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Extraction, Encapsulation and Fortification of Carotenoids from Pumpkin and Sweet Potato

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Abstract

Carotenoids are healthy antioxidants that shields the body from illnesses. The richest sources of carotenoids are yellow orange vegetables, among them sweet potato and pumpkin are naturally good sources. Encapsulation improves antioxidant potential and maintaining stability. Fortification of carotenoid prevents vitamin A deficiency. The aim of the research was to extract carotenoids using solvents from sweet potato and pumpkin and to estimate the extraction yield and encapsulate the carotenoid using 15% maltodextrin as wall material by spray drying with inlet temperature of 150˚C and fortify the encapsulated powder in gingelly oil. The physiochemical properties of the encapsulated powder and the fortified oil were analyzed and the carotenoid content was estimated. The resulted values showed the extraction yield (91.3±0.15%), bulk density (0.50±0.01g/ml), moisture content (13±0.2%), hygroscopicity (21.3±0.26%), the encapsulation efficiency before and after encapsulation were found to be 91.5±0.1% and 90.3±0.15%. The carotenoid content in the extract and encapsulated powder were 52±0.24µg/g and 47±0.6µg/g. The resulted values of the physiochemical properties of oil showed bulk density (0.85±0.03g/ml), peroxide value (4.72±0.02mEq/kg) and the smoking point (185˚C±3). From the results obtained, we can conclude that encapsulating carotenoids by spray drying improved carotenoid retention and fortification helped in preventing vitamin A deficiency.

***Key words*:** Encapsulation, Carotenoid, Fortification, Spray drying, Encapsulation efficiency

Millions of people in low- and middle-income countries suffer from deficiencies in one or more micronutrients like iron, zinc, and vitamin A, which jeopardises their physical and mental health. Food fortification is a potential strategy that has been shown to improve social, economic, and health outcomes (Olson *et al.*, 2021). Micronutrient deficiency is primarily caused by inadequate nutrient-dense food consumption as well as nutrient losses from unhealthful diets, infections, and menstrual blood loss (women of reproductive age) (Olson *et al.*, 2021). Food fortification, micronutrient supplementation, nutrition education, and disease control measures are the four main strategies that the World Health Organization (WHO) and Food and Agriculture Organization (FAO) have adopted to improve dietary intake. One method that has a track record of improving dietary diversity and significantly lowering micronutrient deficiencies is the fortification of staple foods(Olson *et al.*, 2021). Encapsulation is a method for encasing active ingredients inside of a carrier material. It is a helpful tool for enhancing the absorption of living organisms and bioactive molecules into food(Nedovic *et al.*, 2011). Maltodextrin (MX) is a polysaccharide that is frequently used in the encapsulation of active substances as a wall material or transporting agent(Saavedra–Leos *et al.*, 2018). One of the most popular microencapsulation and drying techniques in the food and pharmaceutical industries is spray drying because it is adaptable, affordable, effective, simple to scale up, and provides powder of high quality(Desobry*et al.*, 1997). It has been widely utilised for decades to encapsulate bioactive food constituents such proteins, lipids, vitamins, enzymes, colours, and flavours (Gharsallaoui*et al.*, 2007).

Carotenoids are important for safeguarding bodily cells and function as potent antioxidants as a result. There are many roles for carotenoids in maintaining human health. They typically perform antioxidant effects, although individual carotenoids may also work through other mechanisms; for example, β-carotene has a pro-vitamin A role, while lutein/zeaxanthin produce macular pigment in the eye. (Tos*et al.*, 2014). Carotenoids cannot be produced by humans; instead, they must be consumed through food in order to be used for vital physiologic processes. Most carotenoids are consumed by humans in their diets; 90% of circulating carotenoids are composed of α-carotene, lycopene, lutein, zeaxanthin, β-cryptoxanthin, and β-carotene (Tos*et al.*, 2014). According to extensive epidemiological research, eating fruits and vegetables high in carotenoids is thought to improve health by lowering the risk of a variety of illnesses, especially some cancers and eye conditions.(Krinsky& Johnson, 2005). One of the most underappreciated and underutilised food and medicinal plants

is the pumpkin (Cucurbita spp.). Its production is hindered by a shortage of seeds that have undergone genetic improvement. It is a remarkable vegetable with the capacity to be consumed both as a nutritious food and as medicine. Pumpkin flesh and peels are rich in phytochemicals (β-carotene, total flavonoids, and total phenolics) that support the immune system and fight ageing(Hosen *et al.,* 2021). Sweet potatoes are a food with high nutritional value that are eaten all over the world. It provides energy, fibre, vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), potassium, vitamin C, and vitamin A (orange-fleshed sweet potato) in abundance. Sweet potatoes with coloured flesh also contain bioactive substances that support preserving consumer health. The beta-carotene content of pink, yellow, and green varieties is also high. (Mohanraj and Sivasankar, 2014).

The present study focuses on encapsulation of carotenoids, the most prominent micronutrient which is also known as pro Vitamin A, using spray drying to enhance their antioxidant potential and to maintain their stability and to fortify the encapsulated carotenoid in cooking oil. As pumpkin and sweet potato are rich in Carotenoids, they have been chosen as source of carotenoids in this study. Pumpkin and sweet potato have high nutritive value and antioxidant activities.

The present study is associated with the following objectives:

- To extract Carotenoid from pumpkin and sweet potato
- To encapsulate the extracted Carotenoid
- To analyze the physiochemical properties of the encapsulated powder
- To fortify the encapsulated carotenoid in cooking oil
- To analyze the physiochemical properties of the fortified oil and to determine encapsulation efficiency.

