, calcium, potassium and phosphorous were the minerals presented in jamun pulp. It contained vitamins such as ascorbic acid, niacin and thiamine.

Raza *et al.* (2015) screened the phytochemical values of the jamun fruit extract from the ethanolic extract. The extract of jamun fruit showed the maximum anthocyanin contents of 5.32±0.31 mg CYE/g, TPC of 1462.37±65.80 mg, and flavonoids of 424.79±41.31 mg/100g. The values of the seed are also mentioned, with the maximum values for flavonoids and total phenolic content (TPC) being 953.91 mg/100g and 1863.25±70.83 mg GAE/100g, respectively.

Raza *et al.,* (2015) revealed the proximate composition of fruit and seed. The fruit contained moisture 82.19±2.46 (% wb) crude protein 2.15±0.06%, crude fat 0.83±0.02 %, crude fiber 1.76±0.05%, Ash 2.04 ±0.06% and nitrogen free extracts (NFE) 11.03±0.33%. The seed contain moisture 16.34±0.49%, crude fat (0.65±0.01%), crude fibre (4.19±0.12%), crude protein (1.97±0.59%), ash 2.18±0.06% and nitrogen free extracts (NFE) (74.67±2.24%). From the results of fruit and seed it was stated that jamun contain low fat contents.

Payel *et al.* (2018) reported the phytochemical, nutritional, mechanical and sensory properties of jamun fruit. Minerals like Na, Ca and K are significantly present in this fruit. Both fruit and seed have high amounts of polyphenols, anthocyanin and tannins. The values of moisture (79.2%), protein (0.65%), sugar (7.88%), ash (1.03%), and fat (0.18%) contents are found in jamun on a fresh weight basis.

Eswarappa and Somashekar, (2020) stated that jamun has anthocyanins and the seeds have alkaloids, antimellin, jambosine which draw up the conversion of starch into sugar. The extracts obtained from different parts of the jamun contain different pharmacological properties. The major parts are moisture (80.80%), acidity (0.63% as sulphuric and 0.88% as malic), ash (0.70%), protein (0.81%) and sugar (12.70%), respectively.

Kumar *et al*. (2023) reported that the kernels which are left as a by-product having more nutritional values. It was rich in phytochemicals and used traditionally as a medicinal product. The kernels contain protein (4.68%), carbohydrates (89.68%), fat (1.28%), fiber (1.21%), iron (4.2%), calcium (135.86%), and ash content (3.13%), respectively.

2.1.3 Therapeutic values of jamun

The jamun fruits are effective in the treatment of diabetes, as well as in alleviating disorders of the heart and liver (Singh and Singh, 2006). Different parts of Jamun, such as - fruits, seeds and stem bark have antidiabetic as well as antihyperglycemic activity, antileishmanial, antifungal, anti-inflammatory activity, neuropsycho-pharmacological activity, antimicrobial, antibacterial, radio-protective, gastro-protective, antifertility activity, anorexigenic activity, anti-diarrheal activity, ulcerogenic and anti-HIV activity and all of this was confirmed in a number of clinical trials (Murugan *et al.,* 2023; Baliga *et al.,* 2011). The ripe fruits contain glucose and fructose as the main components of their sugar's family and no saccharose is present.

According to Aqil *et al*. (2014), anthocyanidins from jamun pulp extract shown high anticancer activity against human non-small-lung cancer cells (A549), with an IC50 value of 59 ± 4 mg/ml. According to Gajera *et al.* (2017), the methanolic extracts of *S. cumini* fruit pulp showed the highest IC50 value at 270 mg/ml, making them a moderate choice for antidiabetic action. It was reported that jamun fruit extract lowered up to 60% of serum ALT level which is effective for the treatment of the hepatocellular injury.

Cartaxo-Furtado *et al*. (2015) reported the promising biological activities of jamun fruit with the presence of tannins for antimicrobial effects, regularization of protein, tissue repair and enzymatic function. The presence of phenolic compounds like gallic acid, chlorogenic acid and rutin showed that jamun fruit have antidiabetic activity (Ayyanar and SubashBabu, 2012; Singh *et al.,* 2018). Inhibition of lipid peroxidation, alteration of cholesterol absorption, lowering cholesterol, processing of lipoprotein has been shown in jamun pulp due to the rich source of anthocyanin and flavonoids.

Jagetia (2017) reported that jamun fruit extract had shown the properties of in vitro and in vivo. A cytotoxic effect and apoptosis in HCT-116 colon cancer stem cell has induced by triggering the DNA fragmentation. It has been demonstrated that jamun fruit extracts activate several enzymes, such as catalase and superoxide dismutase, which might reduce the generation of free radicals and influence the onset of many illnesses. The study also reported that the degreasing of blood glucose level had shown in rats by consuming the aqueous jamun pup extract. It suggested that the hypoglycemic properties might be present in the extract (Singh *et al.,* 2018).

According to yahia *et al.* (2017), for health benefit claims of jamun and other fruits and vegetable, the critical investigation and long term human clinical studies are needed. Jamun fruit and seed having high phenolic compounds which have important application in pharmaceutical application (Singh *et al.,* 2018). Seeds of jamun reduce the conversion of starch and sugar with the presence of alkaloid jambosin, the glucoside jambolin, and antimalin (Jagetia, 2024).

2.1.4 Processing of jamun

The good size and quality jamun exhibit the taste of sweet and flavour of sub acid with minimum astringency which is eatable as a raw product or products like jam and sauces. Pectin is present in the white fleshed jamun which is used to make stiff jelly (Shahnawaz and Shiekh, 2011). A fermented product called "jambava" is manufactured from jamun, which is typically referred to as brandy or distilled liquor. Squash, sherbet and syrup are also made from good quality jamun. The bottled drink was prepared in India by heating the crushed fruits at 140ºF for 5 to 10 min, pressing it for juice extraction, mixing with sugar and water with preservatives like citric acid and sodium benzoate.

Kapoor *et al.* (2015) incorporated the jamun powder in chapatti and evaluated the bioactive compound. It was reported that chapatti which was supplemented with freeze dried powder showed 24.20% of increased total phenolics and antioxidant activity of 33.21%. The sensory score was found to be high.

Jamun is used as ingredients for the processers and food industry in many countries like China and India because of its high nutritional values (Santhalakshmy *et al.*, 2015). The processed food like jam, jelly, chips, squash, wine, vinegar, beverages and pickles are made by utilizing the jamun fruit (Lago-Vanzela *et al.,* 2011). Sun drying is used to produce jamun seed powder. It has rich source of minerals which is used for the treatments like diabetic and urinary disorders (Dagadkhair *et al.,* 2017). It is also reported as “blood purifier” (Swami *et al.,* 2012). In many countries jamun is an essential source for wine production (Sadawarte *et al.,* 2016).

