

Consequences of Extraction Methods on the Structural and Functional Properties of *Aloe vera* L. (*Aloe barbadensis* Miller) Polysaccharides

COULIBALY Ibourahema^{1,*}, KONAN Kouakou Ahossi², TRAORE Souleymane⁴,
COULIBALY Adja Mansagna^{1,3}, ENAN Reine Pelagie⁴, KOUASSI Kra Athanase¹, KONATÉ Ibrahim²

¹Agrovalorisation Laboratory, Agroforestry Training and Research Unit (UFR-AGRO),
University Jean Lorougnon GUEDE PB-150, Daloa, Ivory Coast

²Training and Research Unit in Agroforestry, Laboratory of Host-Microorganism Interactions, Environment
and Evolution (LIHME), Jean Lorougnon Guédé University, Daloa, Côte d'Ivoire

³Laboratory of the Unit of Antibiotics, Natural Substances and Surveillance of Resistance of Microorganisms
to Anti-Infectious (ASSURMI), Pasteur Institute of Ivory Coast (IPCI) BP-490, Abidjan-01, Ivory Coast

⁴Analytical Chemistry Unit, Gembloux Agricultural University, Passages des d'éportés 2, 5030 Gembloux, Belgium

*Corresponding author: ibourahema.ujlog@email.com

Received September 19, 2025; Revised October 21, 2025; Accepted October 28, 2025

Abstract The present work investigated how different extraction techniques affect the chemical and physical characteristics of polysaccharides derived from *Aloe vera* L. Two commercial materials were analyzed: a powdered preparation and a liquid extract from whole leaves. Hydrolysis kinetics were examined for both products. Polysaccharide fractions (A1, A2, A3, and A4) were obtained using hot and cold water extractions as well as ethanol treatment. Molecular weights were determined for each fraction, and protein, galacturonic acid, and sugar contents were quantified. Approximately 25% of total sugars were detected in the powder form. Cold-water extraction (pH 5.3, 25 °C, 4 h) yielded the highest recovery rate of polysaccharides ($69.4 \pm 0.1\%$), outperforming other techniques. A marked reduction was observed in molecular weight (150 to 30 kDa), number-average molecular mass (97 to 29 kDa), and protein content (4.9 ± 0.1 to 0.00%) following fractionation. Conversely, sugar levels increased with purification, reaching $29.2 \pm 0.1\%$, $76.6 \pm 0.1\%$, and $93.4 \pm 0.4\%$ for Poly A, A1, and A2, respectively. The A3 fraction exhibited the highest sugar proportion ($\approx 97.8 \pm 1.5\%$), dominated by glucomannan (mannose $77.3 \pm 6.5\%$, glucose $18.7 \pm 2.8\%$). These findings highlight that fractionation methods can generate highly purified polysaccharides with promising nutritional, functional, and therapeutic applications.

Keywords: polysaccharides, *Aloe vera* L., extraction methods, acemannan, protein, polysaccharides, sugar

Cite This Article: COULIBALY Ibourahema, KONAN Kouakou Ahossi, TRAORE Souleymane, COULIBALY Adja Mansagna, ENAN Reine Pelagie, KOUASSI Kra Athanase, and KONATÉ Ibrahim, "Consequences of Extraction Methods on the Structural and Functional Properties of *Aloe vera* L. (*Aloe barbadensis* Miller) Polysaccharides." *Journal of Food and Nutrition Research*, vol. 13, no. 10 (2025): 408-414. doi: 10.12691/jfmr-13-10-3.

1. Introduction

The genus *Aloe* comprises succulent plants belonging to the family *Liliaceae*. More than 400 species have been identified, including *Aloe arborescens*, *Aloe succotrina*, *Aloe saponaria*, *Aloe ferox*, *Aloe chinensis*, and *Aloe vera* L. (*Aloe barbadensis* Miller) [1,2,3]. To date, over 200 bioactive compounds have been isolated from *Aloe vera* L. Historical evidence indicates that Africa, particularly the arid regions of South Africa, represents the center of origin of this species [4]. The plant is also distributed across desert and semi-arid zones of Asia, the Americas, and the Caribbean, especially in the West Indies and South America. Current research is focused on elucidating the

