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Enhancing Stability of Betalains Extracted by Ultrasonic-assisted extraction from Beta Vulgaris L. Pomace and its characterization

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Research Article

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Abstract

Beetroot pomace constitutes a prolific reservoir of betalains, offering promising prospects for their application as natural food colorants. The study focused on extracting betalains from beetroot pomace, followed by freeze-drying and encapsulation using various carrier agents. The stability of betalains was investigated in conjunction with different encapsulating agents, such as maltodextrin (MD), in combination with guar gum (GG), acacia gum (AG), and tragacanth gum (TG). Each encapsulated formulation underwent thorough analysis of functional and physico-chemical characteristics, including total betalains, antioxidant activity, phenolic content, color attributes, zeta potential, particle size distribution, X-ray diffraction (XRD), FTIR spectroscopy, morphology, and microscopy. The study revealed higher encapsulation efficiency of betalains when encapsulated with various gum combinations alongside maltodextrin. Encapsulated betalains demonstrated favorable coloring properties across different gum samples. Furthermore, betalains encapsulated with maltodextrin and guar gum exhibited greater bioaccessibility of bioactive compounds compared to formulations with maltodextrin, acacia gum, tragacanth gum. These findings suggest the potential of exploring natural waste materials as viable methods to improve the synthesis of encapsulated pigments. The potential utilization and stabilization of these pigments hold significant promise for the food industry, broadening their range of applications.

Introduction

While the food industry faces a substantial challenge with the waste generated from processing fruits and vegetables, ongoing efforts are underway to minimize waste generation and develop sustainable solutions (Sharma et al., 2021a). Byproducts from fruits and vegetables waste can be classified into different categories, including pomace, peels, seeds, and more, each offering potential applications.Managing fruits and vegetables waste isn't just economically viable; it's also environmentally conscientious (Reguengo et al., 2022). The food industry is increasingly adopting innovative methods to utilize food leftovers, promoting a more circular and sustainable approach (Comunian et al., 2021). Beetroot pomace (BRP) is a byproduct of processing beetroot, a colorful, nutrient-dense root vegetable with an earthy flavor and deep red color. BRP contains fiber, antioxidants, vitamins, and minerals that contribute to its potential health-beneficial properties (Sharma et al., 2021b). Various industries have devised inventive approaches to incorporate BRP into their products.

It is utilized in the food industry as a source of natural color and enhances a variety of items, including baked goods, sauces, soups, and juices. Because of its possible health benefits, it’s also employed for producing functional foods and dietary supplements (Chhikara et al., 2019). The enhancement of BRP extract with betalains offers a nutritious alternative to synthetic food dyes. These pigments are rich in bioactive ingredients and not just give an appealing shade of red;however, they could also yield beneficial impacts on health by having anti-proliferative and antioxidant qualities (Fu et al., 2020).

Recognizing their susceptibility to various environmental influences, betalains might lose stabilityunder certain conditions like high temperatures, an alkaline pH, enzyme activity, light, oxygen, and metals. Researchers and food technologists may investigate several approaches, such as the production of protective coatings, encapsulation methods, and better storage conditions, to solve these stability issues (Carreón-Hidalgo et al., 2022).To achieve the intended encapsulation efficiency, stability, and controlled release of bioactive compounds, an appropriate encapsulating material must be used (Pateiro et al., 2021).

Hydrocolloids, including maltodextrin, are widely utilized in the food industry due to their numerous beneficial properties.Maltodextrin is a starch-derived carbohydrate that has demonstrated efficacy and affordability in a range of applications, including thickening, stabilizing, and emulsifying (Rezvankhah et al., 2020).To increase the efficiency of encapsulation and the retention of bioactive substances, a range of carrier materials, such as gums, polysaccharides, and proteins, are frequently used in encapsulation processes. These materials are chosen based on the specific bioactive component to be encapsulated, the desired release characteristics, and their suitability for the intended use (Zabot et al., 2022). Encapsulation offers numerous advantages that significantly improve the application, stability, and management of core particles, particularly in contexts involving delicate substances such as natural colorants (Nabi et al., 2023). In essence, encapsulation emerges as a versatile methodology capable of adaptation to meet specific requirements across diverse applications within various industries (Taheri et al., 2019).

Various methods for encapsulating betalains, such as freeze drying, emulsions, spray-drying and ionic gelation, are described in the literature.The spray-drying method is used sparingly because its high temperature and intense heat treatment tend to degrade pigments, particularly betalains(Calva-Estrada et al., 2022).For the preservation of delicate compounds, such as betalains and other bioactive components, lower temperature encapsulation techniques, such freeze-drying (also called lyophilization), are useful.The meticulous process of freeze-drying involves eliminating water from a product under conditions of low temperature and reduced pressure(Rezaei et al., 2019).Freeze-drying, as a microencapsulation technique, offers promising potential to bolster the stability of betalains and other delicate bioactive compounds. Due to their recognized sensitivity to several environmental variables, betalains may degrade and lose color. By providing a barrier of protection around these molecules, microencapsulation increases their stability and shields them from adverse environments (Ye et al., 2018). The objective of this study was to extract betalains from beetroot pomace and assess their stability and functional properties when encapsulated with various gums and maltodextrin. The research aimed to evaluate the potential of using natural waste materials for producing stable, bioaccessible natural food colorants.The results of this investigation are essential for identifying agentsthat can enhance stability, thereby offering substantial advantages to the food, pharmaceutical, and cosmetic industries. This research holds promise in improving product quality and consumer satisfaction by preserving the vibrant color and resilience of betalains and other bioactive compounds.

Materials and Methods

Materials

Beetroot (Beta vulgaris L.) was sourced from a local market in Chandigarh. Juice was extracted using a juicer, leaving behind beetroot pomace. The pomace was promptly transported to the laboratory under controlled conditions, where it was freeze-dried using a SCANVAC Coolsafe 55 – 4 lyophilizer and stored in a deep freezer for future use.

BetalainsExtraction Procedure

Ultrasonic-assisted extraction (UAE) was conducted using an ultrasonic device (MODEL-Q500, Qsonica, LLC, 53 Church Hill Rd., Newtown, CT, USA) operating at a constant power of 500 watts, a frequency of 20 kHz, and a pulse cycle of 5 seconds on and off. Beetroot pomace (BRP) powder was precisely weighed and mixed with distilled water at a ratio of 1:40 to create a slurry. The slurry was then subjected to ultrasonic treatment at a 40% amplitude for 30 minutes. Following the ultrasonic process, the mixture was filtered using Whatman filter paper No. 1. The resulting supernatant was collected and stored in amber-colored bottles at a temperature of 4 ± 2°C. The supernatant was subsequently used for further analysis, with all experiments performed in triplicate to ensure accuracy (Kaur and Ghoshal, 2024).

Preparation and Encapsulation of Betalains

The encapsulation process utilized a 5% (1:20, w/v) of the maltodextrin DE (Dextrose equivalent), GG 2% (1:50, w/v), GA (1:50, w/v), and GT (1:50, w/v) carriers at blending ratios, after that the betalains extraction of maltodextrin was mixedGG, GA, GT in 1:1 v/v, respectively. The encapsulation of maltodextrin was taken as control.Therefore, the concentration ofencapsulating agentMD was 12.5 mg/mland MG, MA, and MT in the final encapsulated material mixture was 5 mg/mL.Then ultrasound homogenizer (Qsonica, Newtown, USA) sonicated the mixture for five min at an appropriate ultrasonic power of 500 W. The mixes that were encapsulated were frozen at -40°C (Coldlab, CL model 120 – 40, Brazil) and subjected to lyophilization at -59°C (Scanvac, Edward Street, Britain). The end product was in the form of dry powder. Before their further use and examination, the encapsulated pigment powders were kept in 50 mL amber-colored glass airtight containers that were screw-capped(Kaur and Ghoshal, 2025).

Evaluation of Physicochemical Properties of Encapsulated Betalains

Moisture Content

The moisture percentage was determined by utilizing a hot air oven. A 2.0g portion of the sample was placed in an oven and heated at 130°C for 3h after being weighed. The petri plates were taken out after 3h, covered, transferred to desiccators, and allowed to cool down.Subsequent to cooling, the samples are reweighed.The moisture content is then determined through following equation.

Moisture content (%) = $\frac{weight\ of\ fresh\ sample - weight\ of\ dried\ sample}{weight\ of\ fresh\ sample} \times 100$

pH of Encapsulated Betalains

Using a DeLUXE pH METER, an electrical digital pH meter, the pH of the encapsulated betalains solution was measured directly.

Acidity

The acidity of the samples was assessed using the titration method. A 10 mL sample was diluted with distilled water to a final volume of 100 mL. Then, a 10 mL aliquot was titrated with 0.1 N NaOH, using phenolphthalein as an indicator, until a light pink endpoint was reached (Zhang et al., 2021). The acidity level was calculated.

Total Soluble Soilds (TSS)

A drop of encapsulated betalains solution was placed on the prism of hand refractometer (ERMA make) and TSS were recorded.

Encapsulation Efficiency (EE%) andYield (%) of Encapsulated Betalains

The method outlined by Zhang et al. (2021) was slightly modified to determine the betalains encapsulation yield and efficiency. In this procedure, 0.2g of betalains powder was mixed with 10 mL of distilled water and stirred for 10 minutes at 250 rpm using a magnetic stirrer. The resulting mixture was then centrifuged for 10 minutes at 4000 rpm using a Hitachi centrifuge.Encapsulation yield and encapsulation efficiency of betalainswere calculated from Equations (1) and (2) respectively.

Equation (1)

$$\text{Encapsulation Efficiency } (\%) = \frac{\text{C0} - \text{C1}}{\text{C0}} \text{x100}$$

Equation (2)

$$\text{Encapsulation yield } (\%) = \frac{\text{mass of total betalains particles in grams}}{\text{mass of wall material used in grams}} \text{ x100}$$

C_0 represents the theoretical concentration of 0.2g of encapsulated betalains powder (EBP) (mg/g), while C_1 denotes the betalains content in the supernatant (mg/g).