Sood *et al.* (2018) developed and evaluated the quality parameters in noodles by using jamun seed powder. It was reported that 8% of jamun seed powder gave best acceptability and storability. The proximate values such as crude protein, fat crude fibre and ash were evaluated. The values are as follows 10.89, 0.60, 1.43 and 0.91 percent, respectively.

Wadibhasme *et al.* (2020) developed and evaluated the instant drink mix which is fortified with jamun by spray drying. The acceptable powder sample got sensory score of 8.25 which has 25% of maltodextrin. It contains 47.67 mg/g of total anthocyanin content, 3.87 mg/g of total phenolic content, 25.87 mg/g of total flavonoid content and 27.43% of antioxidant activity.

Jagetia (2024) reported that diarrhoea was cured by jamun syrup and jamun vinegar having the properties like stomachic, diuretic and carminative. The important by product of jamun fruit is jamun seed which is a rich source of carbohydrate, protein, lipids, and minerals. It serves as ingredient for food industry. Squash, juices, jams, jellies, pickles, wines, and cookies are all made using jamun which having the sub-acidic, spicy flavour. A delicious beverage to satisfy thirst in summer is jamun fruit squash.

2.2 JUICE EXTRACTION METHODS

According to Alvarez *et al.* (2012), the process of recovering cellular liquid from solid fibrous material. That is, pressing, squeezing, or screening the fruit's liquid portion seems quite straightforward, but it is actually highly difficult, intricate, and unexplained. It is important to keep in mind that every stage of the extraction process has an equal impact on the final product's yield, flavour, quality, composition, shelf life, and expected health benefits.

The mechanical processes have energy issues in addition to reducing the antioxidant potential and qualitative attributes of juice products. In order to increase extraction yields while maintaining the freshness of the fruit, a variety of changes have been made to fruit crushers, choppers, and presses over the 20th century. Even when juice manufacturing facilities have implemented effective control and automation, the quantity and quality of the final product may be decreased by choosing the wrong extraction method, circumstances, or equipment. Each fruit-mashing machine has a different fundamental design depending on the type of fruit and the quality of the finished product. Hard fruits, such as apples, guavas, and pineapples, are turned into a pulp using pulping machines (crushers) and decanters (centrifuges), which separate the rough skin, seeds, and absorbents (Mushtaq, 2018).

Zou *et al.,* (2024) reported that in the current area of juice manufacturing, enzymes were essential because they could increase juice yield and, consequently, processing efficiency, producing a clear and aesthetically pleasing end product. The yield was increased by the enzymatic breakdown of cell walls, which released nutrients from the cells and raised the quantities of sugars, polyphenols, galacturonic acid, total soluble solids (TSS), and titratable acidity. The kind of enzyme, reaction temperature, stirring, pH level, reaction time, enzyme concentration, and the usage of various enzyme combinations affect the enzymatic impact. The studies were also reported in pineapple, apricot and pomegranate which were treated with pectinase enzyme.

Mushtaq (2018) stated that in the Microwave Hydro diffusion Gravity (MHG) method, samples of fruit or plants were exposed to microwave radiation, which quickly warms the substance from the inside out and causes the plant cells to swell until they burst, releasing water and heat. Both events occur in the same direction, and even in the absence of a solvent, the juice inside the cell flows downward due to hydro diffusion gravity. Second, because of the volumetric heating effect, the temperature rises more quickly during microwave treatments, which causes the cell wall to rupture quickly and release steam and crude juice. This was first created to extract phytonutrients, but because it enables quick extraction and a respectable yield, researchers are now advocating for microwave heating and hydro diffusion to produce an organoleptically pleasing juice.

The engineering materials are safer, more intelligent, more dependable, more hygienic, and resistant to corrosion. Fruit Machine Corporation (FMC), Flottweg Processing Technology (FPT), Core Equipment (UK), and B & P Engineering (USA) and numerous other companies are producing juicing equipment with completely automated control, easy operation, excellent performance, minimal maintenance costs, and a waste-management system that is based on cleaning in situ. To boost the yield and stabilise the extracted juice, fruits are frequently treated with specific enzymes (pectinolytic in the case of apples), micro- and ultrasonic waves, electro-plasmolyzed, or lyophilised in addition to mechanical maceration. To enhance pulp homogenisation and juice recovery, enzymatic and ultrasonic macerations are two commonly used technologies (Mushtaq, 2018).

2.3 ULTRASOUND TECHNOLOGY

According to Nonglait and Gokhale (2024), the food industry has given close attention to ultrasound in recent years which is a non-thermal technology. When compared to traditional methods, Ultra sound (US) processing can shorten processing times, save energy, enhance food quality, and increase shelf life. Ultrasound can also be automated, uses less energy, and processes data quickly. All of these factors contribute to its fewer operating costs, high production efficiency, and minimal labour requirements (Chavan *et al.,* 2022).

According to Mehta *et al.* (2022), any sound wave or acoustic energy beyond 20 kHz threshold for human hearing is referred to as ultrasound. Ultrasound offers a wide range of applications in the field of food science. Ultrasonication is widely employed in industries and is referred to as a "green unique technology" because of its involvement in environmental sustainability. Treatments using ultrasonication often range in frequency from 20 to 100 kHz and in power density from 10 to 1000 W/cm^2. Ultrasound is classified as Power ultrasound (20–100 kHz), high-frequency ultrasound (100 kHz–l MHz), and diagnostic ultrasound (1–10 MHz) based on its frequency. Soft tissue surgery, diagnostic imaging, and other fields are among the many uses for high-frequency and diagnostic ultrasound. However, power ultrasonography has been used in food processing procedures, such as the extraction and encapsulation of bioactive ingredients.

2.3.1 Generation of ultrasound

Lepaus *et al.* (2023) explained that the generator, transducer, and emitter were the three important components of the US system. The electrical signal was transformed into a specific frequency by the generator; the transducer then converted this high-frequency electrical signal into mechanical vibrations, which were then emitted by the emitter. For the generation of ultrasound, mostly magnetostrictive and piezoelectric transducers were used.

