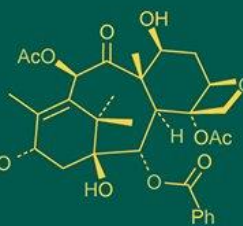
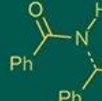


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 1218-1222
www.biochemjournal.com
Received: 25-06-2026
Accepted: 29-07-2026

Gaurav Pratap Singh
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Varanasi, Uttar
Pradesh, India

Dinesh Chandra Rai
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Varanasi, Uttar
Pradesh, India

Dr. Abhishek Dutt Tripathi
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Varanasi, Uttar
Pradesh, India

Corresponding Author:
Dr. Abhishek Dutt Tripathi
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Varanasi, Uttar
Pradesh, India

Preparation and characterization of *Nyctanthes arbor-tristis* flower powder nano-encapsulates using WPC-pectin nano-complexes

Gaurav Pratap Singh, Dinesh Chandra Rai and Abhishek Dutt Tripathi

DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Sn.9599>

Abstract

Nyctanthes arbor-tristis (NAT), commonly known as Parijata, contains bioactive constituents with potential applications in functional foods and nutraceuticals. The present study aimed to develop and characterize NAT flower powder nanoencapsulates using whey protein concentrate (WPC)-pectin nanocomplexes at different core-to-wall ratios (1:5, 1:10 and 1:15). Dried NAT flowers were freeze-dried, powdered and incorporated into bio-polymeric systems, followed by ultrasonic treatment and freeze drying. The nano-encapsulates were evaluated for density, porosity, flowability, hygroscopicity, wettability and colour characteristics. FTIR spectroscopy was also performed to investigate functional groups and possible interactions between NAT constituents and the encapsulating matrix. Increasing the wall-material proportion increased bulk and tapped densities, whereas particle density, porosity and hygroscopicity decreased. Wettability time increased with increasing wall-material concentration, while the formulations exhibited good flow characteristics based on Carr's index and Hausner ratio. Colour analysis showed increased lightness with increasing wall-material proportion. FTIR spectra showed similar characteristic absorption regions among formulations, indicating retention of major functional groups, while variations in peak intensity suggested interactions between NAT constituents and the biopolymeric matrix. Overall, WPC-pectin nanocomplexes demonstrated potential for developing stable NAT-based encapsulated powders for potential food and nutraceutical applications.

Keywords: *Nyctanthes arbor-tristis*, nano-encapsulation, FTIR spectroscopy, freeze drying, functional foods

1. Introduction

Nyctanthes arbor-tristis (NAT), commonly known as Parijata or night flowering jasmine, is a traditionally valued medicinal plant with considerable potential as a source of biologically active phytochemicals. The flowers contain various bioactive constituents that may contribute to antioxidant and other functional properties, making NAT a promising candidate for incorporation into value-added functional food and nutraceutical systems. However, the direct utilization of plant-derived bioactive compounds in food systems can be restricted by their sensitivity to environmental conditions, limited stability and susceptibility to degradation during processing and storage. Encapsulation provides an effective approach for protecting sensitive bioactive constituents by entrapping them within a suitable protective matrix, thereby improving their physical stability, handling characteristics and potential application in food products (Rahane *et al.*, 2025) [8].

Protein polysaccharide complexes have attracted considerable interest as encapsulating systems because of their ability to provide interfacial protection and improve the functional properties of encapsulated bioactive compounds. Whey protein concentrate (WPC), pectin and other biopolymers can form protective matrices capable of incorporating plant-derived compounds. In the present study, WPC and pectin-based nano-complexes were employed as a carrier system for NAT flower powder. The bio-polymeric solutions were prepared at different concentrations and subjected to ultrasonic treatment to facilitate formation of the complexes, followed by incorporation of NAT powder and pH adjustment. The resulting formulations were freeze-dried to obtain stable powdered nano-encapsulates (El-Said *et al.*, 2025) [2].

The characteristics of encapsulated powders are strongly influenced by the ratio between the bioactive core and wall material. Changes in this ratio can affect powder density, porosity, moisture adsorption, wettability, flow behaviour and colour, which ultimately influence the handling, storage and reconstitution properties of the encapsulated product. Therefore, characterization of these properties is essential for determining the suitability of NAT nano-encapsulates for subsequent food applications. In addition, Fourier-transform infrared spectroscopy (FTIR) provides useful information regarding the functional groups present in the encapsulated system and can help identify possible interactions between the NAT constituents and the biopolymeric matrix (Singh *et al.*, 2026) [11].

