***Original Research Article***

**Effect of carrier agents and inlet temperature on physicochemical properties of encapsulated carrot coagulum powder**

**Abstract**

**Background:** The carrot (*Daucus carota*L.) is a popular root vegetable grown throughout the world*.*In the present study, an attempt was made to use the carrot outgrades, which are purely rejected for aesthetic reasons, not meeting the standards based on size and shape. Further enzymes (Pectinase and Cellulase) are used to extract the carrot coagulum from carrot outgrades. Carrier agents were mixed into carrot coagulum and spray dried at three different inlet air temperatures (160, 170, and 180 °C) to encapsulate enzyme-extracted carrot coagulum.

**Aim:** Carrots are nutritious and mainly rich in carotenoids. Often, very high losses are incurred during post-harvesting operations. A significant proportion of carrots are rejected due to bad aesthetics. Therefore, the objective of the study was to utilise such non-commercial carrot out-grades to recover carotenoids and produce encapsulated powder using spray drying.

**Methodology:** The process of spray drying of enzymatically extracted carrot coagulum was standardised by varying carrier agents (maltodextrin and gum arabica) concentration and at different inlet temperatures. Pectinase (Pectinex Ultra SPL from *Aspergillus sacchari* aqueous solution, ≥3,800 units/mL) and cellulose (Celluclast 1.5L from *Trichoderma reesei* aqueous solution, ≥700 units/g) were obtained from Novozymes, Bangalore. Trans-β-carotene was obtained from Sigma Chemical Company.All other chemicals used were of analytical grade. T

**Results:** All physicochemical properties were significantly affected by the carrier agents and temperature. Carotenoid content was highest (9.80%) at an inlet temperature of 170 °C with MD100. Overall moisture content was reduced, while other physical properties were enhanced when the temperature increased. Increasing the gum Arabica content showed a significant increase in moisture content and wettability time, as well as poorer physical properties. Results showed that the physicochemical and microstructural properties of encapsulated carrot coagulum powder (ECCP) were affected by inlet temperatures and carrier agents.

**Conclusion:** Among all the spray-dried powders, the powder dried at 170°C using maltodextrin at 15% alone had comparatively lower moisture content, good flowability, higher solubility, and less wetting time compared to other combination treatments and inlet temperatures, and thus fulfills the requirement of good quality spray-dried powders. Certainly, carrot out grades have a significant content of total carotenoids, which makes the utilisation of such material worthwhile for processing.

**Keywords**: *Enzyme extraction; Encapsulation; Maltodextrin; Gum Arabica; Spray drying*

1. **INTRODUCTION**

According to the United Nations Food and Agriculture Organisation, one-third of food produced in the world is lost or wasted (evaluated as 1.3 billion tons per year) (FAO, 2011) annually during post-harvest operations and post-harvest treatments. Among these foods, fruits, and vegetables are the major contributors due to their composition, commonly overproduced during the season and lack of proper utilisation during the season, and many of these have been rejected purely for aesthetic reasons and not meeting the standards set by the retail buyer. In developing countries, much of the food loss occurs during post-harvesting storage, grading, cleaning, processing, transportation, and packaging**.** Another reasonthese losses are predominantly seen within the supply chain and are influenced by technical, logistical, and managerial shortcomings (Olawale et al.,2025; Kumar & Choubey, 2021). In the overall production of Fruits and vegetables, 76% is consumed, only 4% goes for processing, and waste accounts for 20-22% (Indian Horticulture Database, 2013).

Fruit and vegetable residues are abundantly generated in large quantities during the normal season of cultivation. After harvesting and post-harvesting operations, economic and edible parts of the plants are considered as waste and are left on the plants or dumped on-field side due to defects or damage (abrasion, bruising, scrapes, and skin break) or not meeting the specifications making them unsellable or due to the price being so low that it is not profitable to sell those (Colbert & Stuart, 2015).

Carrots in primary production are generally rejected for many reasons. In a survey, it was found that 50% of the outgrades were at field and packing houses, considered highly edible, were rejected for being the wrong size big, too small, or suffered some form of damage during harvesting, and had no problems with nutritional value. The consumer generally prefers medium-sized carrots over the larger and smaller ones at supermarket stores (Navez et al., 2015). Misshapen, cracked, forked, and poorly developed roots are sorted out and rejected (Dhaliwal, 2017). Generally, these losses can be avoided (Bond, 2016). There are very few studies on the utilisation of such carrot waste to make use of its nutritional quality.

The carrot (Daucus carota L.) is a popular root vegetable grown throughout the world. Carrots probably originated in Asia around northwest India. Cultivation of carrots for medicinal purposes began 2000 to 3000 years ago (Sangeetha & Shanthakumar, 2016). These are inexpensive and highly nutritious. They are an important source of bioactive compounds like carotenoids, phenolics, flavonoids, vitamins, minerals, dietary fibres, and various other functional components. Carotenoids, polyphenols, & vitamins act as antioxidants which can neutralize the effect of free radicals. Carotenoids are important plant pigments that impart a distinctive yellow, orange, and red colour to various fruits and vegetables, apart from their importance in human health and disease (Doymaz & Pala, 2003). In India, this crop covers an area of 88000 hectares and with a production of 1446000 metric tonnes. Moreover, carrot is an important crop for world nutritional security, as it is one of the main dietary sources of provitamin A carotenoids (Kiełkowska & Kiszczak, 2023). Vitamin A is an essential nutrient required for vision in dim light, for growth, for differentiation and proliferation of cells, for reproduction, for immune system integrity to resist infections, and development of bone and teeth (Haskell, 2012). Carrots and the consumption of their value-added products are increasing steadily due to their antioxidant and nutritional properties.