Magnetostrictive transducers generate ultrasonic waves by acting as electroacoustic transducers. Magnetostriction is the basis for these transducers' operation. As long as the material is magnetostrictive, magnetisation results from the application of the magnetic field. Three different types of ferromagnetic material are employed to make the magnetostrictive transducer. These modifications result in the desired mechanical vibrations when a magnetic field is applied. The efficiency of the mechanism is only roughly 60% of the energy transfer to acoustics. The interconversion of electrical and acoustic energies is the focus of piezoelectric transducers. The fundamental idea behind a piezoelectric sensor or transducer is that when a force is applied to a quartz crystal or any other piezoelectric material, it produces electrical charges on its surface. This phenomenon is known as piezoelectricity, and it may be causing the cleaning action (Bhargava *et al.,* 2021). Piezoelectric transducers produce acoustic energy by changing the size of piezo ceramic materials, such as lead zirconate titanate, barium titanate, and lead metaniobate, in response to electrical inputs. With an 80–95% transfer to acoustic energy, this is the most popular and efficient method. In addition to these kinds, ultrasonography is also produced using fluid-driven transducers. The fluid-driven transducer creates vibrations at ultrasonic frequencies that can be used in mixing and homogenisation systems by exerting pressure on a thin metal blade (Mehta *et al.,* 2022).

2.3.2 Principle of ultrasound

The ultrasound works on the principle of cavitation. The bubbles oscillate and burst as ultrasonic waves, propagate, producing mechanical, chemical, and thermal impacts. Shear strains, turbulence, and collapse pressure are examples of mechanical effects (Yusaf and Al-Juboori, 2014), whereas the production of free radicals is an example of chemical effects. Very high temperatures (5,000 K) and pressures (1,000 atm) are produced by the effects in the cavitation zone (Soria and Villamiel, 2010).

According to Jose' *et al.* (2014), the generation of mechanical vibration and acoustic steaming happens when the waves of ultrasound pass through liquid medium. It contains dissolved gas which can expand, bubble formation and collapse by ultrasound. Violent collapse can produce free radicals by generating high temperature and pressure which is called “hot spots” which happed because of the dissociation. The formation of hot spots is limited in duration (Gabriel, 2012).

Majid *et al*. (2015) stated that in liquid system, the ultrasound application was caused by the cavitation. It was reported that frequency of ultrasound produces alternative pressure which results cell rupture. Water inside the oscillating bubbles was hydrolysed by ultrasound, producing H^+ and OH^- free radicals that can be trapped in certain chemical reactions. It was reported that bubble formation in ultrasound has two types which was nonlinear and non-stable. Non-linear type formed large bubble with equilibrium size known as bubble of stable cavitation. Non stable type formed a small bubble which was quickly dissolved known as bubble of transient cavitation

According to Lepaus *et al.* (2023), ultrasound is associated with cavitation process which have the formation of bubble, growth and collapse. The ultrasonic equipment emits the waves which induce compression and expansion zones alternatively. Because of the positive pressure in the middle, molecules are pushed apart throughout the compression cycle. On the other hand, when the expansion cycle applies negative pressure, molecules return to one another. Since the pressure applied to the system is constantly changing, the liquid medium's fluctuation between cycles of compression and expansion encourages the production of bubbles. During the expansion cycle, bubbles' surface area grows as gas diffuses into their interior. Because the internal pressure eventually surpasses the exterior pressure, this continuous process leads to the rise of bubbles and their eventual collapse (Alvarenga *et al.,* 2021).

2.3.3 Method of application

According to Mehta *et al.* (2022), the material which is subjected to ultrasound may be direct or indirect application. Direct immersion of ultrasonic probe into the liquid product medium is termed as direct application. The probe is connected to transducer. For the efficiency, probe diameter contribution is important. The probe with smaller diameter produces maximum cavitation in a narrow field, large diameter expands the energy to a wide area. Metal contamination form the probe is the major disadvantage of this application. For the treatment, analysis of structure, composition and processing the direct energy is used.

Indirect application refers to ultrasonic bath which is easy to handle and more economical but less powerful. For the operations like cleaning, sanitation and food processing ultrasonic bath is widely accepted (Fig 2.2). Using a piezoelectric transducer that is either affixed to the bottom of the processing vessel or immersed in the cleaning solution, ultrasonic cleaners convert low-frequency AC into high-frequency sound waves. High-intensity waves from the transducer cause compression in the solution, tearing it apart and producing millions of macroscopic cavities or bubbles known as "cavitation." This procedure, which involves immersing all products in the cleaning solution, quickly removes all filth. Additionally, compared to the probe system, its operational efficiency is decreased by the non-uniform energy distribution (Lepaus *et al.,* 2023)

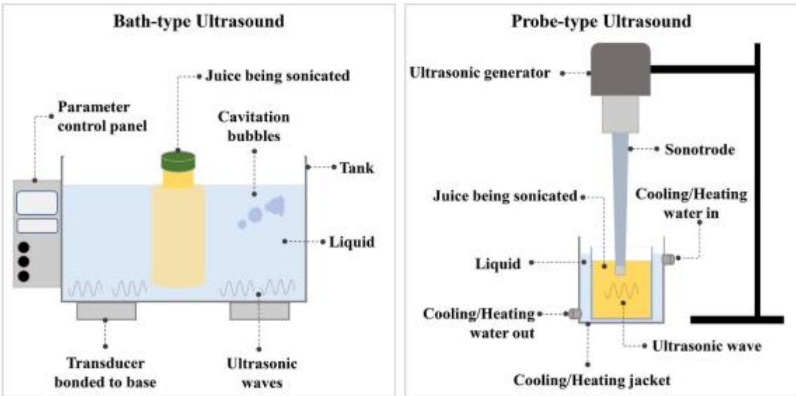

Fig. 2.2 Bath and probe type ultrasound equipment

2.3.4 Applications of ultrasound

Majid *et al.* (2015) reported that the thermo sonication which was a combined ultrasound and heat effect, had been proved as an efficient method for reduction of microbial growth by cavitation. It occurred because of acoustic cavitation which results selectivity loss, cell membrane thinning, increase of membrane permeability, confined heating and radical formation. It was reported that ultrasound was used as disinfectant treatment by electronics industry which was replaced the sanitization works in food industry (Sagong *et al.,* 2011). Ultrasonication has been discovered to be an effective way for microbiological inactivation in Escherichia coli, Listeria monocytogenes, and other pathogens. A power of approximately 100 W was found to be ideal for maximum microbial inactivation (Yusaf and Al-Juboori, 2014).