Determination of Total Phytochemicals from Encapsulated Betalains

A 0.2 g sample of encapsulated betalains powder (EBP) was dissolved in 10 mL of distilled water, selected for its higher solubility, and stirred for 20 minutes at 250 rpm using a magnetic stirrer. The mixture was then centrifuged (Hitachi, Tokyo) at 4000 rpm for 10 minutes (Kaur and Ghoshal, 2024). The resulting supernatant was subsequently analyzed to determine the betalains content, total phenolic compounds, and antioxidant activity.

The total betalain content (mg/g) was determined using the following equation, which combines the concentrations of betacyanin and betaxanthin, measured spectrophotometrically at 535 nm and 480 nm, respectively:

$$\text{Betalains } (\text{mg of BX or BC/g}) = \frac{\text{A} \times \text{ DF} \times \text{ V} \times \text{ MW}}{\text{E} \times \text{ L} \times \text{ M}}$$

The molar extinction coefficient (E) is given in $Lmol^{-1}$ cm^{-1}, with betacyanins and betaxanthins having values of 60,000 and 48,000, respectively. A represents the absorbance at 538 nm for betacyanins (BCs) and at 480 nm for betaxanthins (BXs). DF denotes the dilution factor, and the molecular weights (MW) are 550 g/mol for betacyanin and 308 g/mol for betaxanthin. V refers to the extract volume, L is the path length of the quartz cuvette in centimeters, and M is the mass of dry material used for extraction.

The total phenolic content (TPC) of the encapsulated betalains was determined using the Folin-Ciocalteu assay. A 1 mL sample was mixed with 1 mL of Folin-Ciocalteu reagent and 1 mL of 10% (w/v) sodium carbonate (Na2CO3) solution. After a 1-hour incubation, the absorbance was measured at 760 nm, and the results were expressed as mg gallic acid equivalent (GAE) per gram of dry weight (dw) (Kaur et al., 2022).

Assessment of Antioxidant Properties of Encapsulated Betalains

A 0.2-gram sample of encapsulated powder was dissolved in 10 ml of distilled water, stirred for 20 minutes at 250 rpm, and then centrifuged for 10 minutes at 4000 rpm. The resulting supernatant was then used to assess antioxidant activities through various methods.Different concentrations of the sample were combined with 3 mL of DPPH reagent dissolved in methanol, and the final volume was adjusted to 10 mL using distilled water. The mixture was then incubated in the dark at room temperature for 30 minutes. After incubation, the absorbance was measured at 517 nm, and the IC_{50} value was determined based on the percentage inhibition of DPPH radicals. The inhibition percentage was calculated using the following formula:

$$\text{Inhibition } (\%) = \frac{\text{A control} - \text{ A test}}{\text{A control}} \text{x } 100$$

A control = absorbance of control

A test = absorbance of test

As stated by Ravichandran et al. (2014), the DPPH free radical scavenging method was performed. A stock solution was prepared by dissolving 0.011 g of DPPH in 25 mL of methanol, which was then diluted to achieve an absorbance range of 0.80 to 0.05 at 515 nm. For the reaction, 3.8 mL of DPPH solution was mixed with 0.20 mL of ethanolic beetroot extract. After incubating the mixture at room temperature for 30 minutes, the samples were analyzed using a spectrophotometer set at 515 nm.

Color Analysis

The color analysis of the beetroot pomace extract was performed using a Hunter colorimeter (Hunter Lab Color Flex model, Hunter Associates Inc., USA) with a 45°/0° geometry and standard illuminant C. In this analysis, L* represents lightness (with 0 indicating black), a* indicates the green to red spectrum (− for green, + for red), and b* indicates the blue to yellow spectrum (− for blue, + for yellow).

Hydrodynamic Particle Size and Zeta Potential

The hydrodynamic particle size and zeta potential were evaluated using dynamic light scattering (DLS) with the Litesizer TM 500 Particle Analyzer, produced by Anton Paar.

Functional Properties of Encapsulated Betalains

Water Activity (a_w)

The water activity (a_w) of 1 g of powder was measured using a water activity meter (Aqualab PAWKIT, DECAGON Devices, Inc., USA).

Bulk Density and Hygroscopicity

To determine the bulk density, 2g of encapsulated betalains powder (EBP) was added to a 10 mL cylinder, which was then dropped 10 times from a height of 15 cm into a polystyrene container. The bulk density was calculated by dividing the mass of the powder by its volume (Mahdavi et al., 2016).

A slight modification was made to the hygroscopicity quantification method outlined by Tao et al. (2017). For this, 1g of EBP was placed in a desiccator containing a saturated sodium chloride solution to maintain a relative humidity of 75%. After 24 hours, the samples were weighed, and hygroscopicity was calculated as grams of moisture absorbed per 100g of dry powder. All measurements were performed in triplicate.

Water Absorption Capacity (WAC) and Water Solubility Index (WSI)

The water absorption capacity and water solubility index (WSI) of the encapsulated betalain powders (EBP) were evaluated based on the method described by Syed et al. (2020). A 1g sample of EBP was combined with 10 mL of distilled water in pre-weighed centrifuge tubes. After shaking for 30 minutes, the tube was centrifuged at 3500 rpm for 15 minutes. To calculate the WSI, the supernatant was collected and then dried at 100°C in a pre-weighed petri dish. WAC and WSI were determined using Equations (1) and (2), respectively.

Equation 1

$$\mathrm{WAC\ (g/g)} = \frac{\mathrm{Wt.\ of\ pellet\ \ (residue)} - \mathrm{Wt.\ of\ sample}}{\mathrm{Wt.\ of\ sample}}$$

Equation 2

$$\mathrm{WSI\ \ (\%)} = \frac{\mathrm{Wt.\ of\ dry\ solids}}{\mathrm{Wt.\ of\ sample}} \times\ 100$$

Fourier Transform Infrared of Encapsulated Betalains

FTIR analysis of EBP was performed using an FTIR spectrometer (Nicolet 67,000, Thermo Scientific, USA) at room temperature (28 ± 2°C) within the 4000–400 cm − 1 range. The analysis was carried out with the FTIR software at the SAIF facility, Panjab University, Chandigarh, and the obtained spectra were plotted using Origin software.

X-ray diffraction of Encapsulated Betalains

The structural properties of the encapsulated betalains were evaluated using XRD analysis with a PanalyticalX'pert PRO diffractometer (Panalytical, Almelo, Netherlands), utilizing CuK (Å) = 1.54056 radiation. The samples were scanned within the 5° to 80° (2θ) range (Kaur and Ghoshal, 2024).

Field Emission Scanning Electron Microscopy of Encapsulated Betalains

The surface properties of the encapsulated powder were examined using a FE-SEM (Joel, JSM-7610 F Plus, Tokyo, Japan) with an accelerating voltage of 5.0 kV and a working distance of 8.0 mm, offering magnification from 10 to 300,000. To enhance conductivity, the powder samples were placed on stubs and coated with a gold layer through sputtering. The prepared samples were then subjected to a pre-set accelerated electron beam with a current of 8.0 mA (Kaur and Ghoshal, 2024).

Microscopy of Encapsulated Betalains

The EBP samples were captured at a higher magnification using an optical microscope (Zeiss HBO 100). The image was acquired by positioning the material beneath the microscope.

In-vitro release study of EBP

The *in vitro* evaluation of betalain release from all encapsulated powders (EBP) was performed in simulated gastric fluid (SGF, pH 1.2) and simulated intestinal fluid (SIF, pH 6.8) using a slightly modified approach based on the method by Gupta and Ghoshal, (2024). At the beginning, 0.5 g of EBP was dissolved in 50 mL of SGF, which acted as the release medium. The suspension was stirred at 100 rpm for 2 h at 37°C. Subsequently, the EBP was transferred to a beaker containing 100 mL of SIF and stirred under the same conditions (100 rpm, 37°C) for an additional 2 h. Both SGF and SIF media contained distilled water to enhance betalains solubility.

Samples of 1 mL were collected at specified time intervals (0, 10, 20, and 240 min). An equivalent amount of fresh medium was swiftly added to keep the release conditions stable. A UV-VIS spectrophotometer was used to measure the concentration of released betalains in each sample.

The release data were analyzed using various kinetic models, including Higuchi, Korsmeyer-Peppas models, and Peppas-Sahalin as described by Raj and Dash (2022). All experiments were conducted in duplicate. The equations for the kinetic models are provided in Table 1.

Table 1
Kinetics models used for data fitting of betalains release study of encapsulated betalains powder

Model	Equations
Higuchi	$Q = k_h\sqrt{t}$
Korsmeyer-Peppas	$Q = k_k\,{}^{n}\sqrt{t}$
Peppas-Sahalin	$Q/Q_{\infty} = k_d \times t^m + k_r \times t^{2m}$

In this equation, Q stands for the quantity of betacyanin that has been released at a specific time t, and Q/Q_{∞} signifies the fraction of betalains released up to that moment. The constants k_h and k_k represent the Higuchi and Korsmeyer-Peppas constants, respectively, while k_d and k_r indicate the diffusion and relaxation constants in the Korsmeyer-Peppas model. Furthermore, n is the exponent for release diffusion, and m denotes the Fickian diffusion exponent.

Storage Stability of Encapsulated Betalains

In the food research laboratory, the powders were stored in amber-colored glass bottles at room temperature for 90 days. The stability was assessed every 14 days by quantifying the betacyanins, betaxanthins, and betalains.

Statistical analysis

The mean values, standard deviations, and analysis of variance (ANOVA) were calculated using SPSS 18.0, with Duncan's multiple range tests applied at a significance level of $p \leq 0.05$. The dataset was analyzed in triplicates to determine the mean and standard deviation (S.D.).