Enzyme-assisted extraction methods are gaining more attention due to the demand for eco-friendly extraction methods and technologies (Choudhari & Ananthanarayan, 2007). It results in an enhanced end product quality by enabling the use of milder processing conditions, such as the use of water instead of organic chemicals and lower extraction temperature (Ramadan & Moersel, 2007). Cellulose and pectin form the major components of many fruits and vegetables, which hinder juice extraction; therefore, enzymes like cellulase and pectinase are often used to aid enzyme-assisted extraction. Pectinase and cellulase not only soften the plant tissue but also increase juice recovery and high-quality products (Sharma et al., 2017).

Spray drying is a dehydration technique used extensively in food-related industries for a wide range of products to produce powders and agglomerates (Sagar et al., 2010). Spray drying is a well-known technique, and through this process, many food and pharmaceutical ingredients have achieved a high encapsulation efficiency (Jayaprakash et al., 2023; Samborska et al., 2022). It is an effective drying process to extend the shelf life of the final product and is cost-effective, flexible, and produces products of good quality (Yousefi et al., 2011).

Encapsulation employing the spray drying technique is an efficient and most commonly used method for the preservation of natural colourants, flavours, and bioactive compounds by entrapping the ingredient in a coating with the help of carrier agents (Cai & Corke, 2000; Ersus & Yurdagel, 2007). It is defined as the entrapment of one substance (active agent) within another substance (Carrier agent). Carrier agents used for spray drying influence the process parameters and physicochemical properties. Carrier agents solve the problem of stickiness and hygroscopicity and prevent the degradation of bioactive components (Ferrari et al., 2012). Maltodextrins are commonly used in materials that are difficult to dry, such as fruit juices, flavourings, and sweeteners, and to reduce stickiness and agglomeration problems during storage, thereby improving product stability (Reineccius, 2004; Gabas et al., 2007). The addition of maltodextrin before spray drying has been reported to be effective in preserving compounds in guava juice (Chopda & Barrett, 2001). Gum Arabic has been used as a carrier material, mainly because of its good emulsifying capacity and low viscosity in aqueous solution, which aids the spray drying process. In addition, it provides good retention of volatile substances and confers effective protection against oxidation (Righetto & Netto, 2005; Daza, 2016).Different inlet air temperatures, types, and concentrations of carrier agents such as maltodextrins and gum Arabic, when added to the feed solution, influence the physicochemical properties and stability of the powder. The same core powder shows differences in yield, bulk density, chemical stability, water solubility, hygroscopicity, flow properties, wettability, etc., when coated with different carrier agents.

In the present study, an attempt was made to use the carrots outgrades which are purely rejected for aesthetic reasons, not meeting the standards based on size and shape. Further enzymes (Pectinase and Cellulase) are used to extract the carrot coagulum from carrot outgrades. Maltodextrin (MD100) alone and maltodextrin along with (GA) gum Arabic in two ratios (MD75: GA25, and MD50: GA50) were mixed into carrot coagulum and spray dried at three different inlet air temperatures (160, 170, and 180 °C) to encapsulate enzyme-extracted carrot coagulum. The objective of this work was to evaluate the effect of spray drying on encapsulated carrot coagulum powders using different carrier agents and inlet temperatures to get the desirable physicochemical and microstructural properties of encapsulated carrot powder.

**2. MATERIAL AND METHODS**

Carrots outgrades (market rejects) due to wrong size (too big, too small), damaged during harvesting, misshapen, and discoloured carrots, which were otherwise edible, were obtained from the local market in Yelhanka, Bangalore, India. Pectinase (Pectinex Ultra SPL from *Aspergillus saculeatus* aqueous solution, ≥3,800 units/mL) and cellulose (Celluclast 1.5L from *Trichoderma reesei* aqueous solution, ≥700 units/g) were obtained from Novozymes, Bangalore. The maltodextrin DE 20 and Gum Arabic (Gum Acacia) were obtained from Himedia Pvt Ltd., Mumbai, and were used as carrier agents. Trans-β-carotene used in the study was obtained from Sigma Chemical Company.All other chemicals used were of analytical grade. The experiments were performed immediately after procurement.