Kadam *et al.* (2015) reported that ultrasonically treated seaweed before drying showed improved colour quality, as well as shorter drying times and lower energy costs. Weight loss, water loss, drying time reduction, and an increase in solid growth are all made easier by ultrasound pre-treatment (Osae *et al.,* 2019). Intracellular and extracellular water cavitation results in the formation of new microchannels. In order to eliminate moisture from the surface, ultrasonography also creates air turbulence at the air-product interface (Yao, 2016).

Gallo *et al.,* (2018) mentioned that depending on intensity, ultrasound can increase or decrease viscosity. It also assists the processes like drying, degassing, cellular dispersion, extraction, homogenization and emulsification.

Cárcel *et al*. (2019) stated that the ultrasound application in drying had shown about 20-30% of reduction in drying time which was reported in various research studies. An efficient substitute for the traditional drying method was ultrasonication. The "sponge effect," which improved water diffusion from the product's inner to its surface, made it easier to remove water. Because ultrasonication increased mass transfer, it had been successful in cutting down on drying time. It also increased moisture diffusivity and reduced energy usage. The cavitation of the liquid media containing the sample improved the mass transfer (Nowacka and Wedzik*,* 2016).

According to Bhargava *et al*. (2021), ultrasound can enhance the processes in food industry when it is combined to various unit operations. One of the main challenges in the filtration process is the fouling that results from the filtrate or filter cake being deposited on the membrane surface. Filtration efficiency is decreased as a result of these issues. But ultrasound energy works well to combat this problem. When ultrasound was applied during the filtration process, the retentate layers accumulated are disturbed on the membrane surface, leading to concentration polarisation, while the inherent permeability of the membrane is left intact. Low frequency can control the fouling by removing the cake layer (Camara *et al*., 2020).

2.3.5 Factors affecting ultrasound

Samaram *et al.* (2015) stated that there was a linear relationship between amplitude percentage and power during UAE. Because the power given to the extraction liquid medium was measured by amplitude percent, and 100% amplitude represents the equipment's rated power. Power used in the extraction process varied between 20 and 700 W and was dependent on the component to be extracted and the raw material matrix. As the amount of power used increased, the extraction yields were increased, but eventually fallen. Cavitation bubbles got bigger as a result of the increased power application, and they eventually burst violently. Higher diffusivity and extraction yields resulted from the fragmentation and pore development of plant tissue material caused by the higher impact on implosion. Additionally, the increased power caused more mechanical vibration, which in turn expanded the solvent-tissue material contact area. This improved solvent penetration and raised the extraction yield.

Castello *et al.* (2015) reported that as the US temperature increased, the extraction yield of the total phenolic compound from grape seed increased. The highest yield was recorded at 52.8°C, the highest temperature tested between 40°C and 60°C.Following the maximal extraction, weak cavitation from additional temperature increases results in a low extraction yield. When the UAE extracted the phenolic component from wasted coffee grounds, the yield increased as the temperature rose from 30°C to 45°C; however, the yield fell above 45°C (Dhabi *et al.,* 2017).

Gisbert *et al.* (2021) reported the continuous ultrasound-assisted extraction of aqueous extracts from Ascophyllum nodosum brown edible seaweeds. Three distinct parameters (solvent/solid ratio: 20 to 40 g water/g; sonication amplitude: 80–100%; sonication time: 2–6 min) were taken into account. Polyphenols, carbohydrates, and uronic acid content were used to characterise the extracts, and various techniques (DPPH, FRAP, and ABTS) were used to test the extracts' antioxidant capabilities. It was concluded that extracts made with water as the solvent and sonication technique had antioxidant capacity values (DPPH, ABTS, and FRAP) that were similar to those made with organic solvents and very lengthy extraction times (>5 h). Pure water as a solvent produced higher extraction yields and better extraction kinetics than either pure ethanol or ethanol-alcoholic solutions with a high ethanol content, according to a study. This might be because water might produce a more polar medium that makes it easier to extract phenolic chemicals.

According to Kumar *et al.* (2021), frequency plays a crucial role in increasing cavitation during UAE. High-frequency sound waves generate a lot of reactive radicals, while low-frequency, high-intensity ultrasound produces a significant shear and mechanical force that is ideal for extraction when using ultrasonic assistance. The majority of the research found that a continuous low frequency is better than a higher ultrasonic frequency because it produces fewer cavitation bubbles with a relatively larger diameter, which results in a larger cavitation effect.

Mehta *et al.* (2022) stated that initial increases in sonication time resulted in higher extraction yields; however, as sonication time increases, the yield declined. Increased fragmentation and sonoporation may cause a release of solute in the extracting medium, and an initial increase in time may result in an enhanced exposure of the extracting solvent to plant biomass. Higher sonication times, eventually caused the active component to be structurally destroyed, which lowers the extraction yield. Temperature has a comparable impact on extraction yield as processing time and ultrasonic power. The extraction yield first rises but subsequently falls as the temperature rises. Both the solute and the solvent are impacted by temperature increases; higher temperatures cause the solvent's viscosity to drop, ensuring more solvent penetration into the tissue matrix. Furthermore, the solute or active ingredient that is extracted becomes more soluble in the solvent as the temperature rises.

2.4 DRYING TECHNIQUES

Fruit juices can be dried using a variety of techniques, such as spray drying, lyophilization, drum drying, hot air drying, vacuum drying, refractance window drying, and others (Fan *et al.,* 2019). Freeze-drying and spray drying are commonly used drying techniques that have been engineered up to date in the food industry whereby diverse dehydration principles are employed in each technique specifically (Verma and Singh, 2015).

The fourth generation of drying techniques includes the recently developed idea of refractive window (RW) drying (Shende and Datta, 2019). RW drying is typically used for drying products like heat-sensitive purees and pieces of fruits and vegetables (Karam *et al.,* 2016). In contrast to drum and spray drying, high-sugar juices are challenging to process during RW drying and also demand greater operational expenses (Karadbhajne *et al.,* 2019).

Adnan *et al.* (2018) reported that drying was a well-established and ancient technique for preserving fruits, vegetables, and their derivatives by lowering their water activity (aw) and water content. There were several methods for drying, including sun drying, microwave drying, forced or natural convection drying, and most importantly, spray drying. The final one is a specialised and widely used method for turning liquid feedstocks into concentrated products or powders.

Hasan *et al.* (2019) stated that fruit and vegetable drying using traditional methods, including sun or open-air drying, was a long process that can be resulted in contaminated products of lower quality. Numerous cutting-edge drying methods, including vacuum, infrared, freeze, oven, microwave, sun, and hybrid drying technologies, had been developed globally and were effectively used to a variety of fruits and vegetables. The confectionery, bakery sweet and distilling sectors employed dried items extensively to create a variety of useful by-products, such as sauces, teas, puddings, garnishes, and food supplements for both babies and kids. Crop-specific drying techniques had been refined to preserve the quality of dried goods.