Results and discussion

Physicochemical Composition and Functional Characteristics of EBP

The moisture content of a powder refers to the percentage of water that remains bound to the microparticles after the freeze-drying process. This moisture content varies in different powder formulations depending on factors such as the properties of the gums used, the production methods, and the storage conditions. In this study, the moisture content of various EBP's was observed to range from 2.94–3.24%, as shown in Table 2. These results are consistent with the findings reported by Arepally et al. (2020). The sample made using maltodextrin (MD) exhibited a significantly higher moisture content ($p \leq 0.05$) compared to the other encapsulated powders. This increased moisture content in the encapsulated powder can negatively affect the preservation of the encapsulated components, ultimately reducing the efficiency of the encapsulation process.

Table 2
Physicochemical Properties, Functional Attributes, Phytochemical Content, and Color Characteristics of EBP

Parameters	MD	MG	MA	MT
Physicochemical analysis				
Moisture content (%)	$3.24^{a} \pm 0.48$	$2.94^{d} \pm 0.87$	$3.21^{b} \pm 0.66$	$3.14^{c} \pm 0.71$
Total soluble solids (°Bx)	$9.01^{d} \pm 0.02$	$9.10^{a} \pm 0.02$	$9.05^{b} \pm 0.01$	$9.03^{c} \pm 0.01$
pH	$4.71^{d} \pm 0.07$	$4.77^{c} \pm 0.02$	$4.82^{b} \pm 0.04$	$4.83^{a} \pm 0.04$
Titratable acidity (%)	$0.17^{a} \pm 0.01$	$0.14^{d} \pm 0.01$	$0.15^{b} \pm 0.01$	$0.15^{b} \pm 0.01$
Functional properties				
WAC (g/g)	$4.15^{d} \pm 0.05$	$5.96^{a} \pm 0.03$	$4.43^{c} \pm 0.01$	$4.74^{b} \pm 0.06$
WSI (%)	$82.56^{d} \pm 0.19$	$72.44^{a} \pm 0.32$	$82.73^{c} \pm 0.41$	$82.76^{b} \pm 0.12$
Water activity (aw)	$0.13^{a} \pm 0.03$	$0.10^{d} \pm 0.02$	$0.11^{c} \pm 0.01$	$0.12^{b} \pm 0.01$
Hygroscopicity (%)	$3.39^{a} \pm 0.04$	$1.59^{b} \pm 0.02$	$1.13^{d} \pm 0.08$	$1.29^{c} \pm 0.01$
Bulk density (g/cm3)	$0.69^{b} \pm 0.04$	$0.89^{a} \pm 0.01$	$0.66^{d} \pm 0.06$	$0.68^{c} \pm 0.04$
Color parameters				
*L**	$73.12^{b} \pm 0.36$	$71.07^{d} \pm 0.14$	$74.38^{a} \pm 0.54$	$72.14^{c} \pm 0.17$
*a**	$17.5^{c} \pm 0.19$	$20.95^{a} \pm 0.15$	$15.86^{d} \pm 0.21$	$18.67^{b} \pm 0.13$
*b**	$1.03^{c} \pm 0.02$	$0.46^{d} \pm 0.03$	$2.32^{a} \pm 0.01$	$1.28^{b} \pm 0.07$
Encapsulation yield (%)	$23.13^{d} \pm 0.32$	$32.31^{a} \pm 0.14$	$25.01^{c} \pm 0.07$	$28.19^{b} \pm 0.11$
Encapsulation Efficiency (%)	$84.79^{c} \pm 0.13$	$93.39^{a} \pm 0.11$	$83.82^{d} \pm 0.08$	$90.74^{b} \pm 0.04$
Phytochemical analysis				
Betacyanins (mg/g)	$0.54^{c} \pm 0.11$	$0.80^{a} \pm 0.09$	$0.49^{d} \pm 0.08$	$0.73^{b} \pm 0.12$
Betaxanthins (mg/g)	$0.29^{d} \pm 0.04$	$0.58^{b} \pm 0.02$	$0.30^{c} \pm 0.06$	$0.60^{a} \pm 0.07$
Betalains (mg/g)	$0.84^{b} \pm 0.01$	$1.39^{a} \pm 0.03$	$0.79^{c} \pm 0.02$	$1.33^{a} \pm 0.02$
Total phenols	$35^{d} \pm 0.12$	$68.75^{a} \pm 0.19$	$58.25^{c} \pm 0.21$	$61.75^{b} \pm 0.11$

Values are expressed as means of three replications ± standard deviation. Values with different letters in superscript differ significantly within a row ($p \leq 0.05$)

Parameters	MD	MG	MA	MT
Physicochemical analysis				
(mg GAE/g)				
DPPH (0.1 mg/ml) (%)	$22.52^{d} \pm 0.41$	$38.25^{a} \pm 0.35$	$34.43^{b} \pm 0.28$	$31.93^{c} \pm 0.52$
IC50	0.83	0.91	0.88	0.84
DPPH (mg AAE/g)	$4.16^{d} \pm 0.28$	$8.44^{a} \pm 0.19$	$7.53^{c} \pm 0.32$	$7.56^{b} \pm 0.23$
Hydrodynamic Diamter (nm)	$465.9^{d} \pm 20.95$	$8799^{a} \pm 18.75$	$580.9^{c} \pm 16.85$	$4894^{b} \pm 15.78$
Polydispersity Index (%)	$25.2^{c} \pm 0.07$	$29.2^{b} \pm 0.13$	$31.3^{a} \pm 0.08$	$20.9^{d} \pm 0.09$
Zeta Potential (mV)	$-8.3^{b} \pm 3.19$	$-3.4^{a} \pm 2.88$	$-21.7^{c} \pm 3.07$	$-22.5^{d} \pm 2.84$
Values are expressed as means of three replications ± standard deviation. Values with different letters in superscript differ significantly within a row ($p \leq 0.05$)				

Research conducted by Aziz et al. (2018) in the food industry suggests that maintaining a moisture content (MC) within the range of 3 to 10% is crucial for ensuring the stability of dried powders during storage. If the moisture content exceeds this range, it may increase the water activity, which can lead to reduced shelf life and greater susceptibility to microbial spoilage in food and pharmaceutical products, as noted by Baysan et al. (2021). In this study, the water activity values for the powders produced using different carrier agents such as MD (0.13), gum Arabic (MG, 0.10), maltose (MA, 0.11), and maltodextrin with turmeric (MT, 0.12) showed significant differences ($p \leq 0.05$). These results align with the work of Aziz et al. (2018), who found that maintaining water activity levels between 0.20 and 0.50 is effective for preventing microbial contamination in powdered food products.

Total soluble solids (TSS) is another important parameter in EBP's. TSS refers to the concentration of all soluble substances, including sugars, organic acids, and minerals, that are dissolved in a liquid. The concentration of TSS affects the solubility, stability, and sensory attributes of the powders once they are reconstituted. In this study, TSS values exhibited significant variations ($p \leq 0.05$) between the different carrier agents. The MG powder demonstrated the highest TSS value (9.10 ºBrix) compared to the powders containing MD, MT, and MA, which had TSS values of 9.01, 9.03, and 9.05 ºBrix, respectively (Table 2). These results are consistent with the findings of Cid-Ortega and Guerrero-Beltran (2022), who investigated the lyophilized powder of Hibiscus sabdariffa (Roselle) extracts using gum Arabic and maltodextrin as carrier agents. The variation in TSS values suggests that the choice of carrier agent plays a significant role in the characteristics of the encapsulated powders.

The pH levels of the EBP's were measured, and they ranged from 4.71 for MD to 4.83 for MT, as shown in Table 2. Overall, all the powders exhibited low pH values, indicating a reduced susceptibility to microbial growth during storage. The MD sample exhibited the highest titratable acidity at 0.17%, although this value was not significantly higher ($p \leq 0.05$) than that of the other EBP's. These findings are consistent

with the results reported by Bazaria and Kumar (2017), who studied the impact of maltodextrin's dextrose equivalency in combination with Arabic gum on the properties of encapsulated beetroot juice.

Water absorption capacity is another crucial factor in evaluating the performance of EBP's. This refers to the amount of water that the powder can absorb and retain. In this study, the powder containing MG exhibited the highest water absorption capacity (5.96 g/g), significantly higher ($p \leq 0.05$) than the powders made with MT (4.83 g/g), MA (4.82 g/g), and MD (4.71 g/g) (Table 2). This higher water absorption capacity indicates that the MG encapsulated powder was able to absorb and retain more water, which could lead to enhanced properties in applications where moisture retention is important. This finding is in agreement with the work of Sukri et al. (2020), who studied the impact of maltodextrin and Arabic gum ratios on the physicochemical properties of spray-dried propolis microcapsules.

Water solubility is an important property for powders designed to be reconstituted, as it directly affects their usability and overall quality. In this study, the powder made using MG had a significantly lower solubility (72.44%) compared to the powders made with MD (82.56%), MA (82.73%), and MT (82.76%) ($p \leq 0.05$) (Table 2). This indicates that powders made with MG are less soluble in water, which could have implications for their use in specific applications. Similarly, Yousefi et al. (2015) observed that black raspberry juice powder made with maltodextrin had higher solubility than that made with gum Arabic.

Hygroscopicity, which refers to the ability of a substance to absorb moisture from the surrounding environment, is another key factor in determining the storage stability of powders. In this study, the moisture absorption of EBP's ranged from 1.13–3.39%. The hygroscopicity of these powders was classified into three categories: non-hygroscopic powders (moisture absorption < 10%), mildly hygroscopic powders (10%-15%), and highly hygroscopic powders (15%-20%) (Srivastava et al., 2022). All the powder samples in this study were classified as non-hygroscopic, indicating that they have the potential for stable storage without significant moisture absorption. However, other factors should also be considered to ensure the overall stability of the powders during storage.