chemical composition and nutritional potential of *Aloe vera* L. and other tropical medicinal plants. Earlier investigations revealed the occurrence of numerous primary and secondary metabolites in *Aloe vera* L., many of which are exploited in commercial formulations of juices and topical gels [2,5,6]. Identified compounds include enzymes such as lipases and proteases, polysaccharides like glucomannans, amino acids, vitamins (A, B12, C, and D), anthraquinones, saponins, lignin, and various steroids [7]. The nutritional potential of *Aloe vera* L. has been well established. According to [8], *Aloe barbadensis* contains a high level of carbohydrates (73.07%), while its protein (2.73%) and lipid (0.27%) contents are comparatively low. Previous analyses reported sodium and potassium concentrations of 5280 ppm and 10,670 ppm, respectively [9]. Further work [10]

emphasized that to achieve optimal nutrient profiles, supplementation of *Aloe vera* L. with external sources of nitrogen, phosphorus, and potassium may be required. In addition, *Aloe barbadensis* has been noted for its role in maintaining osmotic balance and regulating body pH. Several biological activities have been documented, including antiseptic effects from saponins and anthraquinones, anti-tumor and anti-inflammatory activities, antioxidant functions associated with vitamins, and immunomodulatory properties of glucomannans [1,2,5,11]. Glucomannan, also referred to as acemannan, is the principal functional polysaccharide in the gel, composed of acetylated mannose chains interlinked with glucose and branched with galactose residues [12]. The gel is largely aqueous, containing about 97–98.5% water, with the remainder comprising polysaccharides and pectic substances, which vary depending on species, growth conditions, and processing methods [13,14]. Phytochemical investigations have identified numerous additional bioactive molecules in *Aloe vera* L. [12,15]. Importantly, glucomannan is considered the major contributor to its medicinal properties, including wound healing and chronic care. Despite these findings, limited work has focused on the optimal conditions required to isolate polysaccharides from *Aloe vera* L. Moreover, seasonal changes, geographic origin, cultivation practices, and extraction procedures may significantly influence its chemical composition and nutritional value. The objective of this study was therefore to isolate *Aloe vera* L. polysaccharides and to assess how different extraction methods affect their chemical and physical properties.

2. Materials and Methods

2.1. Raw Materials

This investigation was carried out using two commercially available *Aloe vera* L. products obtained in Gembloux, Belgium. The first material was a spray-dried gel powder (*Aloe Gel* SD 200X) supplied by Will & Co BV, while the second consisted of a liquid extract derived from whole leaves (38.8 FIOZ 1QT., 1.8 FIOZ) marketed by Forever Living Products. For the purpose of this study, the powdered preparation was designated as gel solid (GS), and the liquid extract as gel liquid (GL). Both samples were selected to represent the two main forms of *Aloe vera* L. extracts currently available on the international market, namely a concentrated dehydrated product and a stabilized liquid form. These materials differ not only in their processing technology but also in their potential composition, stability, and bioactive content, making them suitable candidates for comparative evaluation. Prior to experimentation, all samples were stored in their original sealed containers under controlled laboratory conditions to prevent degradation and ensure reproducibility of results.

2.2. Methods

The hydrolysis kinetics of *Aloe vera* L. polysaccharides were investigated under controlled experimental conditions. Reactions were carried out using trifluoroacetic acid (2 M) at 110 °C for variable durations

ranging from 1 to 8 hours. These assays allowed the determination of the most suitable conditions for the hydrolysis of the powdered *Aloe vera* L. sample, thereby establishing the optimal parameters required for subsequent analyses.

2.2.1. Extraction Polysaccharides A

Polysaccharides were extracted from both gel solid (GS) and gel liquid (GL) samples using different procedures. For hot-water extraction, GS (20 g) was suspended in water and heated at 90 °C under constant stirring. After filtration and centrifugation (6000 rpm, 30 min, 15 °C), the supernatant was concentrated, and polysaccharides were precipitated overnight with 96% ethanol. Following a second centrifugation step (10,000 rpm, 30 min, 10 °C), the residues were pooled, homogenized in distilled water, freeze-dried, and finely ground to yield fraction A (MIA) [16]. A similar procedure was applied to GL (100 mL), with the additional step of concentrating the supernatant to 500 mL by rotary evaporation prior to ethanol precipitation. For cold extraction, GS (20 g) was homogenized in water for 30 min, centrifuged (6000 rpm, 45 min, 15 °C), and the supernatant filtered before ethanol precipitation, following the same downstream protocol as above. In boiling ethanol extraction, GS (20 g) was treated with refluxing ethanol under stirring for 30 min, filtered through nylon paper (11 µm), and the residue oven-dried at 40 °C for 6 h before grinding to obtain polysaccharide fraction A (MIA)..