According to Sultana *et al.* (2024), the main goal of drying is to increase the shelf life of solid, liquid, or semisolid foods by removing water from them. By preventing microbial development and lowering chemical & enzymatic reactions, drying stops food from spoiling and degrading in quality while being stored. Furthermore, drying increases the availability of foods during off-season, improves transportation facilities, lowers handling costs, increases the applicability for producing functional foods, nutraceuticals and many other value-added food products, including encapsulated fish oil.

Khatri *et al.* (2024) stated different drying techniques contrast to conventional drying techniques like sun drying or hot air drying. Novel techniques like freeze-drying and vacuum drying use lower temperatures, which decreases heat-induced damage to the food's nutritional value and sensory qualities and helps preserve the vital nutrients, like vitamins and antioxidants, in food by reducing the exposure to oxygen and high heat, which can break down these substances. Innovative drying techniques, such as freeze drying, produce goods that are simpler to rehydrate, increasing consumer convenience while maintaining texture and flavour. A new method of dehydration called foam-mat drying is utilised to turn liquid solutions into powdered goods. These days, companies frequently employ foam mat drying in conjunction with other drying modes to dry fruit juice and create shelf-stable powder for immediate use.

2.5 SPRAY DRYING

Tonon *et al.* (2008) stated that spray drying was commonly employed to create fruit juice powders. It produces high-quality powders with less water activity that were simpler to carry and store. The physico-chemical qualities of powders made by spray drying were dependent on a number of process variables, including the kind of atomiser and the parameters of the drying air (temperature, pressure), as well as the liquid feed (viscosity, particle size, flow rate). In order to produce goods with improved sensory and nutritional qualities as well as improved process yield, it is crucial to optimise the drying process.

Verma and Singh (2015) reported that spray drying was a single processing step that used a hot gas to quickly dry a liquid or slurry into a dry powder. Spray drying was the recommended technique for products that are sensitive to heat, such as foods and medications. To distribute the liquid or slurry into a controlled drop size spray, all spray dryers used some kind of atomiser or spray nozzle. Moisture evaporated when the spray and drying medium come into contact. Both co-current and counter-current flows of the heated drying gas can be directed towards the atomiser. These operational parameters are used into the spray drying process design to improve product recovery and yield final products that meet exact quality standards.

The economical, quick, and one-stage drying technique known as spray drying was first used to make fruit powders but is now being used to make concentrated fruit juice products. The spray-drying method's unique selling point is the comparatively greater surface area achieved via atomisation, which results in the development of spherically shaped, regular droplets in the drying chamber (Adnan *et al.,* 2018). The operation of a standard spray-drying evaporator (Fig 2.3), which typically applies hot air at high drying temperatures (150–220ºC) to dry the feed droplets within 50–80ºC at the outlet, involves a short drying contact time. Fruit juices that include thermosensitive elements including vitamin C, β-carotene, lycopene, anthocyanins, and others cannot be dried with this approach. Furthermore, it is challenging to dry fruit juices high in sugars without a carrier agent because to their gluiness and low glass transition temperatures.

Sobulska and Zbicinski (2020) suggested that the spray drying method was frequently used to produce food items in powder form, such as sugar-rich foods like honey and fruit juices. By drastically lowering the moisture content and lowering the chance of spoiling, spray drying of these kinds of products extended their shelf life. Fruit juice and honey powder also had the added benefit of lowering packing, storage, and shipping costs. The advantages of the powder form, like improved flowability and ease of mixing with other components, create opportunities for the creation of novel products with intricate compositions that might be used in the pharmaceutical, cosmetic, and food industries.

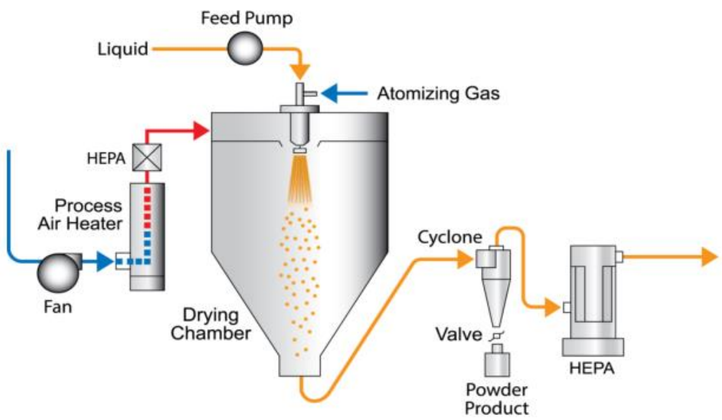

Fig. 2.3 Parts of spray dryer

2.6 MICROENCAPSULATION

"A process to entrap an active compound within a stable, protective substance to produce encapsulates of varied size and functional properties" is a definition of encapsulation. Typically, the enclosing composition is referred to as the "wall," and the active element as the "core." The structural components of encapsulation are the wall and core. For foods, encapsulation can be done for an ingredient of food composition (such as flavours), as well as for the food substance as a whole (e.g. chocolate). This divides encapsulation technology into three categories: macro, micro, and nanoencapsulation. The resulting capsule size indicates the category. When the particle size is more than 5000 µm, the technique is called macro encapsulation; when it produces particles that are between 0.2 and 5000 µm and between 2000A^{o} and 0.2 µm, it is called micro and nano encapsulation, respectively. (Anandharamakrishnan and Ishwarya, 2015).

Ephrem *et al.* (2018) examined the process of encapsulating probiotics, enzymes, and bioactive components to create fruit juice preserves that are fortified. Fruit juices are nutrient-dense, low-fat, non-alcoholic, and lactose-free drinks that show promise in customer demand. Fruit juices lose shelf life due to microbial, enzymatic, and chemical degradation. Consumers' need for nutritious fresh fruit juice has led to the use of probiotics, vitamins, antimicrobials, and anti-browning chemicals to preserve and fortify freshly extracted juices. Because of these bioactive compounds' poor water solubility and physicochemical instability, especially in acidic foods, their application is proven to be insufficient. Therefore, to improve stability, the creation of encapsulating systems through the insertion of bioactive chemicals should be taken into consideration.