Bulk density, which refers to the mass contained within a specific volume of powder, varied considerably in this study, ranging from 0.89 to 0.66 g/cm³ (Table 2). The powder made with MG exhibited a significantly higher bulk density (0.89 g/cm³) compared to the powders made with MD (0.69 g/cm³), MA (0.66 g/cm³), and MT (0.68 g/cm³). However, no statistically significant differences in bulk density were observed between the MT, MD, and MA powders ($p > 0.05$). The results are consistent with those reported by Ferrari et al. (2013), who found a correlation between increased moisture content and bulk density in powders formulated with either gum Arabic alone or a combination of maltodextrin and gum Arabic.

In conclusion, this study provides valuable insights into the physicochemical properties of EBP's, highlighting the impact of different carrier agents and their influence on key parameters such as moisture content, water activity, TSS, pH, water absorption, solubility, hygroscopicity, and bulk density. These findings contribute to the understanding of how various factors affect the quality and stability of

EBP’s and provide guidance for optimizing encapsulation processes in food and pharmaceutical applications.

ColorAnalysis of EBP

Color was evaluated based on three parameters: luminosity (L*), the red-green scale (a*), and the yellow-blue scale (b*). The color values for the various EBP’s are detailed in Table 1 and Fig. 1. Among the samples, the MA sample exhibited the highest lightness, with an L* value of 74.38, followed by MD at 73.12, MT at 72.14, and MG at 71.07, indicating a gradual decrease in lightness. The inclusion of guar gum in the MG sample resulted in an increased a* value of 20.95, likely due to interactions between the components, alterations in the microstructure, or chemical reactions occurring during processing. While the MA sample showed a decrease in the a* value to 15.86, this change was considered statistically non-significant ($p \leq 0.05$). The b* value for the MG sample decreased to 0.46, whereas the MA sample showed an increase in b* value to 2.32, reflecting a rise in the yellowness of the sample's color, potentially influenced by the addition of acacia gum. These results align with the findings of Nabi et al. (2022) and Mahdavi et al. (2016).

Encapsulation Efficiency (EE%) and yield (%) of EBP

The encapsulation efficiency (%EE) of various powders was observed to be 93.39% for MG, 90.74% for MT, 84.79% for MD, and 83.82% for MA, revealing notable differences between them ($p \leq 0.05$). These results suggest that maltodextrin in combination with guar gum offers superior protection for betalains compared to other encapsulating agents. This observation is consistent with previous research conducted by Laureanti et al. (2023), who explored the encapsulation of bioactive compounds using different gums. The powder yields ranged from 23.13–32.31%, with the highest yield (32.31%) achieved by the MG-encapsulated powder. In contrast, powders encapsulated with MD, MA, and MT showed lower yields of 23.13%, 25.01%, and 28.19%, respectively, and these differences were statistically significant ($p < 0.05$). These yield results are in alignment with the findings of Mahdavi et al. (2016) and Castro-Enríquez et al. (2020). Additionally, Zhu et al. (2021) found that moderate ultrasound treatment facilitated the formation of betalain microcapsules by promoting the uniform distribution of the encapsulating solution. However, excessive ultrasound power was shown to disrupt the microcapsules due to cavitation effects. Prenhacasilva et al. (2020) further emphasized that strong electrostatic interactions and hydrogen bonding played a critical role in the effective adhesion of betalains to polymers during the encapsulation process.

Phytochemicals constituents of EBP

Betalains, the vibrant pigments responsible for the red and yellow hues in certain fruits, exhibit a wide range of biological activities that have been the subject of extensive research. The total betalains content in EBP’s ranged from 0.84 to 1.39 mg/g, with the MG-encapsulated powder showing significantly higher betalains concentrations when compared to other formulations. This observation suggests that

MG may possess a superior binding affinity for the target molecules of betalains, which could explain its enhanced ability to encapsulate these compounds. The stabilization or retention of betalains in powdered form is significantly influenced by the particular characteristics of the encapsulating agents used, a notion that has been corroborated by studies such as those by Ravichandran et al. (2014). According to research by Castro-Enríquez et al. (2020), MG powder exhibited a higher encapsulation efficiency for betalains when compared to other powders, further supporting the idea of MG's enhanced binding capability.

In addition to betalains, the total phenolic content (TPC) is another important metric for evaluating the antioxidant potential of plant extracts. Phenolic compounds, being major contributors to antioxidant activity, play a vital role in the overall efficacy of EBP's. The efficiency with which these phenolic compounds are encapsulated is crucial in determining the success of the encapsulation process. Table 1 presents the TPC values of three distinct samples of EBP, expressed in mg GAE/g. In this study, the TPC of the powders ranged from 35 to 68.75 mg GAE/g, revealing that the fluctuations in phenolic content were influenced by the type of carrier agent used, a finding consistent with the observations of Munteanu et al. (2021). Furthermore, research by Casati et al. (2019) highlighted the bioactive compound content within encapsulated freeze-dried powders from fruits like blueberry, elderberry, blackcurrant, and maquiberry, reinforcing the idea that the encapsulation process can effectively preserve these bioactive compounds. These findings align with those of Karrar et al. (2021), who suggested that MG samples could improve the stability of phenolic compounds, thereby enhancing their antioxidant potential.

The ability of carrier agents to bind antioxidant compounds was further explored in Table 1, which demonstrated differences in their efficiency. The radical scavenging activity (RSA) of the EBP's, assessed using the DPPH radical method, ranged from 22.52–38.25%. Additionally, the total antioxidant levels of the three different samples, expressed in mg AAE/g, ranged from 4.16 to 8.44 mg AAE/g. This variability in antioxidant activity can be attributed to the different types of carrier agents used in the encapsulation process. These results were in line with studies by Li et al. (2022) and Kumar et al. (2023), which investigated the encapsulation of betalains through various hydrocolloids derived from beetroot extract.

Hydrodynamic Particle Size, Polydispersity Index (PDI) and Zeta Potential of EBP

Table 2 and Fig. 2 present the hydrodynamic particle sizes of different EBP's. The hydrodynamic particle size refers to the effective size of a particle or molecule in a fluid, accounting for their motion and interactions with the surrounding solvent molecules. This measurement assumes the particle is spherical (Maguire et al., 2018). The largest hydrodynamic particle size was observed in MG (8799 nm), while the smallest was in MD (465.9 nm). These results suggest that the hydrophilic properties of these polymers could promote water absorption, leading to the hydration and swelling of the encapsulated particles. The combination of maltodextrin and guar gum may lead to aggregate or cluster formation during encapsulation, thereby increasing the apparent hydrodynamic size (Laureanti et al., 2023). For MD,

the smaller particle size might result from the fragmentation of larger particles into smaller units, coupled with the formation of a uniform coating around the core material, ensuring a more consistent distribution during encapsulation (Ghosal et al., 2010).

The study also employed the PDI (polydispersity index), a numerical measure of the particle size distribution within a sample. A lower PDI signifies a more uniform distribution, while a higher PDI indicates a broader distribution (Daassi et al., 2023). The PDI values for different EBP's were as follows: MA (31.3%), MG (29.2%), MD (25.2%), and MT (20.9%), showing that the samples exhibited a polydisperse nature. Maltodextrin, a carbohydrate polymer, contributed to stabilizing particle dispersions by reducing aggregation and encouraging a more consistent size distribution (Qiu et al., 2017). The inclusion of guar gum and gum acacia led to wider size distributions due to various interactions during the encapsulation process (Šeremet et al., 2024; Dejoro et al., 2019). However, the PDI decreased with the MT encapsulation mixture, resulting in a more uniform particle size distribution compared to individual components or other combinations. Zeta potential, which measures the attraction and repulsion forces between particles, was also evaluated to assess the stability of the solution; higher zeta potential values indicate greater stability (Serrano-Lotina et al., 2023).

Table 2 and Fig. 3 display the zeta potential of different encapsulations. MG exhibited the highest zeta potential, recorded at -3.4 mV, followed by MD, MT, and MA. Smaller molecules or dispersed particles tend to exhibit higher zeta potentials, as they resist aggregation, promote dissolution or dispersion, and enhance system stability (Zhang et al., 2021). Therefore, the high zeta potential observed in the MG combination suggests a successful formulation that significantly enhanced the stability of the dispersion.

Fourier Transform Infrared (FTIR) of EBP

Figure 4 presents the FTIR spectra of betalain microcapsules encapsulated with different hydrocolloids, revealing similar absorption bands that confirm the presence of the same phytochemical compounds in all the samples, consistent with the observations made by Li et al. (2022). The peaks between 3441 and 3454 cm^{-1}, corresponding to the O-H functional groups in sugars and phenols, indicate the presence of betalains. The pure betalain extract and the MG sample showed prominent absorption peaks at 3454 cm^{-1} and 3430 cm^{-1}, respectively, attributed to O-H stretching. This shift in frequency, which is higher than those observed in the MD, MA, and MT samples, is associated with ionic bonding involving water molecules in the crosslinking process, as described by Abdin et al. (2021). Furthermore, sharp peaks in the pure extract, MD, MG, MT, and MA samples were attributed to the symmetric stretching of methylene (CH_2) groups. The peaks at 1418.74–1419 cm^{-1} were due to the symmetrical stretching vibration of C–H bonds in alkanes. Phosphorus compounds were identified by a peak at 1237 cm^{-1}, while C-O stretching, which is characteristic of phenols, appeared in the 1300 – 1000 cm^{-1} range. The peak at 1370 cm^{-1} corresponded to –OH bending vibrations, and 2925 cm^{-1} was observed for C-H stretching vibrations. The C-O bond stretching vibration appeared at 1151–1154 cm^{-1}, with the peak at 1151 cm^{-1}

in the MG sample suggesting the presence of phosphorus compounds. The C-O-C vibration mode was detected as a bending vibration at 1024–1026 cm^{-1}, which is indicative of phenolic compounds. Amide bands, indicating nitrogen-containing functional groups, were observed between 1634–1639 cm^{-1}. Absorption bands at 668 cm^{-1} in the MG sample and in the range of 762–853 cm^{-1} were attributed to C-Br stretching, as described by Mansour et al. (2020). Additionally, the pyranoid ring skeletal vibrations, peaking between 700–764 cm^{-1}, were linked to the bending vibrations of C-H bonds in aromatic compounds such as benzene rings, providing structural insights into organic molecules containing aromatic groups, as noted by Li et al. (2022).