MATERIALS AND METHODS

Procurement of raw materials

Pumpkin (*Cucurbita Moschata)*, sweet potato and gingelly oil were procured from the local market in Chromepet, Chennai, Tamil Nadu, India. The fruits were thoroughly washed and cleaned. The cleaned fruits were used for extraction of carotenoids.

Processing of raw materials

Extraction of carotenoids

The washed pumpkin and sweet potato were peeled, cut into slices, blanched in water at 60˚C for 2 mins, ground to paste and kept in freezer for 30 mins. The samples were extracted using Acetone and hexane solvents in the proportion of 4:3. Macerate the sample for 5 mins and filter it through Whatman filter paper 42. Then rinse again with 50ml of solvent concentration, wash the sample with 10ml of each solvent and 50ml of diethyl ether is added. Finally wash the sample in 50ml sodium chloride and distilled water, until it becomes colourless. The filtered extract is collected through a separating funnel and the carotenoid layer present in the top is collected, while the remaining watery layer is discarded. To remove the solvent, rotary evaporation for 10 minutes is carried out at 40˚C and the extracted carotenoid were collected and stored at 4˚C for further process. (Athira*et al.,* 2022).

Encapsulation of carotenoids

The extracted carotenoids were homogenized using maltodextrin 15% as a wall material at 4200 rpm for 15 mins. Then the solutions were fed into spray dryer (Chennai). The inlet and outlet temperatures were 150˚C and 73-80˚C and the feed flow rate and pressure were 200ml/hr and 2.0 bars. Then the powder is collected and used for fortification (Do. H T *et al.,* 2019).

Fig 1 Spray dried carotenoid powder

Fig 2 Carotenoid fortified gingelly oil

Fortification of carotenoids in cooking oil

The encapsulated carotenoid powder was fortified in 1 litre of gingelly oil using high speed homogenization process by developing a premix. The encapsulated powder is added to the oil by heating 100ml of the oil at 50˚C. The powder was completely dissolved after 30 mins and then the prepared premix was added to the remaining 900ml of the oil by homogenization using high speed mixer at 4500 rpm for 30 minutes to ensure complete fortificant dispersion (Gurumeenakshi *et al.* 2019).

Analytical methods

Assessment of physiochemical parameters of extraction yield and encapsulated powder

Extraction yield

According to Adam *et al.* 2019,the extracted yield was calculated using the following method. The extraction yield of the extract is determined using the formula:

$$Y = \frac{We}{Wt} \times 100$$

Where, Y = Extraction yield
We = Weight of extract after filtration
Wt = Weight of sample and water

Estimation of carotenoids

Carotenoid estimation was done in both extract and encapsulated powder. According to Knockaert *et al.,* 2012, accurately weigh 2g of sample and dissolve it in hexane with 0.1% butylated hydroxytoluene up to final volume of 10ml. By using spectrophotometer, the absorbance value was assessed at 470 nm. The total carotenoid content was calculated by taking specific coefficient for beta carotene.

$$\text{Carotenoid concentration } \frac{ng}{mg} = \frac{A * \text{Volume (ml)} * 10^4}{E_{1cm}^{1\%} * \text{sample weight (g)}}$$

Where,

A – Absorbance value

Volume – total volume of sample solutions

$E_{1cm}^{1\%}$ - extinct coefficient = 2560 for beta carotene in hexane

Moisture content

The moisture content analysis was conducted according to the method of AOAC. One gram of sample was taken and dried in an oven at 70°C until constant weight and triplicated the analysis and calculated as; (Shinde DD, 2017)

$$\text{Moisture content} = \frac{\text{Weight of water loss}}{\text{Weight of the powder sample}} \times 100$$

Hygroscopicity

According to Etzbach *et al.,* 2020, the amount of moisture that was absorbed after the powders were exposed to humid air with a relative humidity of 81% was used to calculate hygroscopicity. 1 g of powder was weighed in an aluminium dish and placed in a desiccator with 200 mL of a saturated solution of Na_2SO_4 at 25˚C to determine the hygroscopicity. After 1, 3, 7, and 24 hours, the weight gain was measured in triplicate, and the moisture absorption was calculated using the equation below.

$$\text{Moisture absorption (\%) after 1, 3, 7, 24 hours} = \frac{\text{Weight gain after 1,3,7,24 hr}}{\text{Weight of the sample}} \times 100$$

Bulk density

According to Sarkar *et al.* 2019, the bulk density of the powder that was encapsulated was determined by weighing the mixture and figuring out the corresponding volume. Approximately 5g of the substance was put into a graduated measuring cylinder with a capacity of 10 ml.

$$\text{Bulk density} = \frac{\text{Weight of powder}}{\text{Volume of powder}}$$

Encapsulation efficiency

According to Saénz *et al.,* 2009, encapsulation efficiency is calculated based on the carotenoid content in the powder before and after encapsulation.

$$\text{Encapsulation efficiency (\%)} = \frac{A}{B} \times 100$$

Where,

A = Total carotenoid content in the feed emulsion

B = Total carotenoid content in the encapsulated powder

Assessment of physiochemical parameters of fortified oil

Bulk density

According to El-Massry *et al.,* 2019, bulk density of the fortified oil was determined by considering the weight and volume of the sample.

$$\text{Bulk density} = \frac{\text{Weight of the fortified oil}}{\text{Volume of the fortified oil}}$$

Smoke point

The oil stops glistening and begins to burn at the smoke point, emitting bluish smoke (AOAC, 2000). Smoking point was determined using a Laboratory thermometer. At this temperature, the fat in the oil begins to degrade into glycerol and fatty acids, and the resulting glycerol will then degrade further to produce acrolein, one of the primary components of bluish smokes (Wang, 2002). The oil was heated in a cup with a sample amount until a steady blue smoke emerged. The temperature at which the bluish smoke appeared was recorded as the smoking point of the oil.