One of the most popular methods for encapsulating bioactive compounds for use in the food sector is spray drying (Assadpour and Jafari, 2019). It is distinguished by being a quick, inexpensive, and scalable process that atomises a liquid (solution, suspension, emulsion, etc.) to produce dry particles in a continuous operational stage. The product is sprayed using an atomiser and concurrently encounters a hot air stream that dries the ground material. The particles fall by gravity and dry in the drying chamber before eventually reaching the cyclone and being gathered as powder (Gómez-Gaete *et al.,* 2024).

According to Jafari *et al*. (2023), the process of encapsulating solid, liquid, and gaseous components in sealed capsules with diameters ranging from nanometres to millimetres in order to preserve and prolong their shelf life is known as microencapsulation. It is a practical technique for enhancing the dispersion of bio actives in food and facilitating their passage into the gastrointestinal system. The combination of the encapsulating material and the nucleus, which might be physical, chemical, or physicochemical in character, is the primary difference between the various methods of encapsulation. The most popular encapsulation method for bio actives is spray drying encapsulation due to its low cost, ease of usage, and reputation for producing high-quality microcapsules.

2.6.1 Encapsulation techniques

Encapsulating an active compound within a protective shell is the common aim of all microencapsulation techniques. The encapsulation processes are classified into two types: mechanical or physical, and chemical processes. The former processes use commercially available equipment to create and stabilize the microencapsulates, while the latter utilizes the possible chemical interactions that can be promoted by varying the process conditions. The mechanical processes involve the controlled precipitation of a polymeric solution where the physical changes occur, while the chemical processes involve polymerization reactions (Anandharamakrishnan and Ishwarya, 2015). The various encapsulation methods under the two categories are listed in Table 2.2.

Table 2.2 Methods of encapsulation

Mechanical process	**Chemical process**
Spray drying	Simple coacervation
Spray cooling	Complex coacervation
Spray chilling	Ionotropic gelation
lyophilization	Interfacial polymerization
Emulsification	Solvent evaporation
Co-crystallization	Inclusion complexation
Electro spraying	Solvent exchange method
Fluidized bed coating	Liposome entrapment

2.7 CARRIER MATERIALS

Phisut (2012) reported that the physicochemical characteristics of powders vary depending on the drying conditions and carrier agents used. Understanding food characteristics is crucial for streamlining operations and lowering expenses, particularly when it comes to powders made or utilised in the food and pharmaceutical sectors. The low glass transition temperature (Tg) of the low molecular weight sugars basically sucrose, glucose, and fructose found in these products is the primary cause of the powder sticking issue. The temperature at which the polymer's amorphous phase changes from rubbery to glassy states is known as the glass transition temperature (Tg).

By adding certain carrier agents, such as gums and polymers, to the product prior to atomisation, these issues can be resolved. Additionally, microencapsulation also makes use of a carrier agent. It can shield delicate food ingredients from adverse environmental factors, conceal or maintain tastes and scents, lessen volatility and reactivity, and enhance appeal to food product merchandising.

Du *et al.* (2014) examined two distinct ratios of five distinct carrier materials: egg albumen, whey protein concentrate, gum Arabic, starch sodium octenyl succinate, and maltodextrin. The best yield was obtained from gum Arabic and starch sodium octenyl succinate among the investigated carrier materials. Maltodextrin, whey protein concentrate, and egg albumen came next. It was asserted that these carrier materials were more effective since whey protein concentrate and egg albumen were utilised in smaller ratios than other carrier materials. Furthermore, because gum Arabic and starch sodium octenyl succinate have larger molecules than maltodextrin, their higher glass transition temperature value explains their better yield compared to maltodextrin.

Anandharamakrishnan and Ishwarya, (2015) stated that the first step in the spray drying encapsulation process was selecting the wall material. The kind of wall material affected the flowability, mechanical stability, and ultimate shelf life of the encapsulated product after drying, in addition to the feed emulsion stability prior to drying.

2.7.1 Maltodextrin

Kha *et al.* (2010) conducted the study on spray drying of gac fruit. Maltodextrin has been referred to as an appropriate drying aid to maintain its antioxidant qualities and colour. Maltodextrin concentration and drying temperature generally had a substantial effect on the colour properties of spray-dried powders. Maltodextrin concentration had a substantial impact on product colour and brightness ($p < 0.01$). Increasing the concentration of maltodextrin from 10% to 20% significantly increased the lightness of the products. Higher encapsulation efficiency (EE) was the result of increasing the concentration of maltodextrin; nevertheless, there was not a significant difference in EE between 20% and 30%.

Anandharamakrishnan and Ishwarya (2015) mentioned that maltodextrin was a creamy white powdered hygroscopic polysaccharide with a taste that was either bland or only mildly sweet. Even in concentrated solutions, it had a low viscosity and was very water soluble. This made it possible for emulsions to have a higher solid content, which was beneficial for core retention during spray drying. Because it's inexpensive, it could be a good substitute for gum Arabic (GA), although it could also be combined with GA, whey protein, or modified starches to get optimal encapsulation outcomes. This is due to MD's weak emulsification ability, which could result in inadequate lipophilic core retention.

Ciechanowska *et al*. (2020) suggested that maltodextrin was one of the most widely utilised carriers in the manufacturing of powder. Among other things, it was previously used to make powdered watermelon, mango, acai, and cranberries. In terms of technology, maltodextrin was superior to other carrier agents, such as inulin, because it had a reduced propensity to condense the solution prior to the spray-drying procedure. Maltodextrin was used to reduce fat content, which lowers the calorie content of several foods. There are various kinds of maltodextrin that can be separated based on the kind of starch that is hydrolysed, such as rice, corn, oats, or potatoes; alternatively, barley and wheat are examples of less popular starch types. It was reported that the addition of maltodextrin produced the maximum water activity when compared to the maltodextrin–inulin mixture and inulin, the type of carrier had an effect on the a_w values of the cranberry powders. This could be impacted by the carriers' water activity (a_w).

2.7.2 Corn starch

Vanzela *et al.* (2013) attempted to preserve carotenoids in dehydrated pumpkin by using the starches from cassava and maize to create an edible covering. Results shown that trans-a-carotene and trans-b-carotene were well-retained by the maize starch coatings, and the better colour qualities were displayed by dehydrated goods.

The prolonged digestion of regular maize starch in encapsulated form was investigated by Xu and Zhang, (2014). Together with the quantity of slowly digesting starch, starch is the primary carbohydrate with the highest glycaemic index and nutritional value that helps with glycaemic management. Starch capsules demonstrated a significant increase in resistant and poorly digested starch. It is the perfect ingredient for glycaemic control and the development of speciality foods due to its pleasing sensory qualities.