X-ray diffraction (XRD) of EBP

Betalains are typically regarded as amorphous pigments, and due to their non-crystalline nature, they were not anticipated to generate clear diffraction peaks in the XRD pattern. However, any impurities or crystalline phases present in the encapsulated powder could potentially influence the overall XRD results. Figure 5 presents the XRD analysis of EBP's MD, MG, MA, and MT. The MD encapsulated powder exhibited distinct, intense peaks at 22.76° and 43.25°, which were attributed to the amorphous nature of the MD encapsulated powder. Crystalline peaks in the other EBP samples appeared to be similar. The XRD spectra revealed that the powder particles had a semi-crystalline structure, as evidenced by broadened peaks. This peak broadening could be linked to the amorphous characteristics of the particles, where the compact inter- and intra-chain molecular bonding was disrupted, resulting in a reduction in crystallinity. According to Yu et al. (2021), the broadening of peaks could serve as an indicator of particle size, with smaller particles generally showing broader diffraction peaks.

Field Emission Scanning Electron Microscope (FESEM)Analysis of EBP

FESEM imaging provided insights into the surface morphology of the encapsulated particles (Fig. 6). The MD sample displayed particles with a range of shapes, from spherical to irregular. The MG sample revealed encapsulated particles exhibiting various features such as smoothness, roughness, or porosity, which were influenced by both the encapsulation process and the ratio of maltodextrin to guar gum. The inclusion of guar gum in the MG sample likely played a role in forming a protective barrier around the betalain pigments, thereby affecting the external structure of the particles. The MA sample displayed cross-sectional views that highlighted core-shell structures, suggesting the successful encapsulation of betalains within the maltodextrin and gum Arabic matrix. Likewise, the MT sample, exhibiting core-shell structures, contained betalain pigments at the core, surrounded by layers of maltodextrin and gum tragacanth. These layers provided protection and influenced the release kinetics of the encapsulated material (Rezaei and Nasirpour, 2018).

Microscopy of EBP

Figure 7 presented microscopic images of different encapsulated beetroot powders (EBPs). The presence of smaller particles in the MT sample indicated the successful encapsulation of betalains within a maltodextrin matrix. This reduction in particle size pointed to a high degree of precision in the encapsulation process, which resulted in uniform particle sizes and their even distribution. Furthermore, the higher particle density observed in the MG sample was likely due to the thickening and gelling properties of guar gum, which forms viscous solutions and gels, thereby leading to the formation of densely packed particles arranged in a more compact structure (Rajabi et al., 2024).

In vitro release study of EBP

Figure 8 highlights the in vitro release profile of betalains from encapsulated powders in simulated gastric fluid (SGF) and simulated intestinal fluid (SIF). After 2 hours of incubation in SGF, the quantified release of betalains was 0.42 ± 0.13 mg/g for MD-EBP, 0.69 ± 0.15 mg/g for MD-GG-EBP, 0.66 ± 0.21 mg/g for MD-AG-EBP, and 0.39 ± 0.11 mg/g for MD-TG-EBP. Maximum release occurred at the 2-hour mark, followed by a gradual increase in SIF, reaching levels of 0.75 ± 0.18 mg/g, 1.25 ± 0.21 mg/g, 1.19 ± 0.18 mg/g, and 0.71 ± 0.13 mg/g, respectively, after 4 hours.

Among the tested formulations, MD-GG-EBP demonstrated the most efficient release profile, achieving 50%, 75%, and 90% release of betalains within 90, 150, and 170 minutes, respectively. This highlights guar gum's superior ability to enhance betalain release compared to other carriers. Conversely, MD-AG-EBP, MD-EBP, and MD-TG-EBP required 110, 130, and 140 minutes, respectively, to release 50% of betalains, with 90% release achieved at 170, 190, and 230 minutes. These findings emphasize the significant role of the encapsulating material in shaping betalain release kinetics, with MD-GG-EBP promoting a faster release due to its unique interactions with betalains and surrounding fluids under simulated digestive conditions.

Table 3

Correlation Coefficient (R^2) for different kinetic models for encapsulated betalains powders with maltodextrin and its combination with various gums

Models	MD-EBP	MD-GG-EBP	MD-AG-EBP	MD-TG-EBP
Higuchi	0.987	0.988	0.972	0.981
Korsmeyer–Peppas	0.988	0.989	0.989	0.989
Peppas-Sahlin	0.989	0.989	0.989	0.988

As detailed in Table 3, the Peppas-Sahlin model provided the best fit for describing the release kinetics, supported by high correlation coefficients (R^2 = 0.989) for most formulations. Analysis of model parameters revealed that as the time required to release 90% of betalains increased, the diffusion constant (k_d) decreased, whereas the relaxation constant (k_r) and release exponent (m) increased. These changes reflect the structural influence of the encapsulation matrix on release behavior. The k_d/k_r ratio exceeding 1 across all formulations confirmed that diffusion predominantly governs betalain release,

consistent with similar findings in encapsulation studies involving saffron extract (Mirhadi et al., 2019). Furthermore, release exponent (n) values derived from the Korsmeyer-Peppas model remained below 0.5, indicating Fickian diffusion as the primary release mechanism, as observed in previous studies (Guerra-Ponce et al., 2016).

Comparable studies on betalain-rich fruit and vegetable by-products, such as prickly pear peel and amaranth pomace, have demonstrated similar release profiles. Research by Suzuki et al. (2024) on encapsulated red beet pomace highlighted that polysaccharides like GG and MD significantly influence betalain release rates, with GG enabling faster release due to its high solubility and enhanced interactions with betalain compounds.

Storage Stability of EBP

Figure 9 illustrates the retention of betacyanin, betaxanthin, and total betalains in powders over a 90-day storage period at room temperature. Significant pigment degradation was observed under the studied conditions. The variations in the encapsulated beetroot powders (EBP) indicated the considerable effect of the gums used on the preservation of betalains throughout the storage duration. The betalain content decreased differently across the various encapsulating agents, with reductions of 33.34%, 14.39%, 18.99%, and 8.22% for MD, MG, MA, and MT, respectively. It was observed that maltodextrin as an encapsulation medium improved betalain stability, making it a preferable choice either alone or in combination with other polysaccharides (Castro-Enríquez et al., 2020). However, when used independently, maltodextrin's low molecular weight and shorter chains resulted in increased hygroscopicity, leading to higher moisture content and reduced pigment retention. On the other hand, combining it with other compounds provided an economic advantage due to maltodextrin's cost-effectiveness and availability. The combination of guar gum, Arabic gum, xanthan gum, and pectin was found to be effective in encapsulating red beet betalains, thereby improving their stability (Pateiro et al., 2021; Laureanti et al., 2023; Kaur and Ghoshal, 2025). Among the samples, MG showed the highest stability, followed by MD, MA, and MT. These results were consistent with those of Li et al. (2022), who enhanced the stability of betalains extracted from red dragon fruit peel through ultrasound-assisted microencapsulation with maltodextrin. Similarly, Adejoro et al. (2019) found comparable outcomes in their study on starch and gum Arabic-maltodextrin microparticles encapsulating acacia tannin extract for ruminant nutrition. These findings aligned with the work of Carreón-Hidalgo (2020), who examined the enhancement of betalain storage stability, and Laureanti et al. (2023), who studied the microencapsulation and storage stability of bioactive compound extracts using maltodextrin and gum Arabic via spray and freeze-drying techniques.

Conclusion

The encapsulation of powdered BRP extracts with various gums had a positive effect on their moisture content and hygroscopicity, which could contribute to an extended shelf life. The powder encapsulated with guar gum and maltodextrin exhibited the lowest moisture retention and hygroscopic properties,

along with enhanced physicochemical characteristics. The microparticles containing maltodextrin showed a spherical morphology. Among the different formulations, MG had the highest encapsulation efficiency, while the MD control sample showed comparatively lower efficiency. Microencapsulation significantly improved the bioaccessibility of antioxidant compounds in the extracts, particularly in the MG and MT samples, which exhibited notable increases in the bioaccessibility of all bioactive compounds. Throughout a 90-day storage period, the EBP samples maintained lower moisture content, suggesting promising stability and potential for future use. Maltodextrin encapsulation emerged as the optimal formulation for enhancing the stability of bioactive compounds in BRP extracts and improving their bioaccessibility, indicating its potential for developing health-promoting foods. Further research should investigate the behavior of encapsulation within food matrices and its effects on storage stability.