Peroxide value

Peroxide value analysis of the fortified oil was determined according to the method of AOAC Official Method 965.33. 2 g of oil sample was weighed in order to calculate the peroxide value (PV). The conical flask containing the weighed oil was then filled with 15 ml of glacial acetic acid, 10 ml of chloroform, and 1 ml of saturated KI solution. The mixture was thoroughly shaken until it turned brown, and it was then left in a dark area for five minutes. 75 mL of distilled water and 2 mL of the starch solution were added to the mixture after the five minutes had passed. The mixture was then titrated with 0.01 M Na2S2O3 until the dark blue solution turned into a colourless solution.

$$\text{Peroxide value (mEq/kg)} = \frac{(\text{Vs} - \text{Vb}) * \text{N} * 1000}{\text{w}}$$

Where,

Vs – Volume of sodium thiosulfate solution in the sample

Vb – Volume of sodium thiosulfate solution in the blank

N – Normality of sodium thiosulfate solution

w – Mass of substance

RESULTS AND DISCUSSION

Evaluation of physiochemical properties of the extraction yield

Extraction yield

Carotenoids were extracted from sweet potato and pumpkin using a variety of organic solvents and solvent combinations. Acetone and ethanol served as the polar solvents, while hexane served as the non-polar solvent (Luengo *et al.,* 2014). According to (Luengo *et al.,* 2015), the highest carotenoids extraction yield is obtained when polar and non-polar solvents are combined.

Organic solvent extraction of carotenoids yields good extraction rates without the need for expensive machinery. The most important factor in effective carotenoids extraction is solvent selection, which primarily depends on the carotenoid content of the food. In general, hexane and acetone are frequently chosen for the extraction of carotenes (nonpolar) and xanthophyll (polar), respectively. On the other hand, acetone, ethanol, and hexane are most frequently used to extract both polar and nonpolar carotenoids simultaneously. Additionally, the water miscibility of acetone and ethanol facilitates the effective extraction of carotenoids from wet tissue (Saini and Keum, 2017).

The solvent extraction technique was the most frequently used and practical technique, according to Cheng *et al.,* 2019, because it acted as a physical carrier for transferring important compounds between different phases like solid, liquid, and vapour. Hexane, acetone, and ethanol were the most widely used solvents for removing carotenoids from plant materials. Hexane is one of the industry's most popular solvents for extracting β-carotene because of its high affinity for carotenoids. Using semi-polar solvents like acetone, ethanol, or ethyl acetate, semi-polar carotenoids like lutein are extracted.

Table 1 Extraction yield of carotenoids

Weight of extract after filtration (in g) (We)	Weight of sample (in g) (Wt)	Extraction yield (Y) %
91. 3 ± 0.15	100	91.3 ± 0.15%

Values represent mean ± standard deviation

In this study, the extraction yield of carotenoid was found to be 91.3± 0.15% which was given in (Table 1). This is higher than the extraction yield of carotenoid obtained from pumpkin peel using cellulase enzyme and pectinase enzyme which were reported as 77.7% and 71.4% (Ghosh and Biswas, 2016). As reported by Shi *et al.,* 2010, the highest yield of carotenoid from pumpkin using SC - CO_2 extraction was 73.7%. According to de Andrade Lima *et al.,* 2019, the extraction yield of carotenoids was found to be 96.2%. Debora Pez Jaeschke *et al.,* 2016, reported the extraction yield of total carotenoids from microalgae Chlorella species as 73%.

Hexane have high affinity for carotenoids, therefore the presence of hexane as a solvent during extraction resulted in higher extraction yield percentage of carotenoids (Cheng *et al.,* 2019). The presence of acetone which is a polar solvent and hexane which is a non-polar solvent also increased the extraction yield as combination of polar and non-polar solvents resulted in higher extraction of carotenoids (Luengo *et al.,* 2015).

Estimation of carotenoids

The carotenoid content in the extracted sample was found to be 52 µg/g ± 0.24 which was given in (Table 2). This is slightly higher when comparing with the results obtained by Kahraman *et al.* 2018 where the total carotenoid content in extracted pumpkin ranged from 34.44 – 39.72 µg/g. The carotenoid content extracted from sweet potato were found to be 54.7 µg/g. (Mohanraj and Sivasankar, 2014b). The carotenoid content is influenced by the use of solvents during extraction (Shi *et al.*, 2010). Hexane having higher affinity to carotenoids increased the carotenoid retention in the extract.

Table 2 Total carotenoid content in extract

Parameters	In extract (B) (µg/G)
Total Carotenoid content	52 µg/g ± 0.24

Values represent mean ± standard deviation

Evaluation of physicochemical properties of the encapsulated powder

The Physicochemical properties of the spray dried carotenoid powder were given in the tables below. From the results obtained, we can observe that the Physicochemical properties were significantly affected by the spray drying process. The properties were also affected by the wall material concentration and the inlet temperature.

Estimation of carotenoids in the encapsulated powder

The carotenoid content of the encapsulation powder was found to be 47 µg/g ± 0.6 which was reported in table 3. In a study, the total carotenoid content of spray dried Gac aril powder reported for different inlet temperatures of 140 °C, 160 °C, and 180 °C were 0.819, 0.716, and 0.640 mg β-carotene/g (Thumthanaruk *et al*. 2021).