**2.1 Preparation of enzyme-extracted carrot coagulum**

Extraction of carrot coagulum from outgraded carrots was followed according to the methods (Wagner & Warthesen, 1995; Stoll et al., 2003; Darshan, 2015) with a little modification. Carrot outgrades were immediately processed after procurement. Carrot out-grades were cleaned thoroughly to remove dirt and insecticide residue. Carrots that were spoiled were discarded. Carrots were washed under running potable water. After this, they were surface-dried with a clean, dry cloth to blot out the water that adhered to the surface. They were then peeled and cut into small pieces (approx. 0.5 cm diameter). Carrots were blanched at 80 °C for 7 min in 2 parts (1:2) of boiling acidified water containing 0.2 % citric acid and cooled. Blanched carrots were further pulped by a domestic grinder (Philip), then a press cloth was used to extract the juice from the pulp. The extracted carrot juice was treated with enzymes pectinase (200 ppm) and cellulase (200 ppm) and kept in dark conditions at 40 °C for 4 hours for sedimentation. The enzymatic reaction was terminated at 90 °C for 1 min. The supernatant was removed, and then the enzymatically extracted carrot coagulum was collected. The carrot coagulum was analysed for total carotenoids, pH, and TSS. Erma hand refractometer was used in the range of 0 to 32 °Brix to measure the TSS of carrot and carrot coagulum.

**2.2 Encapsulation of carrot coagulum by spray drying**

The total soluble solids and pH content of the carrot coagulum were approximately 8.00±0.11 °Brix and 4.50±0.10, respectively. The TCC of carrot coagulum is 13.23±0.62 (mg/100g).

Initially, the enzyme extracted carrot coagulum as such was directly fed in the spray drier. But all the powder adhered to the wall of the drying chamber and recovery was extremely low. The quality of finished product was assumedly unsatisfactory as it appeared to be very sticky. This can be attributed to a high content of reducing sugars in carrots. In literature review (Fakir et al., 2015), it was seen that, to overcome this problem carrier agents such as maltodextrin and gum Arabic are commonly employed. Thus, these two carrier agents were used in this study. Encapsulation was prepared by mixing the carrot coagulum with 15 g of MD100, MD75: GA25, and MD50: GA50 and making the volume 100 ml. Before feeding the mixture to the spray drier, the mixture was stirred for approximately 20 min to homogenise the mixture and to reduce its viscosity. Then these mixtures were fed to the spray dryer. The mixtures were constantly and thoroughly stirred under magnetic stirring to ensure homogeneity during the drying process. Lab-scale spray dryer JSIL LSD-48 (Mumbai) with a 0.7 mm diameter nozzle and co-current flow was employed to prepare the spray-dried powders. Spray drying was carried out at a constant aspirator rate of 90%, a feed pump of 12%, and a pressure of 1.5-2.0 kg cm-2. Three inlet air temperatures were investigated, i.e., 160 °C, 170 °C, and 180 °C, and the outlet air temperature for each of the corresponding inlet air temperatures was 80, 86, and 92±5 °C. Initial trial runs were performed to select different inlet air temperatures and concentrations, and types of carrier agents. The dried powders were collected and packed in metalised polyester and stored in desiccators containing silica gel for further analysis.

**2.3 Physicochemical properties of encapsulated carrot coagulum powder**

The prepared carrot juice powder was analysed for its physicochemical properties. Additionally, microstructures of encapsulated powder were observed with scanning electron microscopy.

**Moisture content**

Moisture contents of the powders were dried at 105 °C. The samples were removed from the oven, cooled in a desiccator, and weighed. Drying was continued till constant weights were recorded. Samples were worked in triplicate, and the mean was recorded (AOAC, 2000).

Moisture content (%) =

**Total carotenoid content (mg/100g)**

Total carotenoids from carrots and carrot coagulum were analysed according to the following method (Ranganna, 1986). About a 2 g sample was mixed with 5 mL of acetone. The mixture was shaken on a vortex for 10 min. The filtrate was poured into a separating funnel, and 15 ml of petroleum ether was added and then washed repeatedly with distilled water to remove residual acetone. The lower aqueous phase was discarded. Filter paper (Whatman No. 1) covered with anhydrous sodium sulfate (10 g) was used to remove residual water. The extract volume was adjusted to 25 ml using petroleum ether containing 3% acetone, followed by absorbance estimation at 452 nm using a spectrophotometer.

**Tapped bulk density (g/ml)**

To determine the bulk density (g/mL), a standard graduated cylinder with a 10 mL volume was used. Initially, the empty measuring cylinder was weighed, then the powder was added and gently tapped 20-25 times at a vertical distance of 10 cm, and the volume of the weighed sample was recorded. The measurement was done in triplicate at ambient temperature(Goula et al., 2004)

Bulk density (g/mL) =

**Determination of loose bulk density**

The loose density of the powder was determined by pouring the powder sample into a 100 mL glass cylinder. The weight of the sample was measured when the sample volume reached 1 ml(Cai & Corke, 2000).

Loose density (g/mL) =

**Flowability (Carr index)**

The flowability of powder was expressed as the Carr index (CI) in terms of tapped density (ρT) and bulk density (ρB) (Jinapong, 2008).

CI=

**Cohesiveness (Hausner ratio)**

The cohesiveness of the powders was evaluated in terms of the Hausner ratio (HR). It is calculated from the bulk density (ρB) and tapped density (ρT) (Jinapong, 2008).

HR =

**Wettability**

The wettability was evaluated according to the method (Vissotto et al., 2010). The time required for 1 g of powder deposited on the liquid surface to become completely submerged in 100 ml of distilled water at 25 °C without agitation (Fuchs et al., 2006).