Abbreviations

MD
Maltodextrin
MG
Maltodextrin + Guar Gum
MA
Maltodextrin + Acacia Gum
MT
Maltodextrin + Tragacanth Gum
BRP
Beetroot Pomace
EBP
Encapsulated Betalains Powder

Declarations

Ethics statement for the use of human and animal subjects (may require consent to participate and consent to publish for human subjects):

Reply: Not required

Consent for publication: All the authors are agreed to submit our work in your journal

Reply : yes

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Figures

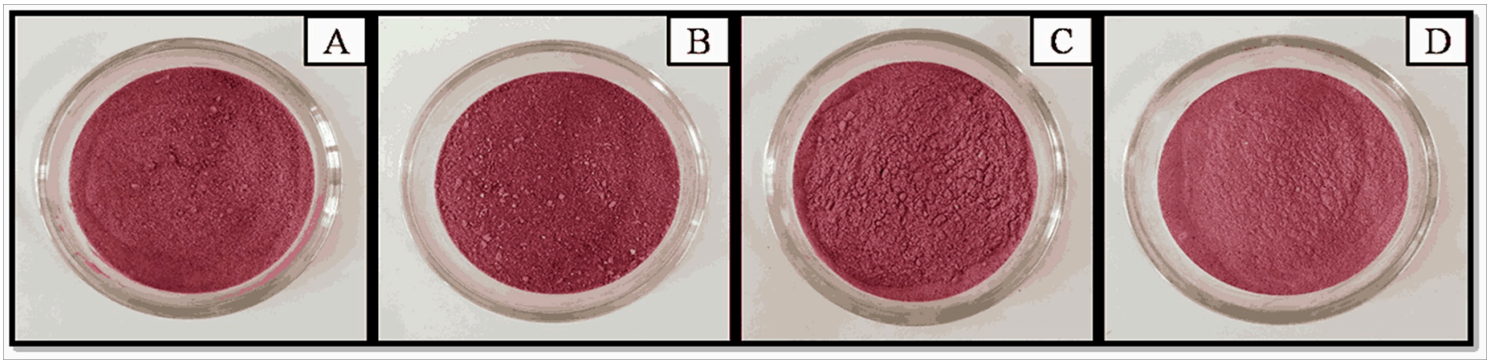


Figure 1

Encapsulated betalains, (A) Maltodextrin; (B) Maltodextrin-Guar Gum; (B) Maltodextrin -Acacia Gum; (C) Maltodextrin-Tragacanth Gum

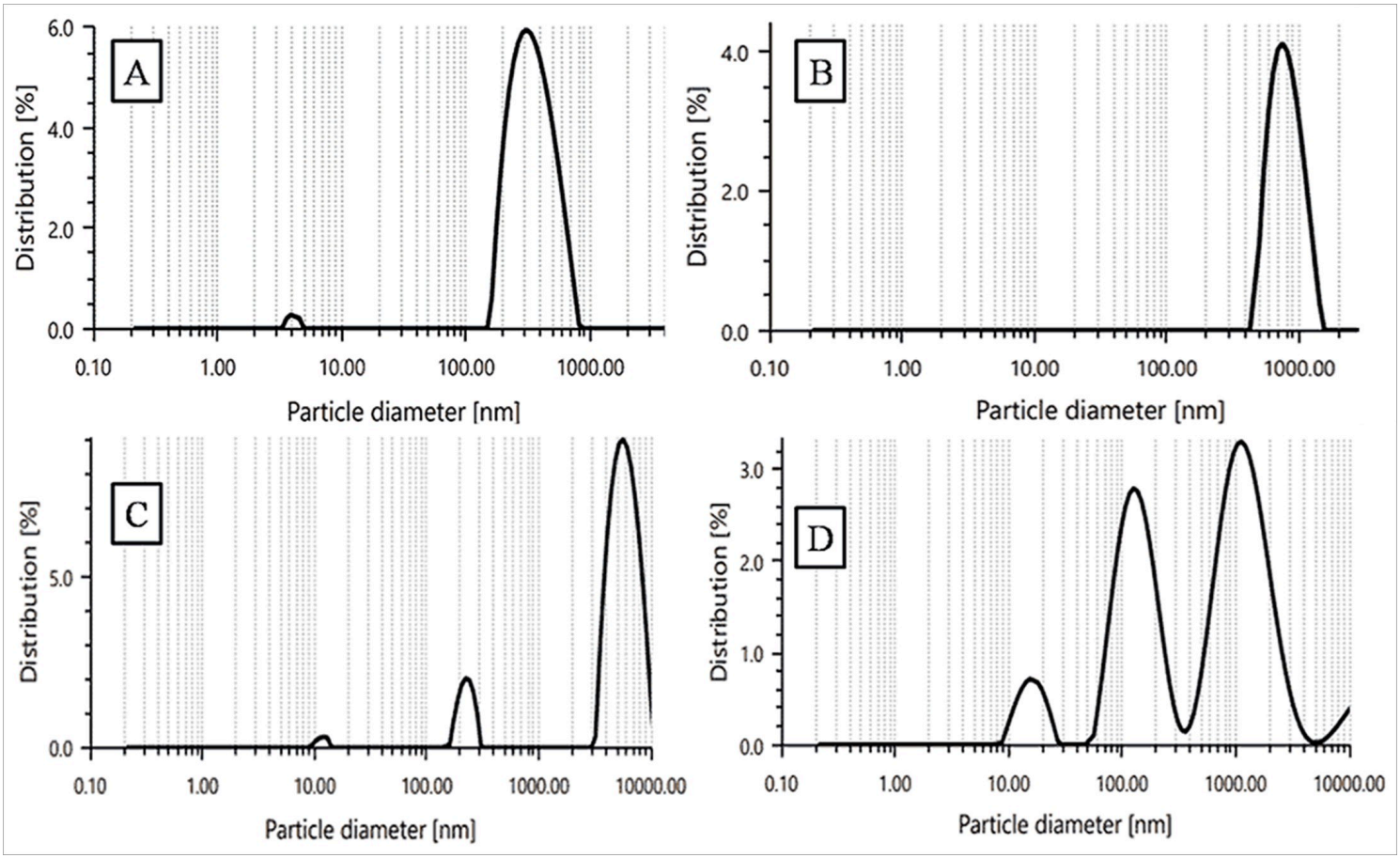


Figure 2

Particle Size Distribution of encapsulated powders (A) Maltodextrin; (B)Maltodextrin-Guar Gum; (C)Maltodextrin-Tragacanth Gum; (D) Maltodextrin -Acacia Gum

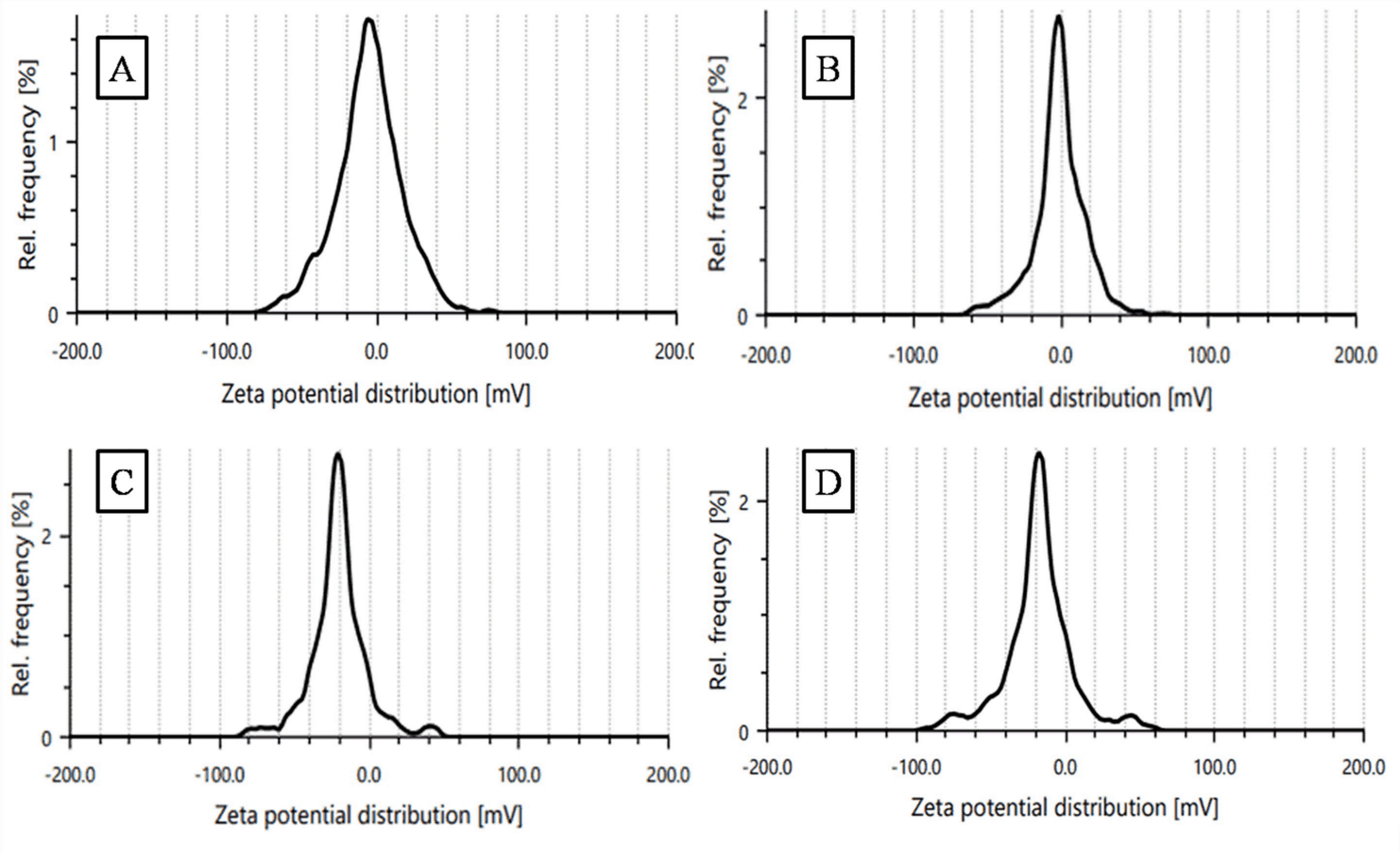


Figure 3

Zeta potential of encapsulated powders (A) Maltodextrin; (B) Maltodextrin-Guar Gum; (C) Maltodextrin-Tragacanth Gum; (D) Maltodextrin -Acacia Gum