Accordingly, the present study was undertaken to prepare NAT flower powder nanoencapsulates using WPC and pectin-based nano-complexes at different core-to-wall ratios (1:5, 1:10 and 1:15) and to evaluate their physical, flow, hygroscopic, wettability and colour characteristics. FTIR analysis was further performed to investigate the functional groups and possible interactions between NAT constituents and the encapsulating matrix. The study provides a basis for identifying an appropriate core-to-wall ratio for the development of stable and functionally suitable NAT-based encapsulated powders.

1.1 Preparation of *Nyctanthes arbor-tristis* flower powder

Dried flowers of *Nyctanthes arbor-tristis* (NAT) were procured from the Botanical Garden, Banaras Hindu University (BHU), Varanasi, India. The flowers were manually sorted to remove extraneous matter and visibly damaged or discoloured flowers. The sorted flowers were subjected to freeze drying using a laboratory-scale freeze dryer. Prior to freeze drying, the samples were appropriately arranged in sterile trays and frozen at -50°C for 24 h (Rao *et al.*, 2025) [9]. The frozen flowers were subsequently dried under vacuum until a constant moisture content was achieved. The freeze-dried flowers were then collected and gently ground using a stainless-steel laboratory grinder to obtain a homogeneous powder. The resulting NAT flower powder was passed through an appropriate sieve to obtain uniform particle size and stored in airtight, light-resistant polyethylene bags at low temperature until further analysis (Hafeez *et al.*, 2025) [4].

1.2 Preparation of biopolymeric solutions

First, by dissolving WPC (4, 6, and 8 g) in deionized water, the solutions of protein with 4, 6, and 8% concentrations (w/v) were prepared. To prepare sodium alginate solutions with 0.5, 0.75, and 1% concentrations (w/v), deionized water was heated to 70°C , and then sodium alginate powder was added with constant stirring. Maltodextrin was then used to increase the dry matter of the solutions. For this purpose, by dissolving 30 g of maltodextrin in deionized water, a maltodextrin solution with an initial concentration of 30% (w/v) was prepared. By using a magnetic stirrer at 1000 rpm, the solutions were mixed for 30 min. Finally, the protein solutions were placed in a refrigerator overnight, and the alginate solutions were kept at room temperature for complete rehydration (Heydari *et al.*, 2021) [5].

1.3 Preparation of WPC-pectin nanocomplexes loaded with NAT extract

After preparing the biopolymeric solutions in the previous stage, they were treated with an ultrasonic homogenizer (20 kHz with a 12 mm probe, Ultrasonic Technology Company, Iran) for 10 min at a temperature of 25°C and 350 W by placing the sample container in a water-cooled container. During the ultrasonic treatment, NAT flower powder (20% of the total solids) was added into the mixture. Then, adjustment of pH was performed with HCl and NaOH 1 N to form the complexes (Jafari *et al.*, 2007) [5]. Part of microcapsules were stored at -20°C during 24 h and freeze-dried in a freeze-dryer for 24 h (initial temperature $25\pm 2^{\circ}\text{C}$ and pressure 0.220 mbar), for further use (Heydari *et al.*, 2021) [5].