Table 3 Total carotenoid content in encapsulated powder

Parameters	In powder (B) (µg/G)	P value
Total Carotenoid content	47 µg/g ± 0.6	0.00**

Values represent mean ± standard deviation
**Significant at 1% level (p<0.01)

Moisture content

The amount of water in a food product is measured by its moisture content, also known as water content. It is often stated as a percentage of weight on a wet basis (Vera Zambrano *et al.*, 2019). The moisture content of the product in a spray drying system is influenced by the water content of the feed (Halliday and Walker, 2001). The end product will have more moisture because the feed had a larger initial water content. Powder's moisture content plays a key role as a drying efficiency indicator (Kurozawa*et al.*, 2009).

Fig 3 Moisture content of the encapsulated powder

Table 4 Moisture content and hygroscopicity of the encapsulated powder

Physicochemical property	Value
Moisture content	13% ± 0.2
Hygroscopoicity	21.3% ± 0.26

Values represent mean ± standard deviation

The moisture content of the encapsulated powder was found to be 13% ± 0.2 as shown in (Table 4). This is in accordance with the results obtained by (Thumthanaruk *et al*., 2021), where the moisture contents of the spray-dried Gac aril juice powders produced at various inlet temperatures (140 °C, 160 °C, and 180 °C) ranged from 9.89-10.86%. Mulyadi *et al.*, 2017, reported moisture content from 5.4 - 7.1% after spray drying of carotenoids. According to Santana *et al.*, 2013, the moisture content ranged from 0.3 - 1.9% after spray drying goldenberry powder which was lower when compared to the resulted value. According to Asha Monicka*et al.*, 2017, the moisture content after spray drying was reported as 2.91%. González-Peña *et al.*, 2021reported the range of moisture content from 2.5 to 6.9% for spray dried carrot and mamey powder. Etzbach*et al.*, 2020 reported the moisture content of spray dried goldenberry juice powder as lower than 5.25%. Siregar & Margareta, 2019reported the moisture content of the spray dried red melinjo powder to be 5.08%. According to Goula *et al.*, 2004, spray-dried powders with lower inlet temperatures tend to aggregate due to their increased moisture content. This is especially true for sticky powders that are rich in sugar content. Agglomeration would reduce the amount of oxygen that powders were exposed to, protecting the lycopene and beta carotene from oxidation. As carotenoids are highly heat sensitive, increasing the inlet temperature will contribute to loss of carotenoids from the powder. Therefore, the extract was spray dried at lower inlet temperatures due to which slightly higher moisture content was observed.

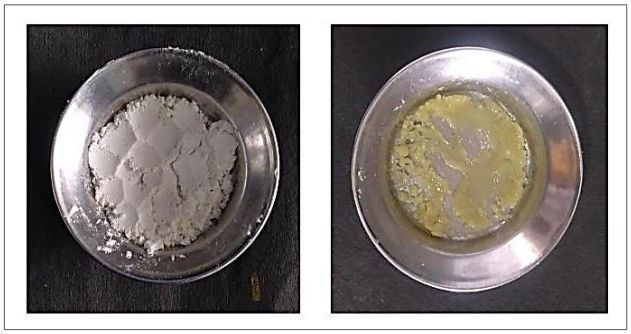

Fig 4 Hygroscopicity of the encapsulated powder

Hygroscopicity

According to Norea *et al.* 2016, hygroscopicity is influenced by the product's composition, including its low molecular weight sugar, organic acid, and moisture content, as well as the amount of drying agents present. In powdered products, water adsorption, defined as hygroscopicity, is crucial because it can affect how well vitamins and phenolic compounds retain their potency as well as the flowability of the powder. The factor that most significantly affect powder hygroscopicity was maltodextrin content(Kurozawa*et al.*, 2009). According to Ferrari *et al.*, 2012, the substantial water concentration gradient between the product and the surrounding air caused the hygroscopicity values to be inversely related to the moisture content of the powder.

Hygroscopicity of the spray dried carotenoid powder was found to be 21.3 % ± 0.26 as shown in (Table 4). This is in accordance with the results obtained by Etzbach *et al.*, 2020,

where hygroscopicity of the spray dried goldenberry powders after 24h ranged between 14.1% and 17.2%.

The encapsulated powder has high hygroscopicity due to the high sugar content in the pumpkin and sweet potato. Food powders with a high hygroscopicity may exhibit a phenomena called caking, which causes the powder to clump together. This result is related to water absorption on the surface of the particles, which creates a saturated solution and makes the particles sticky and able to form hydrogen bonds, which results in the caking(Goula&Adamopoulos, 2008). Fruit products typically have a high sugar content, which results in hygroscopic and sticky powders that have a tendency to clump together (Menezes Oliveira *et al.,* 2013).

Bulk density

A graduated cylinder must be used to measure the bulk volume that a particular powder occupies in order to calculate the bulk density of that powder. Bulk density is defined as the powder's apparent density in relation to the bulk volume. According to the results of prior investigations, the bulk density of the spray-dried powder decreases as the inlet temperature increases (Cai and Corke 2000).

Table 5 Bulk density of the encapsulated powder

Physiochemical property	Value (G/Ml)
Bulk density	0.50 g/ml ± 0.01

Values represent mean ± standard deviation

The bulk density of the given sample was 0.50 g/ml ± 0.01 which was reported in table 5. When inlet temperature is increased, bulk density decreases (Thumthanaruk *et al.*, 2021). This is in accordance with the findings of Pinho *et al.,* 2022 where the bulk density of spray-dried Bintangor powder with 10% to 20% maltodextrin added decreased to 0.45 to 0.48 g/ml respectively. This decrease resulted from quicker evaporation rates and products drying to a more porous or dispersed structure as the inlet temperature increased (Goula and Adamopoulos, 2005).