2.2.2. Fractionation of Alcohol-Insoluble Mater

Polysaccharides A (8 g) were dissolved in water under stirring, and the pH was adjusted to 8.5 with ammonium hydroxide (NH₄OH). Calcium chloride (60 mL) was then added dropwise at room temperature. The resulting calcium pectate precipitate was removed, while the supernatant was concentrated using a rotary evaporator and subsequently dialyzed. Precipitates formed during dialysis were collected by centrifugation, combined with the initial calcium pectate fraction, freeze-dried, and stored. The supernatant was treated with 96% ethanol and kept overnight at 8 °C to allow further polysaccharide precipitation. After centrifugation, the combined residues were lyophilized and ground to yield polysaccharide A1.

For the subsequent fractionation, polysaccharide A1 (500 mg) was dissolved in water and subjected to the same protocol as above to obtain polysaccharide A2. Further separation was achieved by dissolving polysaccharide A2 (400 mg) in water and gradually adding freshly prepared Fehling's solution (20 mL). A pale blue precipitate formed, corresponding to a copper-polysaccharide complex, which was collected by centrifugation and washed several times with ice-cold water. The combined supernatants were concentrated to obtain fraction A4. The copper-complex residue was decomposed using a hydrochloric acid-ethanol mixture (5 % v/v, 50 mL), washed twice with 96 % ethanol, centrifuged, and the resulting supernatants evaporated to dryness. The residues were redissolved in water and homogenized to provide polysaccharide A3.

2.2.3. Characterization of Polysaccharides Fractions

Extraction Yield: The yield of polysaccharides was

expressed as a percentage relative to the dry matter, calculated using the formula:

$$\text{Yield (\%)} = \frac{M_{MIA}}{M_e} \times \frac{100}{M_s}$$

where M_{MIA} is the mass of alcohol-insoluble matter (g), M_e the sample mass (g), and M_s the dry matter content.

Moisture Content: Samples were dried at 105 °C for 24 h, cooled in desiccators, and weighed. Moisture (%) was determined from the weight difference before and after drying [17].

Protein Content: Total protein was assessed via the Kjeldahl method [18]. Following sulfuric acid digestion in the presence of a CuSO_4 catalyst, ammonia was distilled into boric acid and titrated with 0.1 N HCl. Crude protein was calculated using a conversion factor of 6.25.

Molecular Weight: Polysaccharides (200 mg) were dissolved in 100 mL distilled water, filtered (0.45 μm), and analyzed by size-exclusion chromatography with triple detection (light scattering, viscometry, and refractive index) on a TSKPWXL column, eluted with 0.05 M NaNO_3 containing 0.02% NaN_3 at 0.7 mL/min.

Galacturonic Acid Analysis: After enzymatic hydrolysis, galacturonic acid content in fractions (A, A1–A4) was determined by HPAEC-PAD (Dionex) using a Carbopac PA10 analytical column and PA100 precolumn.

Monosaccharide Composition: Polysaccharides were hydrolyzed with 1 M H_2SO_4 (100 °C, 2 h), reduced to alditols with NaBH_4 in DMSO, and acetylated with acetic anhydride/1-methylimidazole. Alditol-acetate derivatives were extracted with dichloromethane and analyzed by GC (Agilent 6890, HP1 column, 30 m $\times$ 0.32 mm, 0.25 μm film). Helium was used as carrier gas (1.6 mL/min). The injection temperature was 290 °C, with a temperature program from 120 °C to 290 °C. Compounds were detected using a flame ionization detector at 320 °C. 2-Deoxy-D-glucose served as the internal standard, and monosaccharide standards included L-rhamnose, D-arabinose, D-xylose, D-mannose, D-glucose, and D-galactose [19,20,21,22,23].