**Solubility**

The water solubility index (WSI) was determined using the following procedure (Jinapong, 2008). The dry powder 1 g was added to 30 ml of water at 30 °C in a 50 ml centrifuge tube, stirred in a vortex for a minute, and then the solution was incubated at 37 °C for 30 min and centrifuged for 10 min at 9500 rpm. The supernatant was carefully poured off into a petri dish and oven-dried at 105 °C until it reached a constant weight. The amount of solids in the dried supernatant as a percentage of the total dry solids in the original sample indicated the solubility. The solubility (%) was calculated based on the weight difference and was expressed as a percentage.

Water solubility index (%) =*×100*

**Hygroscopicity**

Hygroscopicity was determined according to the method suggested by Cai & Corke, 2000 with some modifications. One gram of powder was spread evenly on Petri dishes to allow for a high surface area between humid air and powder. Samples of powder in the dish were placed in a desiccator containing sodium chloride (NaCl) saturated solution at 25 °C and sealed. The samples were weighed after 1 week, and hygroscopicity was expressed as grams of adsorbed moisture per 100 g dry solids of powder (g/100 g).

**Scanning electron microscopy**

A scanning electron microscope (SEM) (Hitachi, Model: TM3030Plus, Tabletop Microscope, Japan) was used to study the morphological properties of the spray-dried powders. An acceleration potential of 15kV was used during the micrograph. The instrument was accessed at the SAIF laboratory of IIHR, Bangalore. Finally, samples were transferred to the microscope. Powder particles were attached to the aluminium stub using a two-sided adhesive copper tape and placed in a metal microscope slide; the samples were then coated with a very thin layer of gold under high vacuum conditions. The samples were systematically examined at 500×, 1000×, and 1500× magnifications. The microparticle size was analysed with SEM micrographs using ImageJ analysis software.

**Statistical analysis**

All analyses were performed in triplicate, and data were reported as mean ± standard deviation (SD). Data were subjected to analysis of variance (ANOVA) using software SPSS version 22 (IBM). Statistical difference was determined using Duncan’s multiple range test at p≤0.05. All the data were expressed as the mean and standard deviation.

**3. RESULTS AND DISCUSSION**

Initially, carrot outgrades were analysed with chemical properties. The chemical properties of carrot outgrades were presented in Table 1.

**Table 1: Chemical properties, carotenoid and total polyphenol content of carrot out-grades**

|  |  |
| --- | --- |
| **Nutrients** | **Values** |
| pH | 6.03±0.05 |
| Titratable acidity (g/100 ml) | 0.18±0.05 |
| Total soluble solids (°Brix) | 5.10±0.25 |
| Reducing sugars (%) | 1.120±0.09 |
| Non-reducing sugars (%) | 3.35 ±0.09 |
| Total sugars (%) | 4.47±0.16 |
| Total carotenoids (mg/100 g) | 12.35±0.45 |
| Total polyphenol content (mg GAE/100 g) | 1.17±0.32 |

\*Mean± standard deviation

**3.1 The moisture content of encapsulated carrot coagulum powder**

Moisture content is an important powder property, related to drying efficiency, powder flowability, stickiness, and storage stability (Premi & Sharma, 2017). Table 2 shows the percentage moisture content of carrot powder after spray drying. The moisture content of the powder varied from 4.10% to 5.75%. Inlet temperature and carrier agents significantly influenced the moisture content of the spray-dried powders. An increase in inlet temperature led to low moisture content due to the increasing rate of water evaporation during the spray-drying process (Kha et al., 2010). As a result, carrot coagulum powder spray-dried at 160 °C resulted in higher moisture content in all carrier agents, while the powder dried at 180 °C had the lowest value using maltodextrin or a combination of maltodextrin and gum Arabic as a carrier agent. A similar trend, that by increasing temperature, the moisture content of spray-dried black carrot, tomato powder, gac fruit aril powder, and watermelon powder significantly decreased, was revealed by previous publications.(Goula et al., 2000; Ersus & Yurdagel, 2007; Quek et al., 2007; Kha et al., 2010).The low moisture content of powder prevents powder deterioration.

Maltodextrin alone had a significantly higher loss of moisture content in comparison with other combinations used. Similar findings were observed in spray-dried gac oil powder (Nhu Quynh et al., 2016) and spray-dried drumstick oil powder (Premi & Sharma, 2017).Further in experiment (Oberoi, & Sogi, 2015), it was observed that as maltodextrin concentration increased from 3% to 10%, it resulted in a powder with low moisture content. Similar results were observed in the present study. The reason could be explained by the fact that the addition of maltodextrin increased feed solids. With an increase in the gum Arabic in the ratio from 25 to 50%, resulted in, an increase in moisture content as powder produced with gum Arabic tends to absorb more water from the surrounding environment (Tran & Nguyen, 2018).Treatments with gum Arabic had higher moisture content compared to maltodextrin while producing apple juice concentrate powder due to the higher water retention capacity of hydrocolloids compared to starch derivatives (Sarabandi et al.,2018). Similar results were obtained while producing lemongrass leaf extract powder and instant soluble sage powder, respectively (Tran & Nguyen, 2018; Nadeem et al., 2013).