Encapsulation efficiency

One of the main objectives of encapsulation is to obtain microparticles with the best application properties. Because they have an impact on the characteristics of the microparticles and the effectiveness of encapsulation, factors such as feed flow rates, inlet air temperature, carrier material type, and formulation are crucial (EE). The types of carrier and core materials used in addition to the drying have a significant impact on the effectiveness of encapsulation during spray drying. (Pinho *et al.,* 2022).

Table 6 Encapsulation efficiency

Encapsulation efficiency before encapsulation	Encapsulation efficiency after encapsulation	P value
91.7% ± 0.1	90.3% ± 0.15	0.00**

Values represent mean ± standard deviation

**Significant at 1% level (p<0.01)

The encapsulation efficiency before and after encapsulation was reported as 91.7% ± 0.1 and 90.3% ± 0.15 as given in table 6. The slight loss in encapsulation efficiency was due to the spray drying process. In samples that have been spray dried, there might be a slight carotenoid loss. This could be because of the atomization step, in which the ingredients may stick to the hot drying chamber walls during processing. The samples had high EE, ranging from 90% to 100% for SD (Pinho*et al.,* 2022). In a study by Thumthanaruk*et al.,* 2021, the encapsulation efficiency of carotenoid powder by spray drying was reported as 89%. Spray drying being an effective method for encapsulation increased the encapsulation efficiency. But slight reduction in encapsulation efficiency of the powder occurred due to the effect of inlet temperature on carotenoid, as carotenoids are heat sensitive.

Evaluation of physiochemical properties of the fortified oil

The physiochemical properties of the fortified oil were analyzed such as bulk density, smoke point and peroxide value.The physical and chemical characteristics of edible fats and oils must be carefully considered since they can have an impact on the quality of oil-based foods(Yasushi Endo, 2018).

Bulk density of fortified oil

The dry weight of the solid/liquid divided by its volume is known as bulk density (BD) (Changmai *et al.,* 2021)

Table 7 Bulk density of the fortified oil

Physiochemical parameter	Value (g/ml)
Bulk density	0.85 g/ml ±0.03

Values represent mean ±standard deviation

The bulk density of the fortified oil was reported as 0.85 g/ml ±0.03 which was given in (Table 7). This is considerably lower than the values obtained by Gurumeenakshi *et al.,* 2019, where the bulk density of fortified gingelly and mustard oil (using high speed homogenizing process) were reported as 0.9240 g/ml and 0.9270 g/ml. The bulk density is influenced by the addition of encapsulated powder and also by the fortification process. As the encapsulated powder had lower bulk density, the fortified oil also had lower bulk density.

Smoke point of the fortified oil

Smoke point indicates the upper temperature limit at which oil can be utilized. Smoke points for the majority of vegetable cooking oils range from 165 to 260°C (Achitoff-Grey N., 2014). Any oil's smoke point refers to the temperature at which it starts to burn and emit smoke. The oil starts to degrade into glycerol and free fatty acids at this temperature. Acrolein, a substance found in smoke, is produced by further breakdown of the glycerol. The smoke is quite unpleasant to the eyes and throat because of the acrolein's presence. Moreover, the smoke point denotes the beginning of flavour and nutritional degradation (Wolke, R. L., 2007). For cooking at high temperatures, oils having a high smoke point are preferable. The experts' opinion is that a cooking oil's smoke point must be at least 170 °C and cannot fluctuate from the temperature of fresh fat by more than 50 °C in order for the fat to still be considered useable. Oil's smoke point rises as its free fatty acid content falls. Free fatty acids are formed when an oil is heated, and the amount of free fatty acids produced decreases as the heating duration increases (Achitoff-Grey N., 2014).

Table 8 Smoke point of the fortified oil

Physiochemical parameter	Value (°C)
Smoke point	185˚C ± 3.0

Values represent mean ±standard deviation

From (Table 8), the smoke point of the fortified oil was reported as 185˚C ± 3. This is slightly higher than the values obtained by Gurumeenakshi *et al.,* 2019, where the smoking point of the fortified oil was reported as 162˚C. Perera *et al.,* 2020reportedthe smoking point of the pure and flavoured coconut oil as 193 ˚C ± 3 and 157 ˚C ± 2.5. Pardeshi,

2020analyzed and reported smoking points of various cooking oils, and the smoking points ranged between 191-265 ˚C. The smoke point is slightly higher which represents good cooking quality of the fortified oil. However, the smoke point of fresh gingelly oil was higher than the fortified oil. Fortification process significantly reduced the smoke point.

Peroxide value of the fortified oil

The most popular technique for determining the oxidative stability of vegetable oils is the Peroxide value. Rancidity is related to the number of peroxides since it reflects the level of primary oxidation. The hydroperoxides formed during the oxidation of fat are indicated by the steadily rising peroxide value (Perera *et al.*, 2020). The most widely used indicator of oil oxidation is called Peroxide value. The peroxide value is determined using potentiometric and titration techniques. The oxidation-reduction process of hydroperoxides with potassium iodide underlies the two techniques (Yasushi Endo, 2018). Peroxide value determination has the benefit of measuring the product's primary lipid oxidation directly (Dermis *et al.*, 2012). The level of oxidation of lipids, fats, and oils can be determined with the help of peroxide. The peroxide value determines the substance's level of oxidation and measures all of the peroxides present (Kouba *et al.*, 2011). Rancidity in lipid-containing dietary products has been linked to it (Dermis *et al.*, 2012). Peroxide value represents how much peroxide oxygen there is in kg of oil. Its units of measurement are milli equivalents. Fresh oils typically have a peroxide value of less than 10 mEq/kg, while peroxide levels between 30 and 40 mEq/kg are typically linked to a rancid flavour (Quiles *et al.*, 2002).