2.2.4. Statistical Analysis

All experiments were performed in triplicate, and results are presented as mean $\pm$ standard deviation. Differences between means were evaluated using Duncan's multiple range test at a 5% significance level. Statistical analyses were conducted with ANOVA using Statistica 7.1 software.

3. Results

3.1. Kinetics of Neutral Sugar Hydrolysis

The hydrolysis kinetics of neutral sugars is shown in Figure 1. Results revealed that the maximum sugar release occurred after 240 min, (4 hours) of hydrolysis, reaching $28.1 \pm 0.01\%$ under the conditions of 2 M TFA at 110 °C. Beyond this point, a progressive decline in sugar content was observed. Specifically, peak concentrations were achieved after 180 min, (3 hours) for mannose ($9.9 \pm 0.2\%$), glucose ($17.9 \pm 1.5\%$), and galactose ($0.5 \pm 0.01\%$). In contrast, the highest yields of

rhamnose, arabinose, and xylose were recorded after 420 min (7 hours), followed by a decrease with prolonged hydrolysis, (Figure 1).

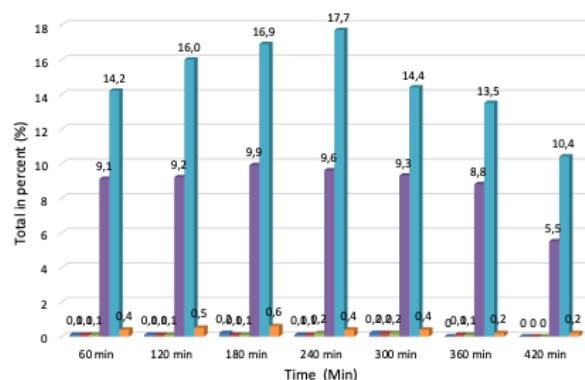


Figure 1. Determination of sugar levels (%) in *Aloe vera* L. powder subjected to extraction with 2M TFA at 110 °C

3.2. Extraction Performance

Extraction yield (R) of Poly A (GS and GL), Poly A1 and Poly A2 of *Aloe vera* L. were presented by Figure 2. Results showed that cold extraction yield ($\approx 69.4 \pm 0.1\%$ at pH 5.3, 25 °C) is higher than hot and alcohol extraction yield $46.3 \pm 0.2\%$ and $50.3 \pm 0.4\%$ respectively. Due to this high extraction yield, the cold extraction method is used for extraction of Poly A1 and Poly A2. After dialysis, the extraction yield increase with polysaccharides fractionment methods to reach $75.8 \pm 0.2\%$ and $92.2 \pm 0.5\%$ for Poly A1 and Poly A2. The lowest extraction yield $\approx 3.0 \pm 0.01\%$ was observed with liquid gel.

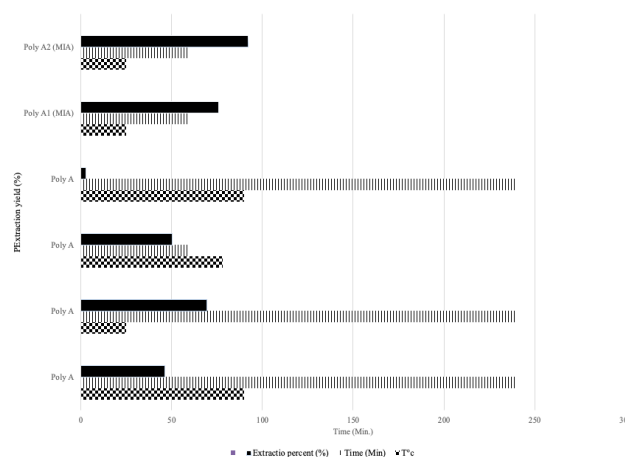


Figure 2. Extraction yield (R) of Poly A (GS and GL), Poly A1 and Poly A2 of *Aloe vera* L.

3.3. Physicochemical and Carbohydrate Composition of *Aloe vera* L. Polysaccharides

The physico-chemical and carbohydrate composition of *Aloe vera* L. polysaccharides (GS, GL, and Poly A) is summarized in Table 1. Dry matter content was high in all samples, exceeding 90%. Protein content showed significant differences ($p < 0.05$) between polysaccharides from GL and GS, whereas no significant difference was

observed for Poly A from GS and GL, regardless of the extraction method (cold, hot, or alcohol). After fractionation, protein content decreased in Poly A1 ($0.2 \pm 0.01\%$) and was only present in trace amounts in PolyA2, A3, and A4.