**3.2 Total carotenoid content of encapsulated carrot coagulum powders**

The TCC of encapsulated carrot coagulum powder was estimated and is depicted in Table 2. Total carotenoid was found in the range of 5.67 to 9.80 mg/100g. The processing of carrot coagulum showed that total carotenoids were decreased in encapsulated carrot coagulum powders during the spray drying process due to heating at high temperatures and exposure to oxygen over the carrot outgrades and carrot coagulum. In one experiment (Goula, 2004), it was concluded that in the spray drying process, the product was converted to droplets, and hence the larger surface area was exposed to air, which enhanced pigment oxidation and further led to lycopene degradation and a concomitant loss of its health-related properties.

As the inlet temperature increased from 160 to 180 °C, the total carotenoid content was significantly reduced in all the combinations of carrier agents. The spray-dried watermelon powder decreases the lycopene and β-carotene content at higher inlet temperatures during the spray-drying process (Quek et al., 2007). In another publication, similar findings were reported (Sarabandi et al., 2019).

There existed a highly significant difference between the treatments. The highest total carotenoid content (9.80 mg/100g) was found in encapsulated powder spray-dried at 170 °C with maltodextrin alone as a carrier agent (MD100) whereas the lowest total carotenoids (5.67 mg/100g) was found in a powder dried with a combination of maltodextrin and gum Arabic (MD50:GA50) in the ratio of 50:50. In their study (Sarabandi et al., 2019) demonstrated that highest amount of total phenolic content (TPC) was in eggplant peel extract microencapsulated with MD at 170 °С. But the replacement of MD with GA reduced the TPC. This can be attributed to better entrapment of polyphenols in the MD structure than in GA. At a lower temperature of 160 °C, the deposition in the drying chamber is observed, hence, carotenoid retention was low. Therefore, encapsulation using maltodextrin at 170 °C was considered suitable for further experiments. Operating temperatures are very important for spray drying of heat-sensitive nutrients (Fang & Bhandari, 2011).

**Table 2: Effect of inlet temperature and carrier agent on moisture content and total carotenoid content of encapsulated carrot coagulum powder**

|  |  |  |  |
| --- | --- | --- | --- |
| **Carrier agents** | **Inlet Temperature (°C)** | **Moisture content (%)** | **Total carotenoid content (mg/100g)** |
| **MD100** | **160** | 4.52±0.11e | 8.57±0.10b |
|  | **170** | 4.16±0.11g | 9.80±0.20a |
|  | **180** | 4.10±0.01g | 7.79±0.36c |
| **MD75:GA25** | **160** | 5.08±0.01c | 7.38±0.05d |
|  | **170** | 4.74±0.04d | 6.66±0.46e |
|  | **180** | 4.28±0.04f | 6.35±0.05e |
| **MD50:GA50** | **160** | 5.75±0.05a | 6.53±0.05e |
|  | **170** | 5.36±0.03b | 5.62±0.05f |
|  | **180** | 5.26±0.04b | 5.67±0.10f |
| **Mean ±SD** |  | 4.81±0.56 | 7.15±1.34 |
| **F value** |  | \* | \* |
| **SEm±** |  | 0.180 | 0.446 |
| **CD at 5%** |  | 0.112 | 0.370 |

\*Significant at 5%,

\* Mean± standard deviation of three replicates

\*Values with different superscripts differ significantly

# MD100- 15% maltodextrin spray dried at 160, 170 and, 180 °C

MD75:GA25- 11.25 % maltodextrin and 3.75% gum Arabic (3:1) spray dried at 160, 170 and 180 °C

MD50:GA50- 7.50 % maltodextrin and 7.25% gum Arabic (1:1) spray dried at 160, 170 and 180 °C

**3.3 Physical properties of encapsulated carrot coagulum powder**

The effect of the carriers and inlet temperature used to produce the carrot coagulum powder on physical properties is illustrated in Table 2. Tapped and loose bulk density ranged between 0.40 to 0.55 and 0.32 to 0.45 g/cm3, respectively, and were significantly affected by the type of carrier agents and inlet temperature. As the temperature increased from 160 °C to 180 °C, the bulk density increased. With an increase in the inlet air temperature, there will be a formation of a dried layer on the droplet surface and which causes the skinning over or casehardening on the droplets, consequently, the droplet expansion at higher temperatures. (Chegini & Ghobadian, 2005; Leon-Martinez et al., 2010). Hence, the bulk density of spray-dried powder increases. The high values of bulk density were seen in the case of maltodextrin due to a more spherical and porous form of microcapsules, which gives rise to a higher surface area, resulting in greater bulk densities(Kulthe et al., 2016).Similar results were found (Goula et al., 2004; Abadio et al., 2004) while spray drying tomato juice and pineapple juice using maltodextrin because of an increase in concentration and particle size of the powder. A further higher bulk density indicates that a large quantity of powder can be stored in smaller containers. It was observed that as the concentration of gum Arabic increased, there was a decrease in bulk density, which may be due to its higher viscosity and structure (Premi & Sharma, 2017). A similar result was reported (Yousefi, 2011) that the lowest bulk densities were observed in anthocyanin spray-dried with Gum Arabic.

