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Bioactive Polysaccharide from *Ziziphus mauritiana*: Isolation, Optimization and Evaluation as Binding Excipient

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Natural polysaccharides have garnered considerable interest as excipients in pharmaceutical formulations due to their biocompatibility, functional versatility and structural diversity. This study focuses on the isolation, optimization and structural characterization of a novel polysaccharide derived from *Ziziphus mauritiana* and its evaluation as a tablet binding agent. The extraction process was optimized using response surface methodology (RSM), ensuring maximal yield under controlled conditions. Polysaccharide yield ranged 5.6-9.4%. Max yield (9.4%) achieved at 1:5 pulp-to-water ratio, 60 ºC extraction. Structural elucidation was performed through Fourier-transform infrared spectroscopy (FTIR), nuclear magnetic resonance (NMR) and gas chromatography-mass spectrometry (GC-MS). Linkage analysis revealed the predominance of →4)-Man*p*-(1→glycosidic linkages, indicating a mannose-rich backbone. Monosaccharide profiling confirmed mannose as a major constituent. The polysaccharide was then formulated as a binder in compressed tablet matrices and compared against potato starch as a standard. The *Z. mauritiana* polysaccharide demonstrated favourable binding characteristics and resulted in significantly slower drug release compared to potato starch. After 12 h, formulations containing the novel binder released approximately 18% less drug, attributed to the presence of the mannose moiety and its influence on matrix integrity and hydration behaviour. The mannose-rich polysaccharide from *Z. mauritiana* exhibits promising potential as a natural binding agent in sustained-release tablet formulations. Its ability to modulate drug release kinetics, combined with its natural origin, supports its application as a viable alternative to conventional starch-based binders in pharmaceutical technologies.

Keywords: *Ziziphus mauritiana*, RSM optimization, Monosaccharide analysis, Binding properties.

INTRODUCTION

Ziziphus mauritiana, commonly known as Indian jujube or Ber, is a spiny, evergreen shrub or small tree, reaching up to 15 m, adapted to arid and semi-arid regions. The foliage consists of alternate, ovate to elliptic leaves. The upper surface is glossy green, while the underside is densely covered with whitish hairs, a highly distinctive feature in botanical terms. Small flowers, greenish-yellow in colour, arise in axillary clusters, which then form the edible drupes; these are variable from globose to ovoid and turn from yellowish to reddish on maturation [1,2].

Phytochemically, *Z. mauritiana* provides ample opportunities of extraction of diverse bioactive compounds from its different parts. Considerable amounts of flavonoids, alkaloids, terpenoids, saponins, tannins, glycosides and phenolic compounds are present in the leaves, fruits and seeds. The main ones identified are triterpenoic acids (alphitolic acid, betulinic acid, oleanolic acid, ursolic acid, *etc.*), cyclopeptide alkaloids (spinosin, frangufoline) and fatty acids (palmitic acid, linolenic acid, *etc.*). Fruits have been reported to be very rich in vitamin C and also in some essential minerals, namely iron, zinc, calcium and phosphorus. Therefore, these phytochemicals are responsible for the traditional and scientifically proven activities of the plant, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic and anticancer activities. Several researchers [3,4] have reported on the phytochemistry of these plants, however, much less work seems to have been done with regard to the polysaccharide of *Z. mauritiana*.

Plant polysaccharides are complex carbohydrates composed of numerous monosaccharide units linked by glycosidic

bonds. They serve essential biological functions in plants, primarily as energy reserves such as starch stored in tubers and seeds and as key structural components, with cellulose providing rigidity and shape to cell walls. Beyond their biological roles, plant polysaccharides are invaluable to humans as renewable natural polymers, offering diverse applications in food, medicine, materials science and biotechnology [5-7]. For example, cellulose is used to produce paper and used as source of dietary fibres for gut health [8]. Pectins can be used as jelling agents in foods (*e.g.* jams) [9]; some gums are used to thicken, stabilize or emulsify foods [10], plant polysaccharides can be used for drug delivery systems [11,12], dressings and/or as excipients [12]; because of their range of functional properties and plant polysaccharides are biocompatible and non-toxic [13]. However, the commercial significance of plant polysaccharides lies primarily in the diversity of their structural features including the composition and sequence of monosaccharide units, the nature of glycosidic linkages (α or β, linear or branched) and their molecular weight distribution [14,15]. These structural variations can directly influence the physicochemical and functional properties of the polysaccharides such as binding affinity, solubility, gel-forming ability, viscosity and mucoadhesiveness, which in turn enable the design of "tailored" formulations for specific pharmaceutical applications, including controlled and targeted drug delivery. In this study, a previously unexplored polysaccharide isolated from *Z. mauritiana* was optimized, characterized and evaluated for its binding properties.

EXPERIMENTAL

Ziziphus mauritiana fruit was obtained from the local trees of Barasat city, India. The plant authenticated by Botanical Survey of India bearing no. CNH/Tech II/2023/96. Standard monosaccharides (galactose, glucose, mannose, rhamnose and sorbose) were procured from Nice Chemicals Pvt. Ltd. Cellulose membrane with retention of MW >12 kDa and AR grade trifluoroacetic acid were purchased from Himedia. All the other chemicals used were of analytical grade.