Table 1. Analysis of chemical and physical characteristics of distinct polysaccharide fractions of *Aloe vera* L

Samples	Dry matter (%)	Protein (%)	Mw (KDa)	Mn (KDa)	Rg (nm)	Ip
GL	4.6 ± 0.1^a	3.8 ± 0.1^b	145	93	22.1	1.6
GS	93.1 ± 0.1^a	4.9 ± 0.1^a	150	97	22.8	1.9
PolyA-GS, (90°C)	93.4 ± 0.8^a	2.6 ± 0.3^c	134	89	21.6	1.5
PolyA-GS, (25°C)	92.3 ± 0.6^a	2.5 ± 0.2^c	128	87	21.4	1.5
PolyA-GL	94.0 ± 0.4^a	2.5 ± 0.3^c	124	82	21.8	1.4
PolyA	94.2 ± 0.3^a	2.4 ± 0.01^c	112	81	21.4	1.4
PolyA1	86.8 ± 0.7^b	0.2 ± 0.001^d	74	69	12.3	1.1
PolyA2	87.7 ± 0.4^b	nd	65	59	13.1	1.2
PolyA3	0.44 ± 0.01^d	nd	30	29	nd	1.1
PolyA4	0.12 ± 0.01^c	nd	45	39	nd	1.0

The molecular weight (Mw) of GS and GL was determined to be 150 kDa and 145 kDa, respectively. Fractionation markedly reduced Mw, from 150 kDa down to 30 kDa. A comparable decrease was observed for the number-average molecular weight (Mn), which declined from 97 kDa to 29 kDa. The radius of gyration (Rg) was consistently lower in Poly A1–A4 compared with GS, GL, and their corresponding Poly A fractions. The polydispersity index (Ip) values ranged between 1.0 and 1.6. Size-exclusion chromatography coupled with a triple detection system (RI, LS, and Visc) revealed two distinct peaks for Poly A2 in the refractive index (RI) detector: the first peak representing high molecular weight species and the second corresponding to low molecular weight species. In contrast, the light scattering (LS) and viscosimetry (Visc) detectors displayed a single peak at 6.35–7.73 (X-axis), characteristic of high molecular weight molecules (Figure 3).

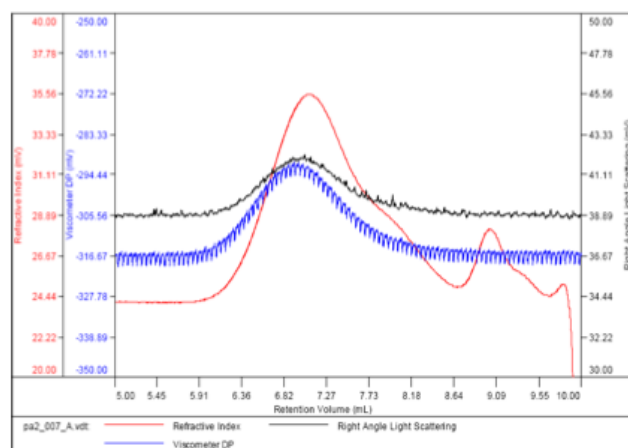


Figure 3. Key aspects of the chromatographic profile of polysaccharide A2

Carbohydrate and galacturonic acid analysis after TFA hydrolysis (2 M, 110 °C, 3 h) revealed that Poly A from GS obtained by cold extraction had the highest carbohydrate content ($29.2 \pm 0.01\%$), exceeding the levels found in GS and GL under all extraction conditions. After dialysis, fractions A1, A2, A3, and A4 contained 76.6%, 93.5%, 97.5%, and 11.4% of total sugars, respectively.

Poly A3 had the highest mannose (77.3%) and glucose (18.7%) ratios compared to Poly A1 (59.9%, 10.2%) and Poly A2 (48.7%, 19.8%). Galacturonic acid was detected only in trace amounts in all samples.