Table 9 Peroxide value of the fortified oil

Physiochemical parameter	Value (Meq/Kg)
Peroxide value	4.72 mEq/kg ± 0.02

Values represent mean ±standard deviation

The peroxide value of the fortified oil was found to be 4.72 mEq/kg ± 0.02 which was given in table 9. This is slightly higher than the peroxide values of pure and flavoured coconut oil which was reported as 3.989 ± 0.006 and 3.626 ± 0.002 (Perera *et al.*, 2020). Dordevic *et al.*, 2020 reported the peroxide values of fortified sunflower oils as a range between 5.99 to 21.08mekv O2/kg. Sarjadi *et al.*, 2019reported the peroxide values of olive and palm cooking oils as 8.00 ± 2.0 and 6.00 ± 2.00. Peroxide value is influenced by the initial moisture content of the encapsulated powder. The resulted value was lower than most of the peroxide values and the value is within the limit, that is the value is below 10 mEq/kg. Peroxide value is also influenced by the further cooking and storage process.

Shelf-life analysis of the fortified oil

A product's shelf life is the amount of time it can be kept in storage without losing its suitability for use or consumption. The unique product's degradation mechanism determines how long a product will last (David Tanner, 2016) A food's shelf life can be described as the amount of time during which it is safe to eat and/or is of a quality that consumers will accept (Fu *et al.*, 2000). All foods, including raw materials, ingredients, and processed goods, should have a reasonable shelf life. It is described as the period of time during which the food product will continue to be safe, be certain to maintain desired sensory, chemical, physical, and microbiological properties, agree with any label disclosure of nutritional data, and be considered acceptable by the consumer (Earle and Earle, 2008).

Table 10 Shelf life study of fortified oil (carotenoid retention)

Days	Total carotenoid content (µg/G)
0^{th} day	42.7 µg/g
1^{st} day	40.1 µg/g
15^{th} day	32.4 µg/g
30^{th} day	21.1 µg/g

The shelf life analysis is done for carotenoid retention in the fortified oil which was reported in (Table 10). On the 0^{th} day after fortification, the carotenoid content in the fortified oil was found to be 42.7 µg/g which was considerably lower when compared with the carotenoid content of powder. On the 1^{st} day, the carotenoid content in the fortified oil decreased significantly and was reported as 40.1 µg/g. On the 15^{th} day, the carotenoid content in the oil reduced to 32.4 µg/g. On the 30^{th} day, the carotenoid content further reduced to 21.1 µg/g. On the 30^{th} day, the carotenoid content notably reduced, because of the longer storage period. Carotenoid degradation occurred during storage after 30 days of storing the fortified oil. It can be concluded that the carotenoid content in the fortified oil may reduce notably after 30 days of storage. Therefore, it can be consumed within 30 days of manufacturing.

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CONCLUSION

Carotenoids are sensitive antioxidants and thus encapsulation helps in maintaining its stability and preserved its antioxidant potential. Extraction of carotenoids by solvent extraction using acetone and hexane helped in preserving more carotenoids as combination of polar and non-polar solvents preserved more nutrients compared to other processes. Encapsulation using spray drying showed significant differences in the powder's physiochemical properties like moisture content, hygroscopicity, bulk density and also caused changes in the carotenoid content and encapsulation efficiency. The properties showed significant changes due to the inlet temperature and the maltodextrin concentration. Higher encapsulation efficiency is obtained due to the increased maltodextrin concentration. Carotenoid retention after encapsulation showed only slight reduction as encapsulation preserved carotenoids by reducing the loss of carotenoids. Fortification of the encapsulated carotenoid powder in cooking oil preserved carotenoids but slight reduction occurred in the carotenoid content due to homogenization process. The encapsulated carotenoid powder could further be used to fortify many food products such as flours in order to enhance nutritional value. Further research can be done by extracting and encapsulating other nutrients to prevent micronutrient deficiencies using this process. Different types of wall material can also be chosen and studied.

LITERATURE CITED

1. Adam, O. A. O., Abadi, R. S. M., & Ayoub, S. M. H. (2019). The Effect of Extraction method and Solvents on yield and Antioxidant Activity of Certain Sudanese Medicinal Plant Extracts. *The Journal of Phytopharmacology*, *8*(5).