Isolation and purification of polysaccharide: The isolation of the polysaccharide was performed as per Pathak *et al.* [16] method with slight modifications. In this process, different ratios (1:3-1:9) of *Z. mauritiana* soft fruit pulp was taken in distilled water after sieving through 100 mesh and cooked for 6 h at temperature ranging from 30-75 ºC. After cooling at 4 ºC overnight, the dispersion was filtered through a muslin towel. The filtered dispersion was centrifuged for 20 min at 3500 rpm (R-8C, Remi, India). The residual debris were removed and the supernatant was concentrated to around 20% of its original volume. The concentrated supernatants were precipitated in 95% ethanol at a ratio of 1:5 (v/v). The precipitate was separated by centrifugation (3500 rpm for 5 min) and dialyzed using cellulose membrane (Himedia 110 M.W. 12-14 kDa) to remove low molecular weight material after 12 h of storage at 4 ºC. The aqueous dialyzed dispersion was collected and lyophilized, yielding a polysaccharide, ZMBP, at different percentages of yield.

Optimization: Polysaccharide extraction from the fruit pulp of *Z. mauritiana* was optimized through response surface methodology (RSM), utilizing Minitab software for statistical modeling. This approach is widely recognized for its effectiveness in optimizing complex processes by enabling systematic experimental design, predictive modeling and interaction analysis among multiple variables. The central composite design (CCD) was employed to investigate both linear and non-linear influences as well as variable interactions impacting extraction efficiency. The main parameters assessed included the pulp-to-water ratio, which was adjusted between 1:3 and 1:9 and the extraction temperature, ranging from 30 ºC to 75 ºC.

Elemental analysis: The elemental composition of the *Z. mauritiana* polysaccharide (ZMBP) was determined using JCM 6000 Plus analyzer (JEOL, Japan). Approximately 2-3 mg of dried polysaccharide sample was accurately weighed into tin capsules. Acetanilide was used as a standard for calibration. The combustion furnace was maintained at 1150 ºC and the reduction furnace at 850 ºC. Oxygen was supplied at a flow rate of 100 mL/min for complete combustion. The resulting gases were separated chromatographically and detected by thermal conductivity detectors. Each sample was analyzed in triplicate and the mean values are reported [17].

Monosaccharide analysis: Standard monosaccharide samples (glucose, galactose, mannose, rhamnose and sorbose) and the isolated ZMBP polysaccharide samples were compared using Fourier transform infrared (FTIR) spectroscopic analysis (Bruker Alpha II, Germany). Spectra were recorded using a Bruker Opus Software. Data was acquired using an FTIR spectrometer across the 4000-400 cm^{-1} range. The resulting spectra allowed for the identification of absorption bands typical of monosaccharide functional groups, alongside unique fingerprint peaks. By comparing these against standard references and published data for monosaccharides, the probable composition of the ZMBP polysaccharide could be inferred [18]. The isolated ZMBP sample (30 mg d.b.) was solubilized in 99% deuterium oxide. ^{1}H & ^{13}C spectra of the polysaccharide dispersion were recorded at 27 ºC on 400 MHz NMR spectrometer (Bruker Advance 400, Tokyo, Japan) with an assigned delay time of 2 s.

Linkage analysis: ZMBP was methylated using a modified Ciucanu & Kerek method [19]. The process involved dissolving ZMBP in DMSO, reacting with NaOH and Methyl iodide, then purified the methylated product *via* chloroform-water partitioning. Methylation was confirmed through FTIR analysis by observing the disappearance of the O-H band. The methylated CGPS was then hydrolyzed with TFA, reduced with $NaBH_4$ and acetylated. Finally, the resulting partially methylated alditol acetates were analyzed by GC-MS to determine the carbohydrate linkages.

Formulation of tablets: Six distinct formulations (F1-F6) of propranolol HCl (10 mg API) were developed. Each formulation incorporated varying concentrations (4-6 mg) of binding agents, specifically potato starch and ZMBP polysaccharide. Lactose (374-376 mg) served as a diluent, while talc (5 mg) and magnesium stearate (5 mg) functioned as a glidant and lubricant, respectively (Table-1).

The process involved dry mixing the propranolol HCl with starch/ZMBP polysaccharide and lactose, followed by the gradual addition of water (refer to Table-1 for specifics). The resulting moist mass was then sieved through a #12 mesh.

TABLE-1
FORMULA COMPOSITION OF TABLETS

Ingredients (mg)	F1	F2	F3	F4	F5	F6
Propranolol hydrochloride	10	10	10	10	10	10
Starch (Potato)	4	5	6	–	–	–
ZMBP	–	–	–	4	5	6
Lactose	376	375	374	376	375	374
Magnesium stearate	5	5	5	5	5	5
Talc	5	5	5	5	5	5

To remove moisture, the granules were dried in a hot air oven at 50 ºC for 30 min. After drying, they were screened again using a #16 mesh and subsequently blended with talc and magnesium stearate. These granules were then compressed into 250 mg tablets using an 8-station tablet punching machine (Kambert, Ahmedabad, India).

Evaluation of granules

Organoleptic evaluations: Granules were visually inspected for colour, shape and uniformity. Odour was assessed by sniffing and taste was evaluated by a trained panel for specific attributes.

Determination of densities, density-related properties, flow rate and angle of repose: The granules were systematically analyzed to evaluate their physical attributes and flow characteristics, which are essential for efficient tablet production and optimal product performance. Key measurements included bulk and tapped densities, which served as the basis for calculating critical flow indicators like Carr's Index and the Hausner ratio-metrics that reveal the granules' packing potential and cohesive tendencies [20]. To further assess flow behaviour, the granules' flow rate was carefully measured, providing insight into their ability to move consistently through processing equipment, a crucial factor in achieving uniform die filling during compression. Moreover, the angle of repose was recorded to gauge interparticle friction and cohesion, offering another perspective on flowability. These analytical procedures mirrored the protocols applied previously to gum powder, ensuring methodological consistency and enabling reliable comparisons between materials [21].