**Table 3: Effect of inlet temperature and carrier agent on physical and functional properties of encapsulated carrot coagulum powder**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Carrier agents and ratio** | **Temp (°C)** | **Tapped bulk density (g/cm3)** | **Loose bulk density**  **(g/cm3)** | **Flowability /Carr Index** | **Cohesiveness/Hausner Ratio** | **Water solubility index (WSI)** | **Wettability (seconds)** | **Hygroscopicity (%)** |
| **MD100** | 160 | 0.49±0.00b | 0.40±0.00b | 17.74 | 1.21 | 93.68±0.02c | 312±4.00g | 12.70g±0.01 |
|  | 170 | 0.53±0.00a | 0.44±0.00a | 16.65 | 1.19 | 94.29±0.01a | 237±3.60h | 14.70e±0.26 |
|  | 180 | 0.55±0.02a | 0.45±0.00a | 17.25 | 1.20 | 94.17±0.02b | 229±5.29i | 15.28d±0.35 |
| **MD75:GA25** | 160 | 0.44±0.00d | 0.36±0.00d | 18.55 | 1.22 | 92.99±0.01f | 394±5.00d | 13.04f±0.12 |
|  | 170 | 0.46±0.01cd | 0.37±0.00cd | 19.81 | 1.24 | 93.56±0.05d | 378±4.00e | 15.19d±0.05 |
|  | 180 | 0.48±0.00bc | 0.38±0.01c | 19.45 | 1.24 | 93.15±0.04e | 353±3.00f | 16.40c±0.06 |
| **MD50:GA50** | 160 | 0.40±0.00e | 0.32±0.01e | 20.66 | 1.26 | 92.70±0.05i | 630±4.58a | 14.59e±0.15 |
|  | 170 | 0.41±0.01e | 0.33±0.00e | 20.41 | 1.25 | 92.90±0.01g | 589±3.60b | 17.33b±0.10 |
|  | 180 | 0.42±0.02e | 0.33±0.01e | 20.56 | 1.25 | 92.79±0.02h | 537±3.60c | 18.42a±0.06 |
| **Mean ± SD** |  | 0.46±0.05 | 0.38±0.04 | 19.01 | 1.23 | 93.36±0.56 | 406.5±141.4 | 15.29±1.79 |
| **F value** |  | \* | \* | - | - | \* | \* | \* |
| **SEm±** |  | 0.01 | 0.01 | - | - | 0.18 | 47.1 | 0.59 |
| **CD at 5%** |  | 0.02 | 0.02 | - | - | 0.05 | 7.09 | 0.29 |

\*Significant at 5%

\*Mean± standard deviation

\*Values with different superscripts differ significantly

# MD100- 15% maltodextrin spray dried at 160, 170 and 180 °C

MD75:GA25- 11.25 %maltodextrin and 3.75% gum Arabic (3:1) spray dried at 160, 170 and 180 °C

MD50:GA50- 7.50 % maltodextrin and 7.25% gum Arabic (1:1) spray dried at 160, 170 and 180 °C

The Carr index and Hausner's ratio of spray-dried carrot coagulum powder ranged between 16.65 and 20.66 % and 1.19 and 1.26, respectively (Table 3). Both indicate the flow characteristics of spray-dried powders. Carr index and Hausner's ratio of powder spray dried with maltodextrin alone at 170 °C were 16.65 % and 1.19, which showed good flow characteristics. Similar results were observed in spray-dried watermelon powder32 and acerola powder with maltodextrin (Righetto & Netto, 2005). In the present study, a combination of maltodextrin and gum Arabic in the ratio 75:25 and 50:50 had fair flow properties at different inlet temperatures.

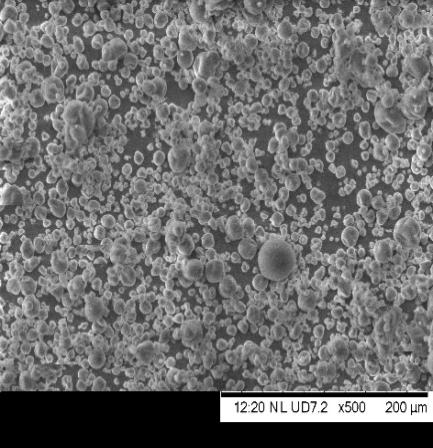
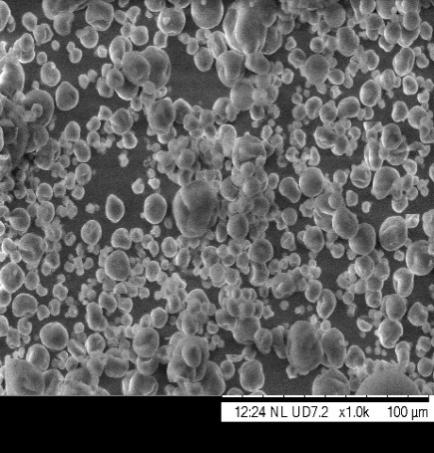
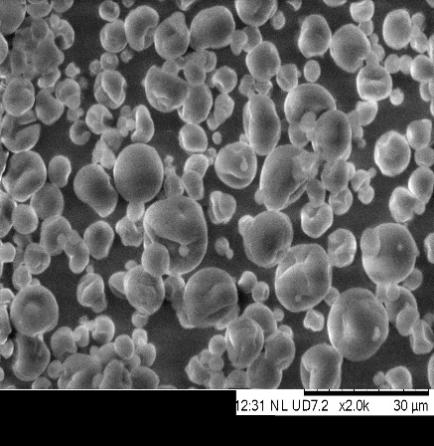
The water solubility index for all treatments was more than 90%, which indicates, the encapsulation process improves solubility (Table 2). Solubility of powders is affected by inlet temperature and carrier agents. The solubility of powder ranged from 92.70 to 94.29%. As the inlet temperature increased from 160 to 180 °C, the solubility also increased. Increasing the inlet temperature produces a powder with a larger particle size. Larger particles are heavier and thus may be easier to sink and get dissolved in water readily; whereas the smaller particles are lighter, tending to float on the water's surface, which causes uneven wetting, therefore, lowers the solubility of the powder (Tonon, et al., 2010). Higher solubility was achieved in MD100% followed by MD75: GA25 and MD50: GA50. Among all the treatments, the spray-dried powder obtained at 170 °C using maltodextrin showed higher solubility (94.29%). The mixture of both carrier agents in different proportions caused a decrease in the solubility because gum Arabic reduced the water solubility and requires high temperatures to achieve better solubility. The same was reported (Loksuwan, 2007; De Marco et al., 2013; Cano-Chauca et al., 2005) to encapsulate β-carotene, bixin, and mango powder, respectively.