1.4 Determination of physical properties of nanoencapsulated powders

The physical, flow and functional properties of the nanoencapsulated powders were determined following the methods described by Parvez *et al.* (2022) [7], with suitable modifications. Briefly, 2 g of powder sample was gently transferred into a 10 mL graduated glass cylinder without compaction, and the occupied volume was recorded to determine bulk density. Tapped density was determined by manually lifting and dropping the cylinder containing the sample from a vertical height of 15 ± 2 mm until no discernible variation was observed between two consecutive volume readings. Bulk and tapped densities were calculated as the ratio of powder mass to the corresponding bulk and tapped volumes, respectively. Particle density was determined by the liquid displacement method, wherein approximately 1 g of powder was weighed into a 10 mL graduated centrifuge tube fitted with an airtight stopper, followed by the addition of 5 mL petroleum ether. The tube was vigorously shaken for 1 min to uniformly disperse the powder particles, and the tube walls were rinsed with an additional 1 mL petroleum ether, giving a total volume of 6 mL. The final volume of petroleum ether containing the dispersed powder was recorded, and particle density was calculated based on the volume displaced by the powder particles. Porosity was subsequently calculated from the bulk and particle densities. The flowability of the nanoencapsulates was evaluated using Carr's compressibility index (CI) and Hausner ratio (HR), calculated from the bulk and tapped densities using the equations $\text{CI} (\%) = [(\rho_{\text{tapped}} - \rho_{\text{bulk}})/\rho_{\text{tapped}}] \times 100$ and $\text{HR} = \rho_{\text{tapped}}/\rho_{\text{bulk}}$, respectively. Wettability was determined using a modified method of Jinapong *et al.* (2008). Briefly, 100 mL of distilled water maintained at $25\pm 1^{\circ}\text{C}$ was transferred into a 250 mL beaker, and a glass funnel mounted on a ring stand was positioned such that a 10 cm gap was maintained between the lower end of the funnel and the water surface. A test tube was placed inside the funnel to close its lower opening, and 0.1 g of powder was placed around the test tube. The test tube was then lifted and the stopwatch was simultaneously started. The time required for the powder to become completely wetted, operationally defined as the point at which all particles penetrated the water surface, was recorded. Hygroscopicity was determined according to Zokti *et al.* (2016) [12], with modifications. Approximately 1 g of powder was placed in a desiccator at room temperature containing a saturated sodium chloride solution providing 75.29% relative

humidity. After 7 days of exposure, the samples were weighed and the increase in mass was considered as moisture adsorbed by the powder; hygroscopicity was expressed as the percentage of adsorbed moisture. Colour characteristics of the nanoencapsulated powders and dried NAT extract were measured using a colorimeter (CM-508d, Minolta Co., Japan) according to the CIELAB system, following Caliskan and Dirim (2016)^[1]. The instrument was calibrated using a standard white ceramic plate before measurement. The colour parameters L^* , a^* and b^* were recorded, where L^* represents lightness (0 = black and 100 = white), positive and negative a^* values represent redness and greenness, respectively, and positive and negative b^* values represent yellowness and blueness, respectively. Hue angle and chroma were calculated from the a^* and b^* values. Encapsulation efficiency (EE) was determined based on phenolic content using the method of Saikia *et al.* (2015)^[10], with modifications. Approximately 200 mg of nanoencapsulate was dispersed in 2 mL ethanol (1:1, v/v) and filtered through an Acrodisc syringe filter to quantify surface-associated polyphenols. For determination of total polyphenolic content, another 200 mg sample was dispersed in 2 mL methanol acid (50:8:42, v/v/v), crushed for several minutes to facilitate disintegration of the wall material, vortexed and ultrasonicated for 20 min using an ultrasonic cleaner (JSGW, Ambala, India). The mixture was centrifuged at $2057 \times g$ for 10 min, and the supernatant was filtered through an Acrodisc syringe filter. The total polyphenolic content was quantified using the Folin-Ciocalteu reagent assay according to Gerolis *et al.* (2017)^[3], with modifications. Encapsulation efficiency was calculated as the percentage ratio of entrapped polyphenolic content to the total polyphenolic content. All measurements were performed in triplicate.

1.5 FTIR study of nano-encapsulated powders.

The functional groups present in the NAT nanoencapsulates prepared at different core-to-wall ratios (1:5, 1:10 and 1:15) were analyzed at room temperature using a Fourier-transform infrared (FTIR) spectrometer. For analysis, an appropriate amount of freeze-dried NAT nanoencapsulate was gently mixed with micronized KBr powder and compressed into pellets. The FTIR spectra were recorded over the wavenumber range of $4000\text{--}400\text{ cm}^{-1}$ to identify the characteristic functional groups and assess possible interactions between NAT constituents and the WPC-pectin encapsulating matrix. Each spectrum was recorded under identical instrumental conditions to facilitate comparison among the different formulations (Singh *et al.*, 2026)^[11].

2. Result and Discussion

2.1 Physical properties, flow characteristics and colour attributes of nano-encapsulated powders.

The physical properties, flow characteristics and colour attributes of the NAT nano-encapsulates prepared at different core-to-wall material ratios (1:5, 1:10 and 1:15) are presented in Table 1. The bulk density of the formulations

increased from 0.48 to 0.53 g/cm³ with an increase in the wall-material proportion from 1:5 to 1:15. Similarly, tapped density increased from 0.51 to 0.67 g/cm³. The increase in density may be associated with improved packing of particles and the greater contribution of the wall material to the dry solids of the encapsulated powder. In contrast, particle density decreased from 1.68 to 1.41 g/cm³ as the wall-material proportion increased.