Evaluation of tablets

Weight variation: A total of 20 tablets were randomly chosen from each production batch for individual weight assessment using a precision analytical balance (Wensar, PGB220, India). The average weight and its corresponding standard deviation were determined. Tablet dimensions, including thickness and diameter, were measured with a Vernier caliper to ensure uniformity.

Crushing strength: Mechanical strength assessment was conducted on a randomly selected set of 20 tablets, employing diametric compression *via* a calibrated Pfizer hardness tester (LabJunction, India). This evaluation quantified the force necessary to induce fracture, providing critical insights into the structural integrity and robustness of the tablet formulation [22].

Friability: To evaluate mechanical durability, 10 intact tablets were randomly selected, carefully dedusted and individually weighed with precision. These samples were then introduced into a friability testing apparatus (Friabiltor; Vinayak Enterprise, India), where they were subjected to rotational stress at 25 rpm for 4 min. Following the procedure, tablets were once again dedusted and reweighed to quantify mass loss. The percentage weight reduction served as a measure of friability, reflecting the formulation's resistance to abrasion and surface degradation during handling and transport [23].

Disintegration tests: Disintegration performance was evaluated using six randomly selected tablets from each formulation batch. Each tablet was tested in distilled water maintained at 37 ± 2 ºC within a calibrated disintegration testing apparatus (Vinayak Enterprise, India). The endpoint of disintegration was defined as the complete absence of any residual granules on the mesh screen, indicating full dispersion of the tablet matrix. This parameter offers essential insight into the breakdown behaviour of formulation under physiological conditions, a critical determinant of oral bioavailability and therapeutic efficacy [24].

***In vitro* dissolution studies:** The release profile of paracetamol from tablets was determined using USP type II dissolution apparatus (LabIndia DS8000, India) at paddle rotation speed of 50 rpm. The dissolution medium was 900 mL of acidic buffer of pH 1.2 maintained at 37 ± 0.5 ºC for 2 h followed by phosphate buffer of pH 6.8 for next 10 h. In all experiments, 5 mL of sample was withdrawn at specific interval at 15, 30, 45, 60, 120, 180, 240, 300, 360, 420, 480, 540, 660 and 720 min. Each withdrawn sample was replaced with an equal volume of fresh medium at the same temperature to maintain sink condition. Absorbance of the samples was measured using UV-visible spectrophotometer (Shimadzu UV 1900, Japan) at 314 nm after appropriate dilution with specific buffers.

Drug release kinetics: The data obtained from *in vitro* drug release studies were evaluated for kinetics of drug release from the tablets by employing the different mathematical kinetic models such as zero order kinetic, first order kinetic, Korsmeyer–Peppas model, Hixson–Crowell model, Higuchi model and the model having a high correlation coefficient was considered the best fitting model [25].

Statistical analysis: Microsoft Excel and Origin® 21 software (OriginLab Corporation, MA, USA) were used for the statistical analysis. All the values are reported as mean and standard deviation.

RESULTS AND DISCUSSION

This investigation demonstrates the successful identification together with structural analysis and pharmaceutical testing of a new mannose-rich polysaccharide (ZMBP) derived from *Z. mauritiana* fruit pulp for using as sustained-release tablet binder.

Yield of polysaccharide: The aqueous extraction technique used for the isolation of unexplored polysaccharide from the ripe fruits of *Z. mauritiana* resulted in the yield of 9.4% (w/w) of ZMBP polysaccharide. The yield was found to be much higher as compared to the other *Ziziphus* sp. (4.48%) varieties, which have been explored earlier [26].

Optimization of polysaccharide: The extraction of polysaccharides from *Z. mauritiana* fruit pulp was optimized using response surface methodology (RSM). The key parameters investigated were the pulp-to-water ratio and extraction temperature. Experimental results indicated that the polysaccharide yield ranged from 5.6% ± 0.23% to 9.4% ± 0.21%, depending on the extraction conditions. The maximum yield of 9.4% ± 0.21% was achieved at a pulp-to-water ratio of 1:5 and an extraction temperature of 60 ºC (Fig. 1).

Statistical analysis using the central composite design (CCD) and quadratic regression model revealed significant linear and quadratic effects of both the pulp-to-water ratio and extraction temperature on polysaccharide yield. The interaction between these variables was also found to be significant. High R-squared values (R^2 = 99.97%, R^2(adj) = 99.94%, R^2(pred) = 93.96%) and a low *p*-value ($p < 0.05$) demonstrated that the developed model accurately predicted polysaccharide yield under varying extraction conditions. Normal distribution of residuals and lack of heteroscedasticity further validated the reliability of the model [27,28].

Elemental analysis: Elemental analysis of the isolated polysaccharide ZMBP was carried out using a JEOL JCM-6000 instrument. The analysis revealed that the major elemental constituents were carbon (49.11%) and oxygen (48.49%). This elemental composition is characteristic of typical carbohydrate based biopolymers, supporting the polysaccharide nature of the compound. The negligible presence of nitrogen or other heteroatoms further corroborates the absence of protein or nucleic acid contamination. These results validate the purity and carbohydrate-rich nature of ZMBP, thereby justifying its suitability for subsequent structural elucidation using advanced techniques such as proton (^{1}H) and carbon (^{13}C) nuclear magnetic resonance (NMR) spectroscopy.