Similar to the solubility index wettability of spray-dried carrot coagulum powder was also influenced by carrier agents and different inlet temperatures. In this study time required to wet the powder ranged from 229 to 630 seconds. The powder produced using maltodextrin had the least wettability time (229 secs) at 180 °C; further, wettability time reduces with an increase in inlet temperature (160 to 180 °C). Reduction in wettability time may be due to an increase in hydrophilic groups, and also due to the lower moisture content of powders produced at a higher temperature. In another study,(Sarabandi et al., 2018) apple juice concentrate powders produced with maltodextrin showed the least wettability time and increased when maltodextrin was combined with WPC because of the formation of a complex structure and lower solubility. A similar observation was reported by **(**Cynthia et al., 2015) in their study, where maltodextrin showed the lowest wettability values in spray-dried tamarind powder. In the present study, all the combinations that were tried (MD50: GA50), dried at 160 ºC, showed high wettability time.

The Hygroscopicity of the powderranged from 12.70 to 18.42 %. The hygroscopicity values were close to those of most spray-dried powders. The hygroscopicity of encapsulated carrot coagulum powder was significantly influenced by carrier agents and different inlet temperatures. The highest value (18.42 %) was in the sample MD50:GA50 spray-dried at 180 ºC, and the lowest hygroscopicity value (12.70 %) was found in MD100 spray-dried at 160 ºC. The powder with the lowest hygroscopicity was obtained at low inlet air temperature. Microencapsulated powders loaded with eggplant peel extract using MD and GA presented hygroscopicity values in the range of 14.91 to 20.72%, which are similar to those in the present study. According to (Tonon et al., 2010)hygroscopicity values, inversely increased with moisture content, such that lower powder moisture content indicated higher hygroscopicity. It also agrees with the spray drying of tomato pulp (Goula & Adamopoulos, 2005). and the encapsulation of anthocyanin pigment of banana bract (Begum & Deka, 2017). The higher the inlet temperature, the lower the moisture content of the powder; this results in higher hygroscopicity. Higher hygroscopicity with higher inlet temperatures was observed in blackberry fruit powder production (Ferrari et al., 2013).

**3.4 Morphological properties**

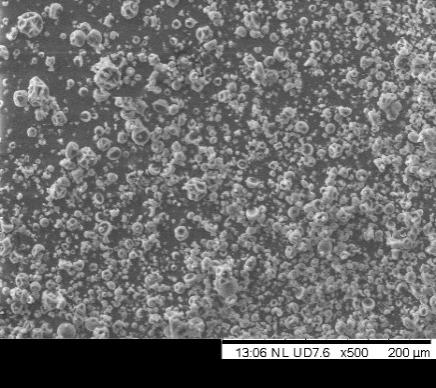
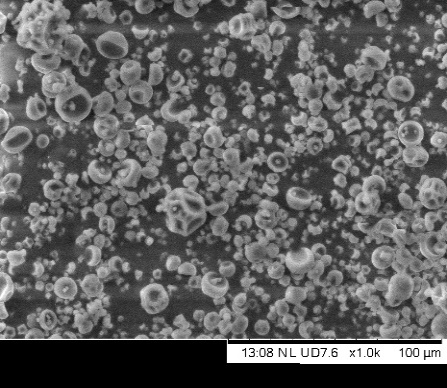
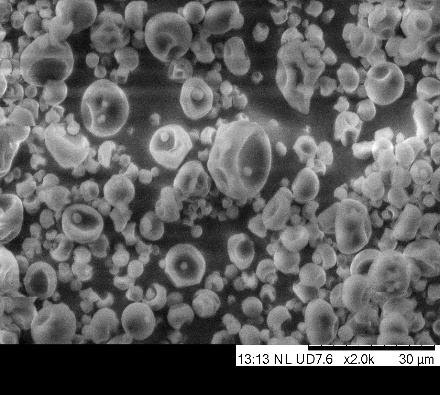
Three encapsulated powders obtained at an inlet temperature of 170 °C using different proportions of carrier agents, such as MD100, MD75:GA25; MD50:GA50, were selected for photomicrographs to study the morphological properties. Fig. 1(a-c, d-f, g-i) presents the SEM photographs of microcapsules for the maltodextrin and a combination of maltodextrin and gum Arabic encapsulated powders containing carotenoids. Microparticles were poly-dispersed in size, regardless of the carrier agents. The microcapsules from encapsulated carrot coagulum using 15 % of maltodextrin (MD100) were more smooth, heterogeneous, larger in size, and more well-distributed (Fig. a-c) and showed fewer wrinkles and dents on their surfaces than a combination of carrier agents (MD75:GA25 and MD50:GA50), which matches the observation mentioned by Mahdavi et al., 2016and Murali et al., 2014in the SEM analysis of microencapsulated barberry and black carrot anthocyanins respectively. According to (Kalusevic et al., 2017)the smoother surface of MD-based microparticles compared to other carriers could be attributed to the difference in sugar composition, which can act as a plasticiser, preventing surface shrinkage during spray drying. A combination of microcapsules MD75:GA25 and MD50:GA50 (Fig. d–f and g-i) had dents on the surface, showing irregular structures with shrinkage on the particle surface, and relatively deep dents were observed could be due to the gum characteristics (Kanakdande et al., 2007) The formation of dents on the surface of spray-dried particles was attributed to the shrinkage of the particles during the drying process (Rosenberg et al., 1990). Cracks or holes were not observed on the surface of any of the samples, and powder particles showed a continuous wall, which indicates a resistant external physical structure regardless of carrier agents.