Chandralekha *et al.* (2016) used a spray drying approach with various wall materials to investigate the survivability of encapsulated yeast cells. A known amount of carrier agents, such as maltodextrin, maize starch, acacia gum, polyethylene glycol 8000, β-cyclodextrin, and skimmed milk powder, were combined with yeast slurry and supplied to the feed separately. Out of the six drying aids, corn starch and maltodextrin produced the best results in terms of cell survival (80.5%) and powder production (59%, w/w), respectively. When considering both powder yield and survivability, maize starch was the most practically appropriate carrier material.

2.7.3 Gum Arabic

The most widely used gum additive is gum arabic, also known as acacia gum, which is a complex branching heteropolysaccharide made up of 1, 3-linked β-D-galactopyranosyl groups and is extracted from Acacia senegal as well as Acacia seyal trees. It's the sole gum. utilised in the food sector due to its low water viscosity and great solubility. The gum's emulsification qualities are high. It has a pale white hue and is made up of D-glucuronic acid, L-rhamnose, D-galatose, and L-arabinose in the ratio 4:2:2:1 (Patel and Goyal, 2015).

Tontul and Topuz, (2017) reported that one of the oldest and most well-known natural gums was gum arabic, which was made from the fluids of acacia trees. In contrast to the other gums, it was very soluble (up to 50%) in both hot and cold water and has a low viscosity. It was made up of a complex heteropolysaccharide with a 2% protein content and a highly ramified structure. The structure's functional characteristics were attributed to the proteins within it, whereas the arabinogalactan fraction possesses the ability to form films.

Sarabandi *et al.* (2018) investigated the effects of pectin and whey protein concentrate (WPC) as supplementary drying aids, as well as maltodextrin (MD) and gum arabic, on the powder yield, physical, functional, and microstructural characteristics of spray-dried apple juice concentrate. The bulk and tapped densities of the samples had MD and GA which were the greatest and lowest, respectively, however the particle density was significantly reduced when WPC was employed. Considering all the factors, including solubility, wettability, and hygroscopicity, 10% WPC combined with MD produced the most economical powder with the greatest yield (60.85%) and suitable flowability, functionality, and physical characteristics.

The impact of the carrier choice on the dry-material, density, colour, hygroscopicity, and anthocyanin content of powders following spray drying was investigated by Turak *et al.* (2019). As carriers, low-crystallized maltodextrin, arabic gum, maltodextrin plus arabic gum combinations (1:1; 2:1; 3:1), and rice starch were employed. The high dry matter content (96–99%) and low hygroscopicity (0.136–0.2 g H_2O g^{-1} d.m.) of all the powders suggested a fair chance of keeping the microencapsulated anthocyanins safe throughout storage.

Bednarska and Turak (2020) investigated on the physicochemical characteristics and quality of chokeberry juice powder which were affected by the carrier materials (maltodextrin 10DE and 15.6DE, arabic gum, GA: MD10 and GA: MD15). High concentrations of gum arabic in powder form were characterised by decreased apparent density and water activity, although at the expense of a decline in colour parameter values. The carrier mixes that contained maltodextrin and arabic gum seemed to have a lot of promise to guarantee chokeberry powders of a higher calibre. Additionally, it seems that the carrier combinations GA: MD had high-quality chokeberry powder with large levels of polyphenols (about 3000 mg/100 g) and anthocyanin (1694–2028 mg/100 g).

2.8 SPRAY DRYING PARAMETERS

Saranya *et al.* (2016) added maltodextrin, horse gram extract, sugar, and milk to microencapsulated banana pseudo stem juice. The product had a moisture level between 2.9 and 4.60%. They demonstrated that as the temperature and maltodextrin concentration increased, the moisture content dropped. The powder's water activity ranged from 0.295 to 0.430. Additionally, they stated that the powder became lighter once maltodextrin was added.

The impact of interior air temperatures on the physicochemical characteristics of spray-dried jamun juice powder was examined by Santhalakshmy *et al.* (2015). The temperature of the inlet air changed from 140 to 160°C, and additional process variables like the outflow maintaining a constant temperature (80°C), maltodextrin content

(25%), and feed flow rate (10 ml/min). Moisture content, water activity, bulk density, solubility, hygroscopicity, colour, powder shape, particle size, and glass transition temperature were all measured on powder samples. Higher intake temperature resulted in the formation of larger particles with higher moisture contents. The temperature of the inlet air causes variations in the powdered jamun juice's colour. Powders become somewhat more vibrant and less purple at higher temperatures.

Fortes *et al.* (2019) investigated how several qualitative aspect of spray-dried guava powders which were affected by the amount of maltodextrin DE 10 (60–75% wb pulp solids foundation). It was found that ascorbic acid retention and powder yield were positively impacted by the maltodextrin concentration, while the amount of maltodextrin had a detrimental effect on hygroscopicity, moisture content, and rehydration.

Shrivastava *et al.* (2021) investigated how different qualitative parameters of spray-dried custard apple pulp powder (CAPP) were affected by the inlet air temperature (IAT), which ranged from 100 to 140°C. The findings demonstrated that a variety of spray-dried custard apple pulp powder (CAPP) quality features are significantly impacted by temperature. They noted that the temperature increases reduced the degree of caking and moisture content while increasing the powder yield, bulk density, solubility index, and dispersibility.

2.9 RESPONSE SURFACE METHODOLOGY

According to Said and Amin (2015), Response Surface Methodology (RSM) is an optimisation tool used in experimentation and research studies in the specialist area of food and herbal plant extraction that may detect relationships between variables. RSM assists in identifying the optimal experimental design to determine how variables relate to one another. The use of RSM to generate a model equation that can subsequently be used for response prediction and optimal condition determination is also covered in this study. When the RSM approach is used in the optimisation process, all of the factors related to the consumer evaluation can be tested quickly, increasing the efficiency of the laboratory test stage.

According to Krishnaiah *et al.* (2015), the primary advantage of the response surface methodology is that the total amount of data needed for evaluation, research, and optimisation significantly reduces the total amount of experimental trials that must be carried out. Compared to the traditional one factor at a time or whole factor testing, response surface approach is a faster and less expensive way to collect research findings.

Singh *et al*. (2019) used response surface methodology (RSM) to examine how different quality parameters of spray-dried jamun pulp powder were affected by varying maltodextrin concentrations (5–10%). It was found that the moisture content dropped as the concentration of maltodextrin increased, and attractiveness while increasing TPC, TAC, dispersibility, and solubility.