4. Discussion

The hydrolysis kinetics revealed that the total sugar content of *Aloe vera* L. polysaccharides reached a maximum after 240 min (4 h) of treatment, followed by a gradual decline with prolonged hydrolysis. Mannose, glucose, and galactose contents peaked concurrently at this point, whereas extended exposure to 2 M trifluoroacetic acid (TFA) at 110 °C induced partial degradation of released sugars due to acid-catalyzed cleavage of glycosidic bonds [24,25,26]. These results emphasize the critical importance of optimizing hydrolysis conditions to prevent monosaccharide degradation. In this context, enzymatic hydrolysis is increasingly favored for structural elucidation of plant polysaccharides because it preserves labile sugars and minimizes unwanted side reactions [27,28,29]. For pectin hydrolysis, mild chemical pretreatments combined with pectinolytic enzymes have been shown to achieve complete depolymerization into galacturonic acid and neutral sugars while maintaining sugar integrity [30,31,32,33].

The gradual release of rhamnose, arabinose, and xylose, which reached their maximal concentrations after approximately 6 h of hydrolysis, may indicate their higher resistance to acid cleavage or their strong covalent linkage to galacturonic acid residues in the pectic backbone [34,35]. The low rhamnose levels observed likely correspond to the rhamnogalacturonan regions of *Aloe vera* L. gel, corroborating previous studies describing Aloe gel as a complex matrix of pectin, cellulose, and hemicellulose polysaccharides [36,37,38].

Extraction yields varied substantially depending on the method and experimental parameters. Poly A extracted from gel solids (GS) yielded approximately 46.3% at 90 °C (pH 5.3), 69.4% at 25 °C (pH 5.3), and 50.3% using ethanol precipitation at 78 °C. Such differences can be attributed to cultivar variability, pH, temperature, and extraction time, all of which influence the solubilization and depolymerization of Aloe gel matrices [39,40,41]. Notably, cold extraction at 25 °C and pH 5.3 produced the highest yield (69.4%), exceeding those previously reported for extractions using CDTA or Na_2CO_3 buffers [42]. Losses observed during fractionation into A1 and A2 fractions likely resulted from dialysis, which removes small molecular weight compounds. Subsequent purification steps enhanced recovery, yielding 75.8% and 92.2% for A1 and A2 fractions, respectively, whereas the liquid gel (GL) exhibited a notably low yield (~3%) due to the removal of soluble impurities during filtration [43,44].

Moisture content was markedly higher in the GL fraction (96.5–98.6%) compared to GS and Poly A fractions, likely reflecting the higher water-binding capacity of the unprocessed gel. Protein contents were approximately twofold higher in GL and GS fractions than in Poly A and declined progressively in A2, A3, and A4 fractions, consistent with the removal of protein impurities during purification. This observation aligns with previous

reports highlighting the protein-depleted nature of purified Aloe polysaccharides [45,46,47,48,49]. Protein removal may enhance the pharmacological properties of acemannan, the principal bioactive polysaccharide, by reducing potential allergenic components [50,51,52].

Fractionation also induced a marked decrease in molecular weight, from approximately 150 kDa in the crude extract to 30 kDa in purified fractions, reflecting molecular disaggregation and the removal of aggregated complexes. Although these molecular weights were lower than some previously reported values (10–1000 kDa) [53,54,55], such discrepancies can be attributed to differences in gel filtration columns, calibration standards, and extraction solvents. The narrow polydispersity indices of A1, A2, and A3 (1.1–1.2) confirmed their high purity and molecular uniformity.

Monosaccharide composition analysis revealed that mannose and glucose were the predominant sugars across all fractions: A1 (59.9% mannose, 10.2% glucose), A2 (48.7%, 19.8%), and A3 (77.3%, 18.7%), consistent with glucomannan being the major structural polysaccharide in *Aloe vera* L. gel [56]. The mannose-to-glucose ratios (M/G) of 5.9, 2.5, and 4.1 further supported this conclusion. Minor sugars : xylose, rhamnose, arabinose, and galactose likely originated from pectic, hemicellulosic, and lignocellulosic components, indicating a heterogeneous polysaccharide network [57]. Trace amounts of galacturonic acid detected in all fractions supported its structural role in cell wall cohesion and possible contribution to bioactivity, though its concentration varied from values reported in earlier studies [58].