The porosity of the powders decreased from 69.5% at the 1:5 ratio to 52.7% at the 1:15 ratio. The lower porosity at higher wall-material concentrations may indicate more efficient particle packing and reduced interparticle void spaces. Hygroscopicity also decreased progressively from 2.80% to 1.95%, suggesting that increasing the proportion of wall material may improve the resistance of the encapsulated powder to moisture uptake. Reduced hygroscopicity is desirable for powdered encapsulates because excessive moisture absorption can adversely affect powder stability, flowability and storage characteristics.

The wettability time increased from 35.0 s for the 1:5 formulation to 53.33 s for the 1:15 formulation. The longer wetting time observed at higher wall-material concentrations may be related to changes in the surface characteristics and composition of the encapsulated particles. Although increased wettability time indicates slower wetting, the values remained within a practical range for reconstitution of the powdered product.

The Carr's compressibility index (CI) ranged from 4.54 to 6.81, while the Hausner ratio (HR) ranged from 1.07 to 1.12. The relatively low CI and HR values indicated good flow characteristics of the prepared nanoencapsulates. Among the formulations, the 1:15 treatment exhibited the lowest CI, whereas the 1:5 formulation showed the lowest HR. Overall, the observed CI and HR values suggest that variation in the core-to-wall ratio had a relatively limited effect on the flow behaviour of the powders.

The colour characteristics of the nanoencapsulates were also influenced by the core-to-wall ratio. The L^* value increased from 47.54 in the 1:5 formulation to 53.55 in the 1:15 formulation, indicating an increase in lightness with increasing wall-material concentration. The a^* values remained positive, indicating a tendency towards redness, whereas the positive b^* values indicated yellowness. The 1:5 formulation exhibited comparatively higher b^* and chroma values, suggesting greater colour intensity, which may be attributed to the higher relative contribution of NAT extract pigments at the lower wall-material concentration. Increasing the wall-material proportion generally resulted in a lighter powder with reduced colour intensity.

Overall, increasing the wall-material proportion from 1:5 to 1:15 resulted in higher bulk and tapped densities, lower particle density, porosity and hygroscopicity, and increased wetting time. The colour characteristics also shifted towards lighter powders with increasing wall-material concentration. These changes demonstrate that the core-to-wall ratio plays an important role in determining the physical, flow and optical properties of NAT nanoencapsulates.

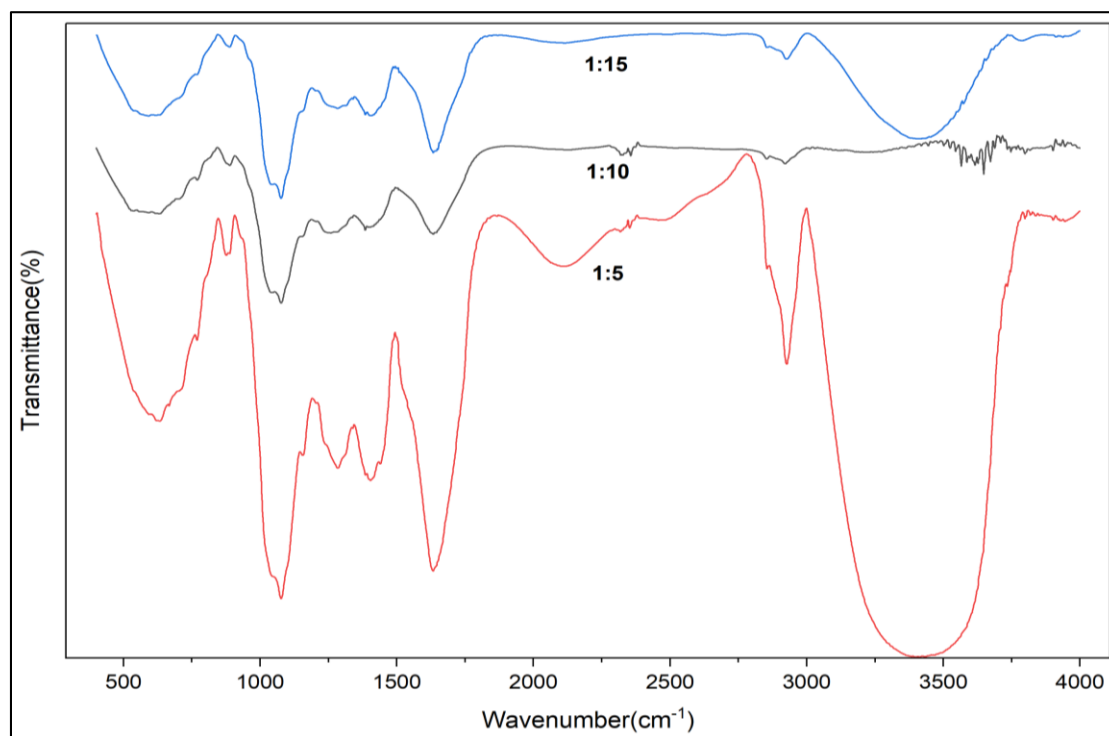
Table 1: Physical properties, flow characteristics and colour attributes of nano-encapsulated powders.