**B**

**C**

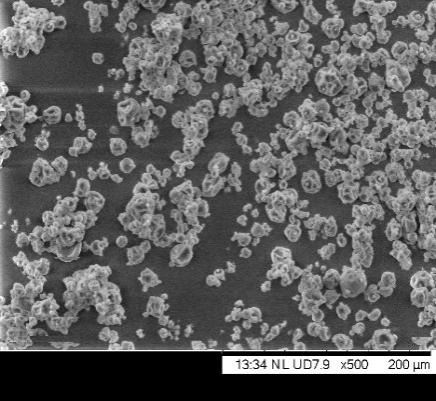
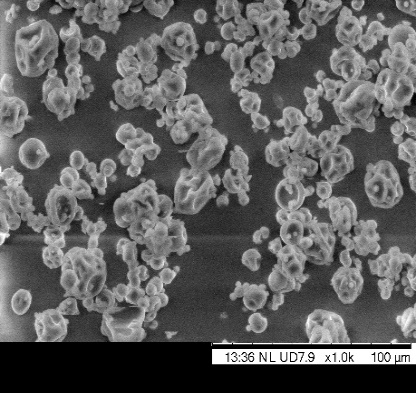
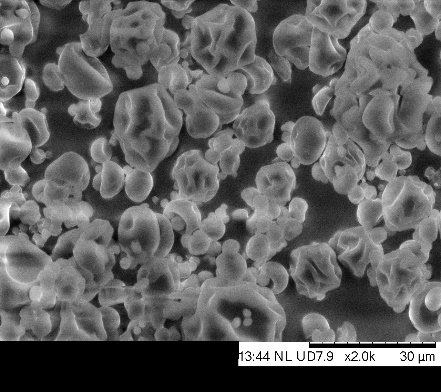
**A**

**E**

**F**

**D**

**I**

**H**

**G**

**Fig. 1**: **Morphology of microcapsules with magnification at A: 500x, B: 1000x and, 2000x and accelerating voltage 15 kV. Micrographs of microcapsules of encapsulated carrot coagulum containing carrier agents MD100 (A-C), MD75:GA25 (D-F), MD: GA50:50 (G-I)**

**CONCLUSION**

This study explored the use of encapsulation of carrot coagulum obtained from carrot waste with different carrier materials. The effect of inlet temperature and carrier agents alone or in combination with the physicochemical properties of carrot coagulum was investigated. Maltodextrin alone was an effective drying aid for spray-drying carrot coagulum. The addition of maltodextrin reduced the stickiness of the products and altered the physical properties of the spray-dried powders. The combination of gum Arabic and maltodextrin used in spray-drying carrot powder resulted in fairly good physical properties and higher moisture content compared to maltodextrin alone. However, maltodextrin alone at 15% concentration (MD100), spray-dried at an inlet temperature of 170 °C, resulted in powders with high content of encapsulated total carotenoids, good flow properties, and higher solubility, reasonably low moisture content, and higher bulk densities. The microstructure of carrot powder encapsulated with maltodextrin showed a smoother structure and fewer dents compared to the combination of carrier agents. Therefore, the spray drying of carrot coagulum at a constant inlet temperature of 170 °C and maltodextrin 15% as a carrier agent resulted in a powder with good physical properties. Certainly, carrot out grades have a significant content of total carotenoids, which makes utilisation of such material worthwhile for processing. Obtained encapsulated powder has potential applications for bakery or extruded cereal products, snacks, ice cream, yoghurt, instant beverages, etc.

**CONFLICT OF INTEREST**

There are no conflicts of interest for the publication of this article.

Consent to Participate: All authors agree to participate in the current work.

Consent for Publication: The authors agree to publish the findings of the current research.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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