Overall, progressive purification enhanced the hexose-rich composition, reduced protein and moisture content, and improved molecular homogeneity particularly in the A3 fraction thereby increasing its potential for biomedical and nutraceutical applications. Differences among studies can be explained by genetic diversity among *Aloe* cultivars, geographical origin, seasonal variation, and extraction protocols. These findings collectively underscore the significance of refining extraction and purification parameters to maximize yield, purity, and functional efficacy of Aloe-derived polysaccharides.

5. Conclusion

Aloe vera L. contains diverse polysaccharides, with their composition affected by extraction method, plant variety, and geographic origin. Cold extraction emerged as the most efficient technique, producing a 69.2 % yield with high carbohydrate content (29.2 %) after acid hydrolysis. Fractionation of polysaccharides (A1–A3) led to decreases in molecular weight and protein content, while increasing monosaccharide concentrations. Mannose and glucose were confirmed as the main sugars, reflecting the predominance of glucomannan. These results provide insights for optimizing extraction and purification processes to obtain *Aloe vera* L. polysaccharides with enhanced functional and medicinal properties.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Université Jean Lorougnon Guédé (UJLoG) for providing the institutional framework that supported the realization of this work. Special thanks are extended to the UFR Agroforesterie and the Microbiology Research and Teaching Unit (UREM) for their technical facilities, scientific guidance, and continuous encouragement throughout the study. The authors also express their appreciation to colleagues and collaborators whose constructive inputs and expertise greatly contributed to the successful completion of this research.

Author Contribution Statement

All authors contributed significantly to this work. Coulibaly Ibourahema designed the study, collected the samples, and performed the Chemicals analyses. Traoré Souleymane assisted in data interpretation and provided critical revisions to the manuscript. Konan Kouakou Ahossi and Foba Foba isaac stephane contributed to statistical analysis and drafting of the results. Kra kouassi Athanase and Coulibaly Adja Mansagna, Enan Reine Pelagie participated in the literature review and preparation of figures and tables. Konaté Ibrahim supervised the research, provided overall guidance, and reviewed the final version of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Liu, C.; Cui, Y.; Pi, F.; Cheng, Y.; Guo, Y.; Qian, H. Extraction, Purification, Structural Characteristics, Biological Activities and Pharmacological Applications of Acemannan, a Polysaccharide from *Aloe vera*: A Review. *Molecules* 2019, 24, 1554.
- [2] Athiban, P.; Borthakur, B.; Ganesan, S.; Swathika, B. Evaluation of Antimicrobial Efficacy of *Aloe vera* and Its Effectiveness in Decontaminating Gutta Percha Cones. *J. Conserv. Dent.* 2012, 15, 246–248.
- [3] España, E.; Kim, J.; Kim, J.K. Utilization of *Aloe* Compounds in Combatting Viral Diseases. *Pharmaceuticals* 2022, 15, 599.
- [4] Yao, X.; Liu, H.; Ren, M.; Li, T.; Jiang, W.-K.; Zhou, Z.; Liu, Z.; Yang, M. Aloe Polysaccharide Promotes Osteogenesis Potential of Adipose-Derived Stromal Cells via BMP-2/Smads and Prevents Ovariectomized-Induced Osteoporosis. *Mol. Biol. Rep.* 2022, 49, 11913–11924.
- [5] Xing, W.; Guo, W.; Zou, C.H.; Fu, T.T.; Li, X.Y.; Zhu, M.; Qi, J.H.; Song, J.; Dong, C.H.; Li, Z.; et al. Acemannan Accelerates Cell Proliferation and Skin Wound Healing through AKT/MTOR Signaling Pathway. *J. Dermatol. Sci.* 2015, 79, 101–109.
- [6] Silva, S.S.; Popa, E.G.; Gomes, M.E.; Cerqueira, M.; Marques, A.P.; Caridade, S.G.; Teixeira, P.; Sousa, C.; Mano, J.F.; Reis, R.L. An Investigation of the Potential Application of Chitosan/Aloe-Based Membranes for Regenerative Medicine. *Acta Biomater.* 2013, 9, 6790–6797.
- [7] T, A.T.; Hermawati, E. Antioxidant Activity Test Combination Inclusion of Curcumin- β -Cyclodextrin Complex and *Aloe vera*. *Pharm. J. Farm. Indones.* 2022, 19, 246–250.
- [8] Gullón, B.; Gullón, P.; Tavaría, F.; Alonso, J.L.; Pintado, M. In Vitro Assessment of the Prebiotic Potential of *Aloe vera* Mucilage and Its Impact on the Human Microbiota. *Food Funct.* 2015, 6, 525–531.