According to Oliveira *et al.* (2021), response surface methodology emerged as one of the most successful approaches for carrying out process optimisation by fusing modelling techniques, optimisation methods, and experiment design and analysis in a more robust manner that makes use of experimental information to improve the procedure.

2.10 PHYSICOCHEMICAL AND QUALITY PARAMETERS OF SPRAY DRIED POWDER

According to Sarabandi *et al.* (2014), the physicochemical characteristics of grape syrup powder are impacted by the conditions of spray drying. They chose the following quality parameters: hygroscopicity, solubility, bulk density, and moisture content, wettability and water activities. The findings showed that while powder wettability and powder solubility values increased as the inlet temperature increased, moisture content, water activity, bulk density, and hygroscopicity reduced as a result of the temperature increase. According to their findings, the powder wettability, bulk density, solubility, and hygroscopicity of powder can all be adversely affected by the carrier agent concentration.

Lgual *et al.* (2014) used the central composite design of the response surface methodology to optimise the spray drying of lulo in order to investigate the effects of the inlet air temperature (120–180°C), the concentration of arabic gum (0–10% w/w), and the concentration of maltodextrin DE16.5-19.5 (0–10% w/w) on certain aspects of the product and process. More than the temperature of the inlet air, gum arabic and maltodextrin increased the yield of the product, decreased the hygroscopicity and water content of the resulting powder, and helped to preserve its nutritional and functional qualities by increasing the amount of ascorbic acid, vitamin C, total phenol and total flavonoid content, and antioxidant capacity. The ideal spray drying parameters for producing lulo powder were 13.4% (w/w) maltodextrin DE16.5–19.5, 3% (w/w) gum arabic, and 125°C inlet air temperature.

Kim *et al.* (2021) used response surface methodology (RSM) to determine the ideal spray-drying parameters for Japanese apricot juice powder (JAJP). Two independent criteria were used in the optimisation process: the inlet air temperature (130–180°C) and Different proportions of the carrier agent (nondigestible maltodextrin (NMD) 10–30%). Research were conducted on JAJP's drying yield, moisture content, bulk density, colour, pH, water solubility index (WSI), and antioxidant activity. The best spray drying parameters were found to be an NMD concentration of 14.7% and an inlet air temperature of 154.5°C, respectively. A drying yield of 55.73%, 4.84% of moisture content, 90.98% WSI, 0.59 g/mL of bulk density, and 169.87 mg/g vitamin C content in JAJP were measured under these ideal circumstances.

2.11 PACKAGING AND STORAGE OF FRUIT JUICE POWDER

The storage stability of spray-dried papaya powder in polyethylene terephthalate and aluminium laminated polyethylene was investigated by Wong and Lim (2016). Following the product's packaging in the appropriate material, the microbiological and physical attributes were analysed after a week. They discovered that the water activity did not rise above 0.6 for both packaging materials, and the temperature and relative humidity were 38 ± 2°C and 90%, respectively. When comparing polyethylene terephthalate packets to aluminium laminated polyethylene packets, the product's moisture content increased. After seven days of storage, the samples in both packets flowability declined. They concluded that aluminium laminated polyethylene was the ideal material for packing papaya powder.

The storage behaviour of spray-dried guava powder packed in LDPE, PET, and OPP laminated film was investigated by Shishir *et al.* (2017). The powder was kept at 5°C and 25°C for ten weeks. The properties of the powder were significantly impacted by packaging film, storage temperature, and time. The PET laminated film had the biggest impact on lycopene, water activity, and moisture retention. The least successful at controlling moisture was LDPE packed powder, which resulted in a rise in the glass transition temperature (Tg) and degree of caking (CD), as well as a loss of colour and lycopene. The moisture gain, water activity, Tg, and CD were all significantly increased by the higher storage temperature (25°C). Guava powder was best stored in PET laminated film at 5°C, which had the longest anticipated shelf life (34.95 weeks), the highest lycopene retention (74.56%), and the lowest moisture content (<3%).

Shiby *et al.* (2017) investigated how two distinct packing materials affected the instant fruit dairy functional beverage mix's storage stability. Metallised polyester (MP) and aluminium laminated polyethylene (ALP) were used to package the freeze-dried pineapple Lassi (PL) powder. Quality Changes were assessed at high temperature conditions (38±1°C, 33% relative humidity). The estimated shelf lives for MP and ALP pouches were 44 and 62 days, respectively. The moisture content, water activity, vitamin C, colour change, and browning index of the samples stored in both packing materials were examined. Since samples stored in ALP retained the majority of their antioxidant qualities, ALP was determined to be superior to MP.

Yian and Phing (2020) investigated the effects of two distinct packing materials on the storage stability of kuini powder: polyethylene terephthalate (PET) and aluminium laminated polyethylene (ALP). The packed powder's physicochemical characteristics were assessed weekly for a total of seven parameters including carotenoid, colour, hygroscopicity, moisture content, water activity, degree of caking, flowability, and water solubility index. In comparison to PET packaging (which has a moisture content of 24.77, a water activity of 0.50, and a hygroscopicity of 28.00), the results indicate that kuini packaged in ALP pouches has superior qualities after 7 weeks of storage, including decreased moisture content (13.33), water activity (0.43), and hygroscopicity (23.37).

2.12 COST ESTIMATION OF SPRAY DRIED POWDERS

Reddy *et al.* (2014) determined how much it would cost to produce spray-dried goat milk powder. Goat milk powder was produced using a homogeniser, a fluidised bed dryer, a spray dryer and a rotating vacuum flash evaporator. One kilogramme of goat milk powder was produced at a total cost of Rs. 475. The developed process technology producing goat milk powder is economically viable, as indicated by the benefit cost ratio of 1.47:1.

Domínguez-Niño *et al.* (2018) reported the final optimized condition of spray drying of inlet temperatures of 180°C, outlet temperatures of 80°C, and the addition of 5% carrier material as the ideal drying conditions. With a moisture content of 2.08% and a water activity of 0.125, 0.2165 Kg/h of dried product was produced under these circumstances. The product cost was $17.06 per Kg, and its energy consumption was 2.0490 KWh/Kg of dry product.

Cumin oil microencapsulation was done using a tall-type spray dryer equipped with a dual fluid atomiser. Maltodextrin and gum arabic were chosen as the wall materials for encapsulation. The improved version of the Response surface approach was used for the encapsulating process. The ideal parameters for cumin oil microencapsulation were an inlet temperature of 162.50 °C, a carrier blend ratio of 1.77, and a core concentration of 10%. One kilogramme of microencapsulated cumin oil was produced at a total cost of Rs. 1577 (Shahama, 2018).