Sample	ρ_{bulk} (g/cm ³)	ρ_{tapped} (g/cm ³)	ρ_{particle} (g/cm ³)	ε (%)	Hygroscopicity (%)	Wettability (s)	CI	HR	L*	a*	b*	Hue	Chroma
1:5	0.48±0.02 ^a	0.51±0.01 ^a	1.68±0.01 ^d	69.5±0.01 ^c	2.80±0.01 ^c	35.00±1.00 ^b	6.81±2.08 ^a	1.07±0.02 ^a	47.54±0.14 ^b	6.01±0.08 ^b	41.56±0.42 ^b	1.43±0.00 ^b	41.99±0.41 ^a
1:10	0.51±0.01 ^b	0.60±0.02 ^b	1.52±0.01 ^c	60.3±0.04 ^c	2.31±0.01 ^b	41.00±1.00 ^c	6.18±0.10 ^a	1.10±0.06 ^a	52.56±0.99 ^a	4.02±0.29 ^a	33.47±2.92 ^a	1.45±0.02 ^a	33.71±2.86 ^b
1:15	0.53±0.01 ^c	0.67±0.02 ^c	1.41±0.01 ^b	52.7±0.05 ^b	1.95±0.01 ^a	53.33±1.50 ^d	4.54±0.63 ^a	1.12±0.13 ^a	53.55±0.80 ^a	4.52±0.10 ^a	41.57±0.11 ^b	1.46±0.00 ^b	41.81±0.11 ^a

2.2 FTIR analysis of NAT nano-encapsulates

The FTIR spectra of the NAT nano-encapsulates prepared at different core-to-wall ratios (1:5, 1:10 and 1:15) are presented in Figure 1. The spectra of all formulations exhibited broadly comparable absorption patterns, indicating the retention of the major functional groups of NAT and the encapsulating matrix after nano-encapsulation. A broad absorption region in the 3200-3500 cm⁻¹ range was observed in all formulations, which can be attributed predominantly to O-H stretching vibrations associated with hydroxyl-containing phenolic and flavonoid constituents of NAT and hydroxyl groups present in the wall materials. The bands in the 2800-3000 cm⁻¹ region correspond mainly to aliphatic C-H stretching vibrations. Absorption bands in the 1600-1650 cm⁻¹ region may be associated with C = O and/or C = C stretching vibrations and, depending on the composition of the wall matrix, may also include contributions from amide groups. The bands observed in the ~1400-1500 cm⁻¹ region can be associated with C-H bending and related skeletal vibrations, whereas the prominent fingerprint-region bands between 1000 and 1200

cm⁻¹ are mainly related to C-O, C-C and C-O-C stretching vibrations. Variations in the intensity and shape of these bands were observed with increasing wall-material proportion from 1:5 to 1:15. Such changes may be attributed to differences in the relative contribution of NAT phyto-constituents and wall-material components and to intermolecular interactions, particularly hydrogen bonding, between the core and wall matrix. Importantly, no complete disappearance of the characteristic functional-group regions was observed among the formulations, suggesting that the principal chemical functionalities of NAT were retained following the encapsulation process. The progressive changes in spectral intensity with increasing wall-material concentration further indicate successful association of NAT constituents with the encapsulating matrix rather than formation of an entirely new chemical structure. Overall, the FTIR results support the successful incorporation of NAT into the wall matrix and demonstrate that the core-to-wall ratio influences the relative contribution and interaction of the functional groups present in the resulting nano-encapsulates (Singh *et al.*, 2026)^[11].