2. A.O.A.C, Official Method 965.33 Peroxide value in oils and fats/Pearson's composition and analysis of food, 17th edition, pp. 641, 2000.
3. AOAC. (2000) Official Method of Analysis. 17th edition. Association of Official Analytical Chemists. Maryland.
4. Asha Monicka, A., Indu Rani, C., & Rajkumar, P. (2017). Storage Stability and Antioxidant Activity of Encapsulated Carotenoid from Pumpkin Pulp. *Madras Agricultural Journal*, *104*(10–12). https://doi.org/10.29321/maj.2017.000090
5. AthiraSurendran, K. Sudha, B. Murugan and Rita Narayanan (2022). Extraction of Carotenoids from Carrot and Pumpkin using different Solvent Proportions. *Biological Forum – An International Journal*, 14(2): 582-586
6. Cai, Y. Z., &Corke, H. (2000). Production and properties of spray-dried Amaranthus betacyanin pigments. *Journal of Food Science*, *65*(7). https://doi.org/10.1111/j.1365-2621.2000.tb10273.x
7. Cheng, S. H., Khoo, H. E., Kong, K. W., Prasad, K. N., &Galanakis, C. M. (2019). Extraction of carotenoids and applications. In *Carotenoids: Properties, Processing and Applications*. https://doi.org/10.1016/B978-0-12-817067-0.00008-7
8. de Andrade Lima, M., Kestekoglou, I., Charalampopoulos, D., &Chatzifragkou, A. (2019). Supercritical fluid extraction of carotenoids from vegetable waste matrices. *Molecules*, *24*(3). https://doi.org/10.3390/molecules24030466
9. Desobry, S. A., Netto, F. M., &Labuza, T. P. (1997). Comparison of spray-drying, drum-drying and freeze-drying for β-carotene encapsulation and preservation. *Journal of Food Science*, *62*(6). https://doi.org/10.1111/j.1365-2621.1997.tb12235.x
10. Do, H. T., Kha, T. C., & Huynh, T. P. P. (2019). Spray-drying microencapsulation of β-carotene by polysaccharide from yeast cell walls. *The Journal of Agriculture and Development* 18(6), 49-57
11. Dordevic, D., Jancikova, S., Lankovova, A., &Tremlova, B. (2020). Monitoring the Stability of Fortified Cold-Pressed Sunflower Oil under Different Storage Conditions. *Potravinarstvo Slovak Journal of Food Sciences*, *14*(1). https://doi.org/10.5219/1348
12. El-Massry, K., El-Ghorab, A., Farouk, A., Hamed, S., Elgebaly, H., Mosa, N., Alsohaimi, I., & Mahmoud, A. (2019). Microencapsulation of Date Seed Oil by Spray-drying for Stabilization of Olive Oil as a Functional Food. *Asian Journal of Scientific Research*, *12*(4). https://doi.org/10.3923/ajsr.2019.516.523
13. Endo Y. (2018). Analytical Methods to Evaluate the Quality of Edible Fats and Oils: The JOCS Standard Methods for Analysis of Fats, Oils and Related Materials (2013) and Advanced Methods. *Journal of oleo science*, 67(1), 1–10. https://doi.org/10.5650/jos.ess17130
14. Etzbach, L., Meinert, M., Faber, T., Klein, C., Schieber, A., & Weber, F. (2020). Effects of carrier agents on powder properties, stability of carotenoids, and encapsulation efficiency of goldenberry (Physalis peruviana L.) powder produced by co-current spray drying. *Current Research in Food Science*, *3*. https://doi.org/10.1016/j.crfs.2020.03.002
15. Ferrari, C. C., Germer, S. P. M., & de Aguirre, J. M. (2012). Effects of Spray-Drying Conditions on the Physicochemical Properties of Blackberry Powder. *Drying Technology*, *30*(2). https://doi.org/10.1080/07373937.2011.628429
16. Gharsallaoui, A., Roudaut, G., Chambin, O., Voilley, A., &Saurel, R. (2007). Applications of spray-drying in microencapsulation of food ingredients: An overview. In *Food Research International* (Vol. 40, Issue 9). https://doi.org/10.1016/j.foodres.2007.07.004
17. Ghosh, D., & Biswas, P. K. (2016). Enzyme-Aided Extraction of Carotenoids from Pumpkin Tissues. *Indian Chemical Engineer*, *58*(1). https://doi.org/10.1080/00194506.2015.1046697
18. González-Peña, M. A., Lozada-Ramírez, J. D., & Ortega-Regules, A. E. (2021). Antioxidant activities of spray-dried carotenoids using maltodextrin-Arabic gum as wall materials. *Bulletin of the National Research Centre*, *45*(1). https://doi.org/10.1186/s42269-021-00515-z
19. Goula, A. M., &Adamopoulos, K. G. (2005). Spray drying of tomato pulp in dehumidified air: II. The effect on powder properties. *Journal of Food Engineering*, *66*(1). https://doi.org/10.1016/j.jfoodeng.2004.02.031
20. Goula, A. M., &Adamopoulos, K. G. (2008). Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: I. Drying kinetics and product recovery. *Drying Technology*, *26*(6). https://doi.org/10.1080/07373930802046369
21. Goula, A. M., Adamopoulos, K. G., &Kazakis, N. A. (2004). Influence of spray drying conditions on tomato powder properties. *Drying Technology*, *22*(5). https://doi.org/10.1081/DRT-120038584
22. Gurumeenakshi, G., Varadharaju, N., Malathi, D., Subbulakshmi, B., & Rajeswari, R. (2019). Fortification of Carotene from Carrots in Cooking Oil. *International Journal of Current Microbiology and Applied Sciences*, *8*(08). https://doi.org/10.20546/ijcmas.2019.808.296
23. Hosen, M., Rafii, M. Y., Mazlan, N., Jusoh, M., Oladosu, Y., Chowdhury, M. F. N., Muhammad, I., & Khan, M. M. H. (2021). Review pumpkin (Cucurbita spp.): A crop to mitigate food and nutritional challenges. In *Horticulturae* (Vol. 7, Issue 10). https://doi.org/10.3390/horticulturae7100352
24. Krinsky, N. I., & Johnson, E. J. (2005). Carotenoid actions and their relation to health and disease. In *Molecular Aspects of Medicine* (Vol. 26, Issue 6). https://doi.org/10.1016/j.mam.2005.10.001
25. Kurozawa, L. E., Park, K. J., &Hubinger, M. D. (2009). Effect of carrier agents on the physicochemical properties of a spray dried chicken meat protein hydrolysate. *Journal of Food Engineering*, *94*(3–4). https://doi.org/10.1016/j.jfoodeng.2009.03.025
26. Luengo, E., Álvarez, I., &Raso, J. (2014). Improving Carotenoid Extraction from Tomato Waste by Pulsed Electric Fields. *Frontiers in Nutrition*, *1*. https://doi.org/10.3389/fnut.2014.00012
27. Luengo, E., Martínez, J. M., Bordetas, A., Álvarez, I., &Raso, J. (2015). Influence of the treatment medium temperature on lutein extraction assisted by pulsed electric fields from Chlorella vulgaris. *Innovative Food Science and Emerging Technologies*, *29*. https://doi.org/10.1016/j.ifset.2015.02.012
28. Menezes Oliveira, D., Clemente, E., Afonso, M. R. A., & da Costa, J. M. C. (2013). Hygroscopic behavior of lyophilized powder of grugru palm (Acrocomia aculeata). *American Journal of Analytical Chemistry*, *4*(October).
29. Mohanraj, R., &Sivasankar, S. (2014a). Sweet potato (Ipomoea batatas [L.] Lam) - A valuable medicinal food: A review. In *Journal of Medicinal Food* (Vol. 17, Issue 7). https://doi.org/10.1089/jmf.2013.2818