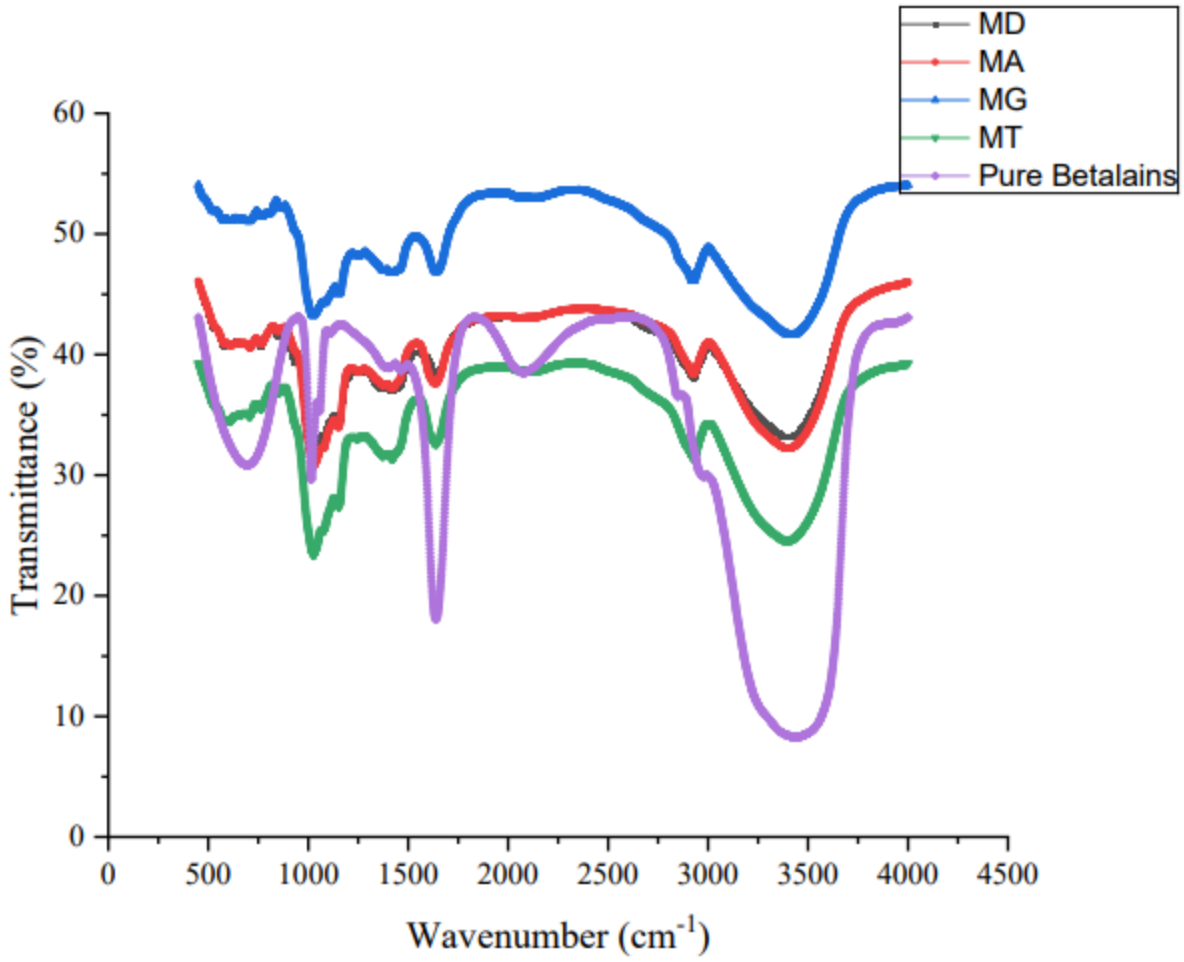


Figure 4

Fourier Transform Infrared of encapsulated powder: MD; Maltodextrin,MG; Maltodextrin+ Guar Gum, MA; Maltodextrin + Acacia Gum, MT; Maltodextrin+ Tragacanth Gum

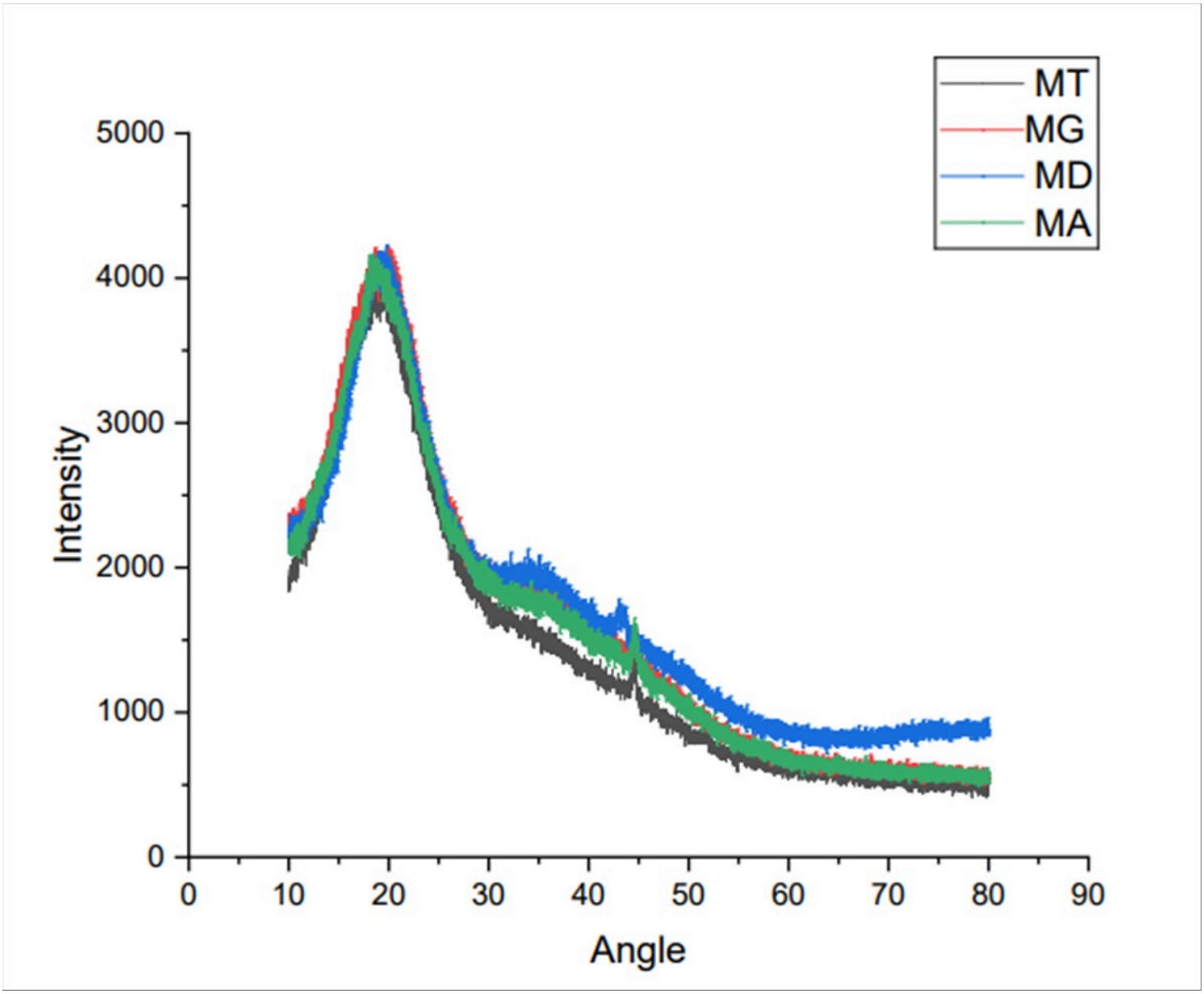


Figure 5

X-Ray diffraction of encapsulated powders: MD; Maltodextrin, MG; Maltodextrin -Guar Gum, MA; Maltodextrin-Acacia Gum, MT; Maltodextrin-Tragacanth Gum

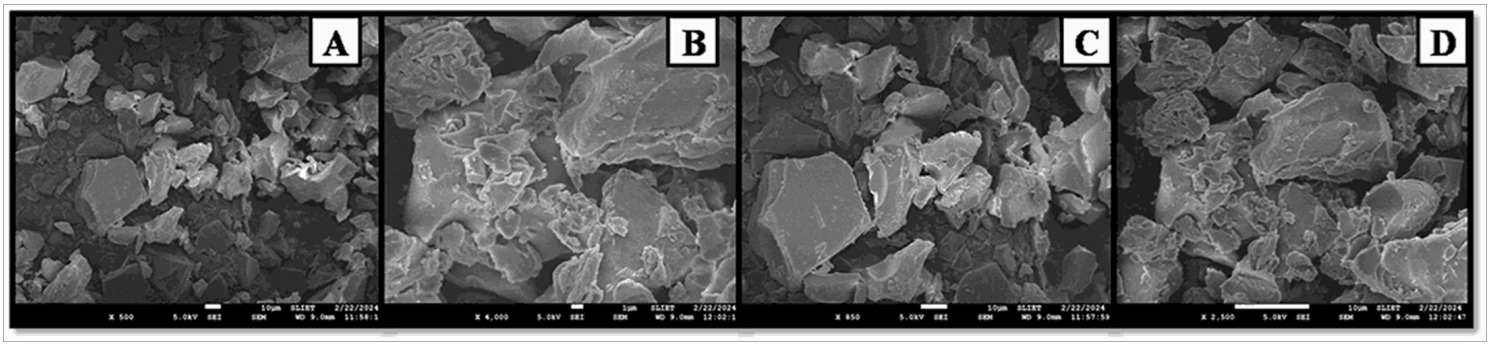


Figure 6

Field Emission Scanning Electron Microscopy (FE-SEM) micrographs of encapsulated powders: (A) Maltodextrin; (B) Maltodextrin-Guar Gum; (B) Maltodextrin -Acacia Gum; (C) Maltodextrin-Tragacanth Gum