FTIR analysis: The FTIR spectrum displayed prominent absorption bands characteristic of distinct functional groups, verifying the carbohydrate structure of polysaccharide. A broad peak near 3300 cm^{-1} corresponded to O–H stretching vibrations, while signals in the 1100-1000 cm^{-1} range were attributed to C–O stretching in the pyranose ring. Absorption bands observed between 900-750 cm^{-1} suggested the presence of α- or β-glycosidic linkages. The fingerprint region (1500–700 cm^{-1}) offered further insight into monosaccharide identification *via* spectral comparison with known standards. Notably, a peak at 1370 cm^{-1} signaled the presence of mannose (Fig. 2). The absence of diagnostic bands around 1450 cm^{-1} and between 1510-1495 cm^{-1} indicated that glucose and galactose were not present. These findings suggest that ZMBP is composed predominantly, if not exclusively, of mannose-based units [29].

Linkage analysis: The GC-MS analysis of the methylated products is summarized in Table-2. The per-methylated alditol acetates (PMAA) of ZMBP was composed of a single monosaccharide unit, namely, 2,3,6-Me$_3$-Man*p*. They were identified by comparing with standard derivatives [30]. The results from the analysis were consistent with monosaccharide analysis demonstrating the presence of (1→4)-linked Man*p* in repeating units (Table-2).

NMR analysis: The anomeric proton at δ 4.35 ppm indicated presence of a β-linked monosaccharide residue (Fig. 3a). The carbon spectrum presented in Fig. 3b contained only one signals at anomeric region δ 95.88 ppm. From corroborating all other peaks present the single monosaccharide residue was identified as β-D-mannopyranose. All the signals of ^{13}C and ^{1}H NMR were confirmed by 2D NMR analysis. All the results confirmed the presence of single sugar residue consistent with: monosaccharide analysis by FTIR data (Table-3) are compared with the literature values [31,32].

Based on these results, it indicates that ZMBP contains →4)-β-D-mannopyranosyl-(1→ as its main structural component. The linear mannose backbone of the homopolymeric polysaccharide stands out due to the structure typically enhances gel formation along with binding properties, which make it suitable for sustained-release dosage form excipients [15,33].

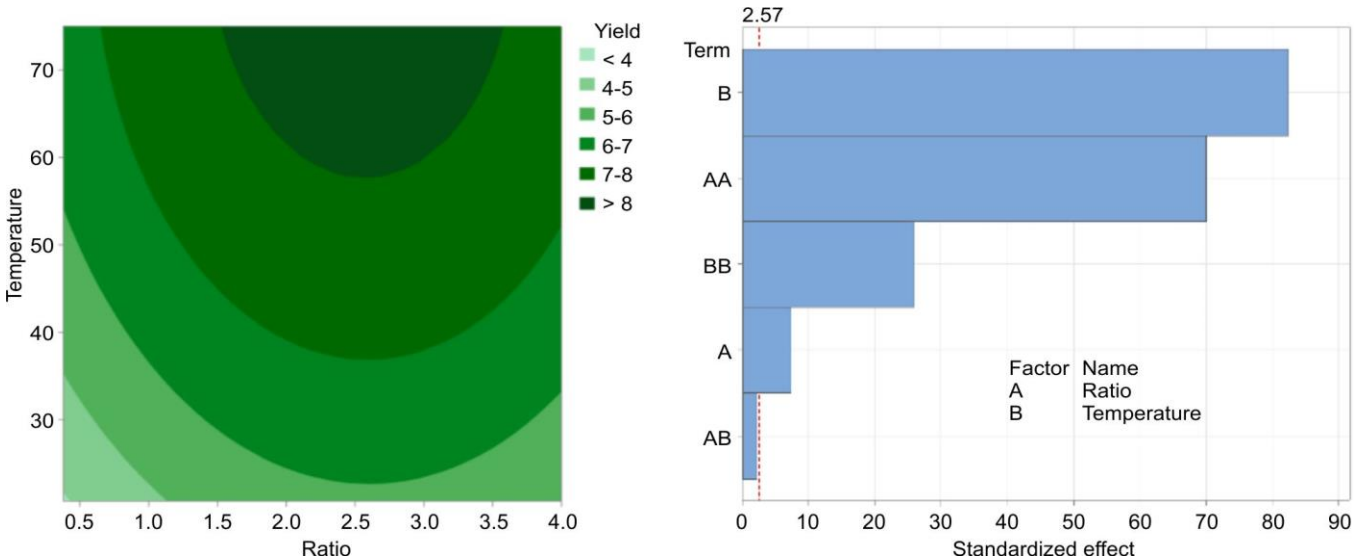

Fig. 1. Contour plot of yield *vs.* temperature, ratio and Pareto chart of the standardized effects (response is yield, α = 0.05)