30. Mohanraj, R., &Sivasankar, S. (2014b). Sweet potato (Ipomoea batatas [L.] Lam) - A valuable medicinal food: A review. In *Journal of Medicinal Food* (Vol. 17, Issue 7). https://doi.org/10.1089/jmf.2013.2818
31. Nedovic, V., Kalusevic, A., Manojlovic, V., Levic, S., &Bugarski, B. (2011). An overview of encapsulation technologies for food applications. *Procedia Food Science*, *1*. https://doi.org/10.1016/j.profoo.2011.09.265
32. Olson, R., Gavin-Smith, B., Ferraboschi, C., & Kraemer, K. (2021). Food fortification: The advantages, disadvantages and lessons from sight and life programs. In *Nutrients* (Vol. 13, Issue 4). https://doi.org/10.3390/nu13041118
33. Perera, D. N., Hewavitharana, G. G., &Navaratne, S. B. (2020). Determination of Physicochemical and Functional Properties of Coconut Oil by Incorporating Bioactive Compounds in Selected Spices. *Journal of Lipids*, *2020*. https://doi.org/10.1155/2020/8853940
34. Pinho, L. S., de Lima, P. M., de Sá, S. H. G., Chen, D., Campanella, O. H., da Costa Rodrigues, C. E., &Favaro-Trindade, C. S. (2022). Encapsulation of Rich-Carotenoids Extract from Guaraná (Paulliniacupana) Byproduct by a Combination of Spray Drying and Spray Chilling. Foods (Basel, Switzerland), 11(17), 2557. https://doi.org/10.3390/foods11172557
35. Quiles, J. L., Huertas, J. R., Battino, M., Ramírez-Tortosa, M. C., Cassinello, M., Mataix, J., Lopez-Frias, M., &Mañas, M. (2002). The intake of fried virgin olive or sunflower oils differentially induces oxidative stress in rat liver microsomes. *British Journal of Nutrition*, *88*(1). https://doi.org/10.1079/bjn2002588
36. Saavedra–Leos, M. Z., Leyva-Porras, C., Alvarez-Salas, C., Longoria-Rodríguez, F., López-Pablos, A. L., González-García, R., & Pérez-Urizar, J. T. (2018). Obtaining orange juice–maltodextrin powders without structure collapse based on the glass transition temperature and degree of polymerization. *CyTA - Journal of Food*, *16*(1). https://doi.org/10.1080/19476337.2017.1337048
37. Saénz, C., Tapia, S., Chávez, J., & Robert, P. (2009). Microencapsulation by spray drying of bioactive compounds from cactus pear (Opuntia ficus-indica). *Food Chemistry*, *114*(2). https://doi.org/10.1016/j.foodchem.2008.09.095
38. Saini, R. K., &Keum, Y. S. (2017). Progress in Microbial Carotenoids Production. *Indian Journal of Microbiology*, *57*(1). https://doi.org/10.1007/s12088-016-0637-x
39. Santana, A. A., Kurozawa, L. E., de Oliveira, R. A., & Park, K. J. (2013). Influence of Process Conditions on the Physicochemical Properties of Pequi Powder Produced by Spray Drying. *Drying Technology*, *31*(7). https://doi.org/10.1080/07373937.2013.766619
40. Sarjadi, M. S., Ling, T. C., & Khan, M. S. (2019). Analysis and comparison of olive cooking oil and palm cooking oil properties as biodiesel feedstock. *Journal of Physics: Conference Series*, *1358*(1). https://doi.org/10.1088/1742-6596/1358/1/012007
41. Sarkar, B. K., Upadhyay, S., Gogoi, P., Das, A., Hazarika, M., Rahman, Z., & Datta, A. (2019). Development and quality evaluation of instant soup mix incorporated with spent hen meat shred. *Journal of Entomology and Zoology Studies*, *7*.
42. Shi, J., Yi, C., Ye, X., Xue, S., Jiang, Y., Ma, Y., & Liu, D. (2010). Effects of supercritical CO2 fluid parameters on chemical composition and yield of carotenoids extracted from pumpkin. *LWT*, *43*(1). https://doi.org/10.1016/j.lwt.2009.07.003
43. Siregar, T. M., & Margareta, M. (2019). Microencapsulation of Carotenoids from Red Melinjo (Gnetumgnemon L.) Peels Extract. *Journal of Physics: Conference Series*, *1351*(1). https://doi.org/10.1088/1742-6596/1351/1/012031
44. Thumthanaruk, B., Laohakunjit, N., & Chism, G. W. (2021). Characterization of spray-dried Gac aril extract and estimated shelf life of β-carotene and lycopene. *Peer Journal* 9. https://doi.org/10.7717/peerj.11134
45. Vera Zambrano, M., Dutta, B., Mercer, D. G., MacLean, H. L., & Touchie, M. F. (2019). Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review. In *Trends in Food Science and Technology* (Vol. 88). https://doi.org/10.1016/j.tifs.2019.04.006.