**Fig 1:** FTIR study of nano-encapsulated powders.

3. Conclusion

The present study demonstrated the feasibility of incorporating freeze-dried *Nyctanthes arbor-tristis* (NAT) flower powder into WPC and pectin-based nano-complexes at different core-to-wall ratios (1:5, 1:10 and 1:15). Increasing the wall-material proportion resulted in higher bulk and tapped densities, lower particle density, porosity and hygroscopicity, and increased wettability time, while the relatively low Carr's index and Hausner ratio indicated good flow characteristics of the nano-encapsulated powders.

The increase in L* value with increasing wall material concentration indicated the formation of lighter coloured powders, with corresponding changes in other colour attributes. FTIR spectra showed retention of the major functional groups of NAT and the encapsulating matrix, while variations in band intensity and shape suggested possible intermolecular interactions, particularly hydrogen bonding, between NAT constituents and the bio-polymeric matrix. Overall, the findings demonstrate that the core-to-wall ratio influences the physical, functional and spectral

characteristics of NAT nano-encapsulates, indicating the potential of WPC-pectin nano-complexes as a suitable carrier system for the development of stable NAT based powdered ingredients for potential food and nutraceutical applications.

References

1. Caliskan G, Dirim SN. The effect of different drying processes and the amounts of maltodextrin addition on the powder properties of sumac extract powders. *Powder Technology*. 2016;287:308-314.
2. El-Said MM, Hamzalıoğlu A, Gökmen V. Characterization of whey protein concentrate-maltodextrin-pomegranate peel phenolic compounds ternary conjugate as a novel food-grade stabilizer for nano-Pickering emulsion. *Food Research International*. 2025;203:115894.
3. Gerolis LG, Lameiras FS, Krambrock K, Neves MJ. Effect of gamma radiation on antioxidant capacity of green tea, yerba mate, and chamomile tea as evaluated by different methods. *Radiation Physics and Chemistry*. 2017;130:177-185.
4. Hafeez HT, Muzammil HS, Ahmad Z, Alsulami T, Waseem M, Mehmood T, *et al.* Assessment of nutritional, antioxidant, physicochemical, and storage stability of carrot powder supplemented goat milk yogurt. *Journal of Agriculture and Food Research*. 2025;19:101581.
5. Heydari MK, Assadpour E, Jafari SM, Javadian H. Encapsulation of rose essential oil using whey protein concentrate-pectin nanocomplexes: Optimization of the effective parameters. *Food Chemistry*. 2021;356:129731.
6. Jinapong N, Supphantharika M, Jamnong P. Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. *Journal of Food Engineering*. 2008;84(2):194-205.
7. Parvez S, Wani IA, Masoodi FA. Nanoencapsulation of green tea extract using maltodextrin and its characterisation. *Food Chemistry*. 2022;384:132579.
8. Rahane RD, Shaikh SA, Andhale AT, Kadam VN, Nimase PA, Musale YJ. Phytochemical and medicinal analysis of night jasmine: A review. *International Journal of Research in Pharmacy and Allied Science*. 2025;4(2):33-46.
9. Rao V, Poonia A, Dhewa T. Metabolomics profiling and techno-functional characterization of freeze-dried pumpkin flower (*Cucurbita maxima*) powder for food fortification. *Food Production, Processing and Nutrition*. 2025;7(1):49.
10. Saikia S, Mahnot NK, Mahanta CL. Optimisation of phenolic extraction from *Averrhoa carambola* pomace by response surface methodology and its microencapsulation by spray and freeze drying. *Food Chemistry*. 2015;171:144-152.
11. Singh GP, Tripathi AD, Rai DC, Maurya VK, Vikranta U, Agarwal A, *et al.* Nutritional and bio-active profiling of papaya leaf-enriched jaggery using High Resolution Accurate Mass Spectrometry (HRAMS). *LWT*. 2026:119682.
12. Zokti JA, Sham Baharin B, Mohammed AS, Abas F. Green tea leaves extract: Microencapsulation, physicochemical and storage stability study. *Molecules*. 2016;21(8):940.