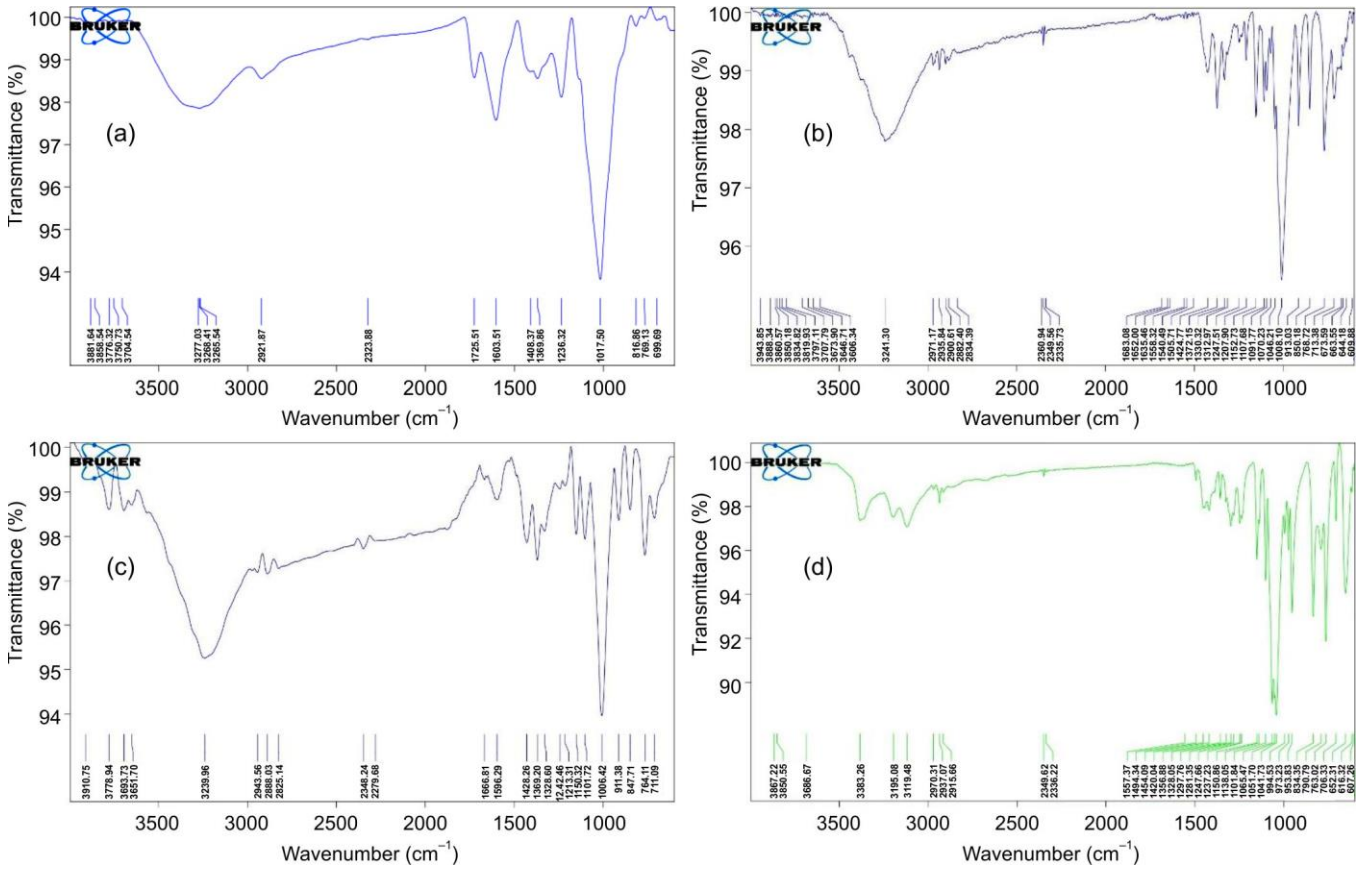

Fig. 2. FTIR spectra of ZMBP sample (a) and standard monosaccharides (b) mannose (c) glucose (d) galactose

TABLE-2
GC-MS DATA ANALYSIS OF METHYLATED ALDITOL OF ZMBP

Methylated sugar	Mass fragments (*m/z*)	Linkage pattern
2,3,6-Me$_3$-Man*p*	45, 74, 89, 118, 129, 143, 160, 188, 280	→ 4)-Man*p*-(1→