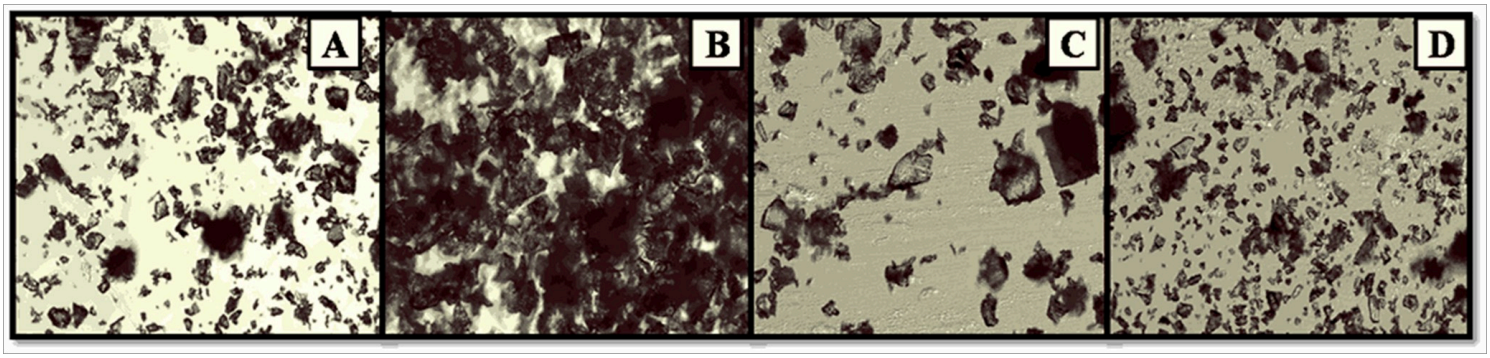


Figure 7

Microscopy of (A) Maltodextrin; (B) Maltodextrin-Guar Gum; (B) Maltodextrin-Acacia Gum; (C) Maltodextrin-Tragacanth Gumat magnification to 10 µm

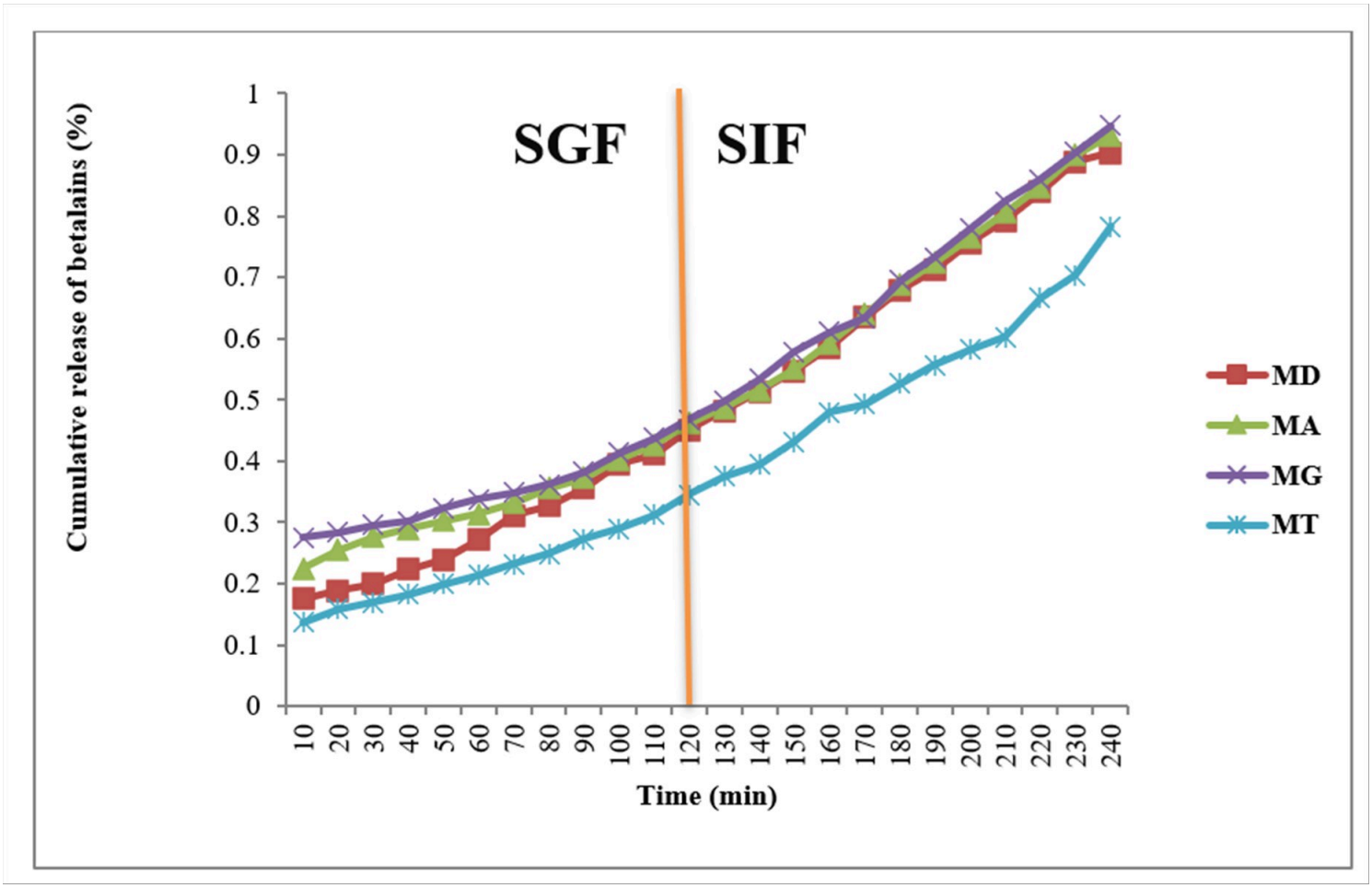


Figure 8

*In vitro*release kinetics of encapsulated betalains powders(A) Maltodextrin; (B) Maltodextrin-Guar Gum; (B) Maltodextrin-Acacia Gum; (C) Maltodextrin-Tragacanth Gum

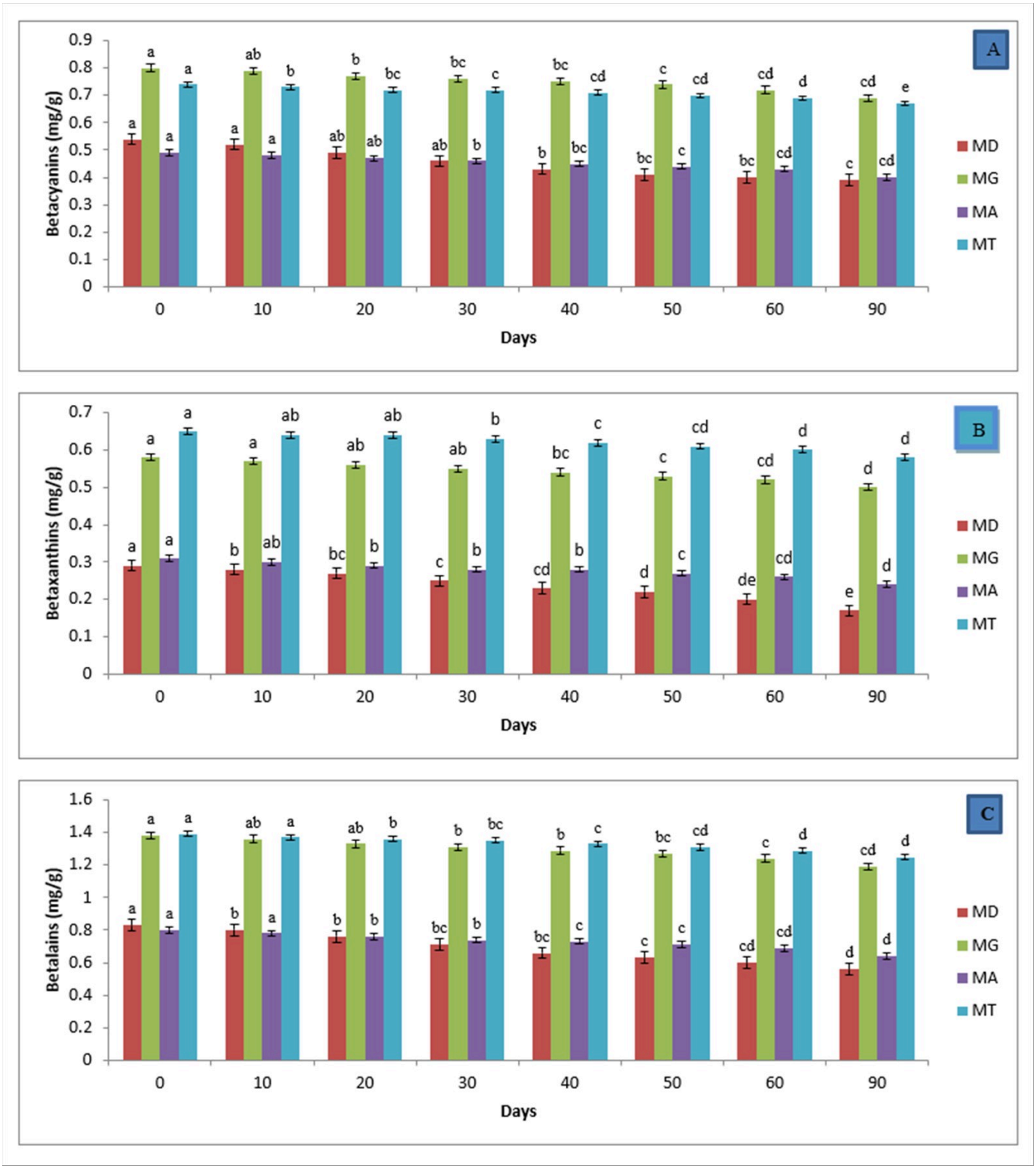


Figure 9

Storage stability of (MD) Maltodextrin; (MG) Maltodextrin-Guar Gum; (MA) Maltodextrin -Acacia Gum; (MT) Maltodextrin-Tragacanth Gum

Supplementary Files

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