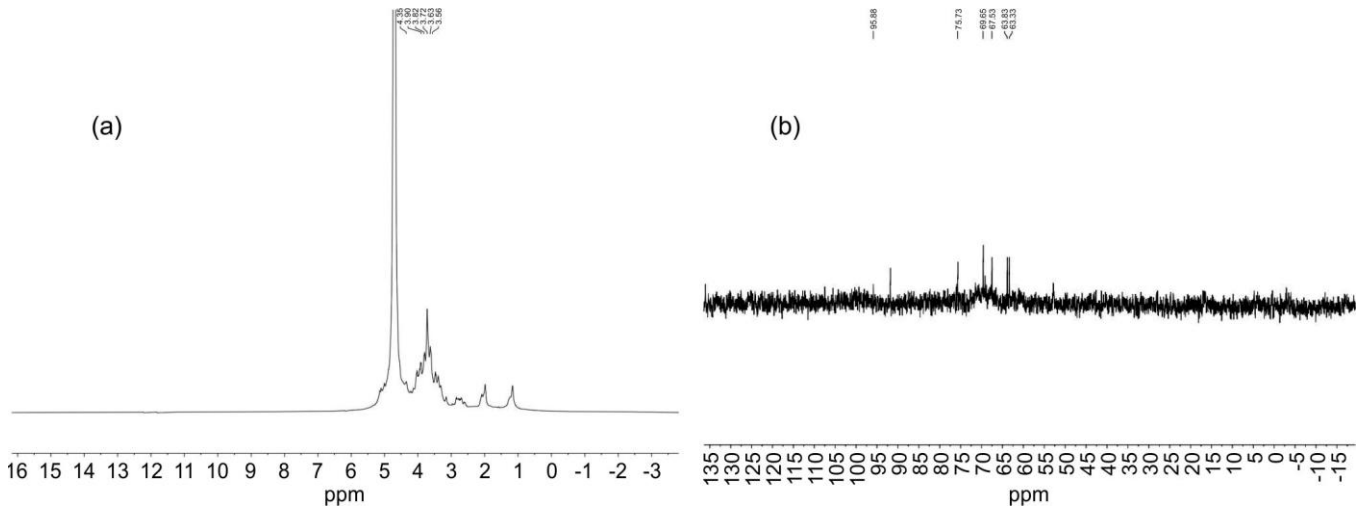

Fig. 3. NMR spectra of ZMBP: (a) ^{1}H NMR; and (b) ^{13}C NMR

TABLE-3
CHEMICAL SHIFT ASSIGNMENT FOR ^{1}H AND ^{13}C NMR SPECTRA OF ZMBP

Residues	H1/C1	H2/C2	H3/C3	H4/C4	H5/C5	H6/C6
β-d-Man*p*	4.35/95.88	63.86/3.63	69.65/3.90	67.53/3.72	75.73/3.82	63.33/3.56(a), 3.63(b)

The reported structure of polysaccharide ZMBP was found to contain residues of D-mannopyranose in its repeating unit, which are known to impart both structural integrity and provide smart disintegration/dissolution properties.

Evaluation of polysaccharide-based tablets

Physical evaluation of tablet: Post-compression, all tablet formulations (F1-F6) underwent comprehensive quality control assessments. Organoleptic evaluation revealed consistent physical attributes, *i.e.* all tablets are white, odourless and presented as concave-round flats with a single breakline. Given the free-flowing nature of the powder material, tablet weight uniformity was consistently achieved, demonstrating efficient die filling. The weight variation for all formulations ranged from 249.92 mg to 253.88 mg, well within the Indian Pharmacopoeia (IP) stipulated limit of < 5% deviation, indicating high batch consistency and low standard deviation values.

The measured tablet thickness across all formulations ranged from 3.8 to 4.2 mm, remaining within the acceptable ± 5% deviation from the standard value. Likewise, the crown diameter of all tablets was consistently uniform, falling within the range of 7.8 to 8.0 mm. Tablet hardness, a critical parameter reflecting resistance to capping, abrasion and breakage during storage, transport and handling, was assessed using a Monsanto hardness tester. All controlled-release matrix tablet formulations of propranolol hydrochloride exhibited an average hardness between 6.0 and 8.0 kg/cm^2, ensuring robust mechanical strength for practical applications [34]. Finally, friability was determined using a Roche friabilator to evaluate the tablets' resistance to abrasion. The average percentage friability across all formulations ranged from 0.447% to 0.72%. These values are well within the pharmacopoeial limit of less than 1%, with F4 exhibiting the maximum friability (0.72%) and F7 the minimum (0.447%), confirming excellent tablet integrity.

***In vitro* evaluations:** *In vitro* dissolution studies (Fig. 4) demonstrated distinct drug release profiles among the formulated tablets. After 2 h at pH 1.2, formulations F1-F3 exhibited a drug release range of 96.38% ± 0.11% to 98.59% ± 0.03%. In contrast, F4-F6 showed a notably lower initial release, ranging from 51.23% ± 0.19% to 58.26% ± 0.17%, suggesting an early indication of delayed release caused due to the better binding property of the polysaccharide.

At the 8 h mark in pH 6.8 medium, the drug release for F1, F2 and F3 was fully completed. For F4-F6 samples, the 12 h release ranged from 82.21% ± 0.13% to 89.03% ± 0.33%. Notably, F6 (82.21% ± 0.13%) displayed significant sustained release even after 12 h. The sustained release is attributed to the natural polysaccharide ZMBP having an ability to form a robust, interlinked gel matrix within the tablet upon hydration (Fig. 4). The mannose units may contribute to strong intermolecular interactions, increasing the binding energy within this network. This dense structure acts as a physical barrier, controlling drug diffusion and erosion, thereby prolonging drug release [35,36].

Drug release kinetics: The *in vitro* drug release profiles of all formulations were systematically evaluated to determine the release kinetics. The release data were fitted to various mathematical models, including zero-order, first-order and

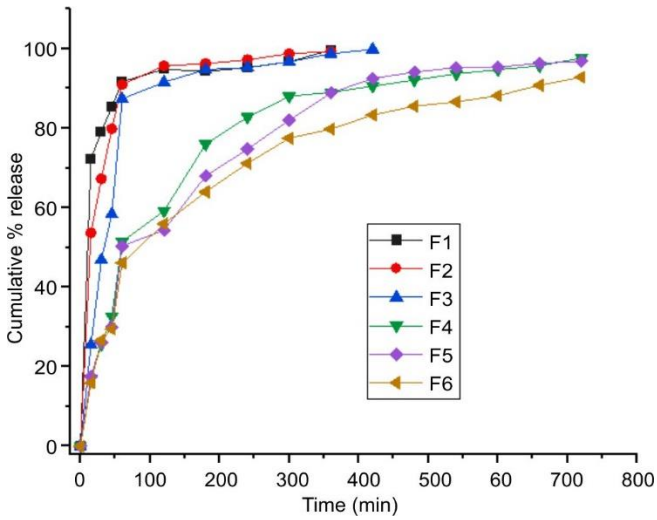

Fig. 4. *In vitro* dissolution profile of prepared tablets

Higuchi kinetics. The selection of the best-fitting model was based on the correlation coefficient (r^2) values derived from each model. Among the models tested, the first-order kinetics exhibited the highest correlation coefficients, ranging from 0.966 to 0.997, suggesting a concentration-dependent release mechanism. In comparison, the Higuchi model yielded r^2 values between 0.878 and 0.969, while the zero-order model demonstrated the lowest fit with r^2 values ranging from 0.837 to 0.954. These results collectively indicate that drug release from all formulations predominantly followed first-order kinetics.

To further elucidate the underlying release mechanism, the data were analyzed using the Korsmeyer–Peppas model. The correlation coefficients (r^2) for this model ranged from 0.891 to 0.941 and the diffusion exponent 'n' values were observed between 0.560 and 0.839 for all formulations (F1-F6). These findings suggest a non-Fickian (anomalous) diffusion mechanism, implying that the drug release was governed by a combination of diffusion and matrix erosion processes. The observed complexity in the release behaviour may be attributed to the structural characteristics of the formulations, which potentially influenced the rate and mechanism of drug release [33] (Table-4).

The results of present study demonstrate ZMBP functions as an effective natural binder which replaces potato starch and other conventional binders while being biodegradable. The structural basic nature of ZMBP enables it to perform effectively without creating biocompatibility issues, which synthetic polymers typically present. The first-order release kinetics dependent on concentration enable release profile adjustment through binder quantity modification. Moreover, the results validate ZMBP as a useful material for creating oral controlled-release drug formulations that could be used in developing gastroretentive and colon-targeted and mucoadhesive delivery systems. The industrial implementation of ZMBP needs additional research about its scalability along with stability and regulatory acceptance [25,33].

Conclusion

The present study successfully isolated and structurally characterized a novel mannose-rich polysaccharide from the

TABLE-4
In vitro DRUG RELEASE KINETICS STUDIES OF THE PREPARED TABLET

Formulations	First order (r^2)	Zero order (r^2)	Higuchi (r^2)	Korsemayer Peppas (r^2)	(n)
F1	0.966	0.837	0.878	0.891	0.560
F2	0.979	0.859	0.886	0.906	0.603
F3	0.986	0.877	0.898	0.921	0.698
F4	0.989	0.889	0.910	0.928	0.727
F5	0.992	0.906	0.934	0.936	0.781
F6	0.997	0.954	0.969	0.943	0.839

fruit pulp of *Ziziphus mauritiana*, with optimization of extraction parameters achieved *via* response surface methodology (RSM). The yield of polysaccharide varied with extraction conditions, ranging from 5.6% ± 0.23% to 9.4% ± 0.21%. The highest yield, 9.4% ± 0.21%, was obtained when using a pulp-to-water ratio of 1:5 and an extraction temperature of 60 °C. Spectroscopic and chromatographic analyses, including FTIR, NMR and GC-MS linkage analysis, confirmed the presence of key glycosidic linkages, particularly →4)-Man*p*-(1→, suggesting a linear mannopyranosyl backbone. The functional evaluation of the polysaccharide as a tablet binding agent demonstrated superior performance compared to potato starch, notably in sustaining drug release, with an 18% reduction in drug dissolution over 12 h. The formulation followed zero order experiments. This retardation effect is attributed to the unique physicochemical characteristics conferred by the mannose moieties. Overall, the isolated polysaccharide from *Z. mauritiana* shows substantial promise as a natural, effective excipient for use in sustained-release pharmaceutical formulations, offering both functional and biocompatible advantages over conventional starch-based binders.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. K. Dhileepan, *Ann. Appl. Biol.*, **170**, 287 (2017); https://doi.org/10.1111/aab.12338
2. N. Tel-Zur and B. Schneider, *Sex. Plant Reprod.*, **22**, 73 (2009); https://doi.org/10.1007/s00497-009-0093-4
3. M. Javed, R. Bibi, K. Nazir and S. Hussain, *Adv. Life Sci.*, **9**, 157 (2022); https://doi.org/10.62940/als.v9i2.944
4. O. Prakash, S. Usmani, R. Singh, N. Singh, A. Gupta and A. Ved, *Phytother. Res.*, **35**, 63 (2021); https://doi.org/10.1002/ptr.6769
5. M. Salehi and A. Rashidinejad, *Int. J. Biol. Macromol.*, **290**, 138855 (2025); https://doi.org/10.1016/j.ijbiomac.2024.138855
6. I. Benalaya, G. Alves, J. Lopes and L.R. Silva, *Int. J. Mol. Sci.*, **25**, 1322 (2024); https://doi.org/10.3390/ijms25021322
7. B.-W. Xu, S.-S. Li, W.-L. Ding, C. Zhang, M. Rehman, M.F. Tareen, L. Wang and S.-C. Huang, *Food Front.*, **6**, 15 (2025); https://doi.org/10.1002/fft2.490
8. J. Fu, Y. Zheng, Y. Gao and W. Xu, *Microorganisms*, **10**, 2507 (2022); https://doi.org/10.3390/microorganisms10122507
9. L. Wicker, Y. Kim, M.-J. Kim, B. Thirkield, Z. Lin and J. Jung, *Food Hydrocolloids*, **42**, 251 (2014); https://doi.org/10.1016/j.foodhyd.2014.01.002
10. D. Saha and S. Bhattacharya, *J. Food Sci. Technol.*, **47**, 587 (2010); https://doi.org/10.1007/s13197-010-0162-6
11. H. Gong, W. Li, J. Sun, L. Jia, Q. Guan, Y. Guo and Y. Wang, *Int. J. Biol. Macromol.*, **211**, 711 (2022); https://doi.org/10.1016/j.ijbiomac.2022.05.087
12. D. Sanjanwala, V. Londhe, R. Trivedi, S. Bonde, S. Sawarkar, V. Kale and V. Patravale, *Expert Opin. Drug Deliv.*, **19**, 1664 (2022); https://doi.org/10.1080/17425247.2022.2152791
13. A.G. Darvill, P. Albersheim, M. McNeil, J.M. Lau, W.S. York, T.T. Stevenson, J. Thomas, S. Doares, D.J. Gollin, P. Chelf and K. Davis, *J. Cell Sci. Suppl.*, **2(Suppl)**, 203 (1985); https://doi.org/10.1242/jcs.1985.Supplement_2.11
14. A. Choudhury, S. Sarma, S. Sarkar, M. Kumari and B.K. Dey, *J. Pharmacopuncture*, **25**, 317 (2022); https://doi.org/10.3831/KPI.2022.25.4.317
15. H. Gong, W. Li, J. Sun, L. Jia, Q. Guan, Y. Guo and Y. Wang, *Int. J. Biol. Macromol.*, **211**, 711 (2022); https://doi.org/10.1016/j.ijbiomac.2022.05.087
16. B. Pathak, S. Samajdar, D. Datta and B. Das, *Trends Carbohydr. Res.*, **16**, 2 (2024).
17. H. Chen, M. Zhang, Z. Qu and B. Xie, *J. Agric. Food Chem.*, **55**, 2256 (2007); https://doi.org/10.1021/jf0632740
18. T. Hong, J.Y. Yin, S.P. Nie and M.Y. Xie, *Food Chem. X*, **12**, 100168 (2021); https://doi.org/10.1016/j.fochx.2021.100168
19. I. Ciucanu and F. Kerek, *Carbohydr. Res.*, **131**, 209 (1984); https://doi.org/10.1016/0008-6215(84)85242-8
20. D. Schulze, Effect of Storage Time and Consolidation on Food Powder Flowability, Powders and Bulk Solids, In: Behavior, Characterization, Storage and Flow, Springer-Verlag Berlin Heidelberg (2007)
21. K.H. Desta, E. Tadese and F. Molla, *BioMed Res. Int.*, **2021**, 5571507 (2021); https://doi.org/10.1155/2021/5571507
22. T. Deshmukh, P. Patil, V. Thakare, B. Tekade and V. Patil, *Int. J. Discov. Herb. Res.*, **1**, 128 (2011).
23. R. Enauyatifard, M. Azadbakht and Y. Fadakar, *Acta Pol. Pharm.*, **69**, 291 (2012).
24. P. Li, L. Zhou, Y. Mou and Z. Mao, *Int. J. Biol. Macromol.*, **72**, 19 (2015); https://doi.org/10.1016/j.ijbiomac.2014.07.057
25. A. Ainurofiq and S. Choiri, *Lat. Am. J. Pharm.*, **34**, 1328 (2015).
26. D. Rout, S. Mondal, I. Chakraborty, M. Pramanik and S.S. Islam, *Med. Chem. Res.*, **13**, 509 (2004); https://doi.org/10.1007/s00044-004-0050-6
27. R. Wang, P. Chen, F. Jia, J. Tang and F. Ma, *Int. J. Biol. Macromol.*, **50**, 331 (2012); https://doi.org/10.1016/j.ijbiomac.2011.12.023
28. Q. Ge, J. Huang, J.W. Mao, J.Y. Gong, Y.F. Zhou and J.X. Huang, *Int. J. Biol. Macromol.*, **67**, 37 (2014); https://doi.org/10.1016/j.ijbiomac.2014.02.055

29. J. Rodrigues, J. Puls, O. Faix and H. Pereira, *Holzforschung*, **55**, 265 (2001); https://doi.org/10.1515/HF.2001.044
30. N. Sahragard and K. Jahanbin, *Carbohydr. Polym.*, **175**, 610 (2017); https://doi.org/10.1016/j.carbpol.2017.08.042
31. D.C. Rodrigues, A.P. Cunha, E.S. Brito, H.M. Azeredo and M.I. Gallao, *Food Hydrocoll.*, **56**, 227 (2016); https://doi.org/10.1016/j.foodhyd.2015.12.018
32. S. Samajdar and K.J. Kumar, *Pharmacogn. Mag.*, **18**, 418 (2022); https://doi.org/10.4103/pm.pm_96_22
33. A.K. Jena, M. Das, A. De, D. Mitra and A. Samanta, *Asian J. Pharm. Clin. Res.*, **7**, 184 (2014).
34. N. Tavakoli, N.G. Dehkordi, R. Teimouri and H. Hamishehkar, *Jundishapur J. Nat. Pharm. Prod.*, **3**, 33 (2008).
35. A.K. Mistry, C.D. Nagda, D.C. Nagda, B.C. Dixit and R.B. Dixit, *Sci. Pharm.*, **82**, 441 (2014); https://doi.org/10.3797/scipharm.1401-14
36. D.S. Panda, N.S.K. Choudhury, M. Yedukondalu, S. Si and R. Gupta, *Indian J. Pharm. Sci.*, **70**, 614 (2008); https://doi.org/10.4103/0250-474X.45400