- [9] Quezada, M.P.; Salinas, C.; Gotteland, M.; Cardemil, L. Acemannan and Fructans from *Aloe vera* (*Aloe barbadensis* Miller) Plants as Novel Prebiotics. *J. Agric. Food Chem.* 2017, 65, 10029–10039.
- [10] Retiu, A.; Budescu, T.; Menae, I. *Aloe vera* Extract For Stomach Acid Use Safe And Effective Treatment. *Int. J. Pap. Adv. Sci. Rev.* 2021, 2, 59–64.
- [11] Sierra-García, G.D.; Castro-Ríos, R.; González-Horta, A.; Lara-Arias, J.; Chávez-Montes, A. Acemannan, an Extracted Polysaccharide from *Aloe vera*: A Literature Review. *Nat. Prod. Commun.* 2014, 9, 1217–1221.
- [12] Im, S.A.; Lee, Y.R.; Lee, Y.H.; Lee, M.K.; Park, Y.I.; Lee, S.; Kim, K.; Lee, C.K. In Vivo Evidence of the Immunomodulatory Activity of Orally Administered *Aloe vera* Gel. *Arch. Pharm. Res.* 2010, 33, 451–456.
- [13] Pugh, N.; Ross, S.A.; ElSohly, M.A.; Pasco, D.S. Characterization of Aloeride, a New High-Molecular-Weight Polysaccharide from *Aloe vera* with Potent Immunostimulatory Activity. *J. Agric. Food Chem.* 2001, 49, 1030–1034.
- [14] Zhang, L.; Tizard, I.R. Activation of a Mouse Macrophage Cell Line by Acemannan: The Major Carbohydrate Fraction from *Aloe vera* Gel. *Immunopharmacology* 1996, 35, 119–128.
- [15] Liu, C.; Leung, M.Y.K.; Koon, J.C.M.; Zhu, L.F.; Hui, Y.Z.; Yu, B.; Fung, K.P. Macrophage Activation by Polysaccharide Biological Response Modifier Isolated from *Aloe vera* L. Var. *Chinensis* (Haw.) Berg. *Int. Immunopharmacol.* 2006, 6, 1634–1641.
- [16] Lee, J.K.; Lee, M.K.; Yun, Y.P.; Kim, Y.; Kim, J.S.; Kim, Y.S.; Kim, K.; Han, S.S.; Lee, C.K. Acemannan Purified from *Aloe vera* Induces Phenotypic and Functional Maturation of Immature Dendritic Cells. *Int. Immunopharmacol.* 2001, 1, 1275–1284.
- [17] Karaca, K.; Sharma, J.M.; Nordgren, R. Nitric Oxide Production by Chicken Macrophages Activated by Acemannan, a Complex Carbohydrate Extracted from *Aloe vera*. *Int. J. Immunopharmacol.* 1995, 17, 183–188.
- [18] Park, M.Y.; Kwon, H.J.; Sung, M.K. Evaluation of Aloin and Aloe-Emodin as Anti-Inflammatory Agents in *Aloe* by Using Murine Macrophages. *Biosci. Biotechnol. Biochem.* 2009, 73, 828–832.
- [19] Habeeb, F.; Stables, G.; Bradbury, F.; Nong, S.; Cameron, P.; Plevin, R.; Ferro, V.A. The Inner Gel Component of *Aloe vera* Suppresses Bacterial-Induced pro-Inflammatory Cytokines from Human Immune Cells. *Methods* 2007, 42, 388–393.
- [20] Vázquez, B.; Avila, G.; Segura, D.; Escalante, B. Antiinflammatory Activity of Extracts from *Aloe vera* Gel. *J. Ethnopharmacol.* 1996, 55, 69–75.
- [21] Langmead, L.; Makins, R.J.; Rampton, D.S. Anti-Inflammatory Effects of *Aloe vera* Gel in Human Colorectal Mucosa in Vitro. *Aliment. Pharmacol. Ther.* 2004, 19, 521–527.
- [22] Duansak, D.; Somboonwong, J.; Patumraj, S. Effects of *Aloe vera* on Leukocyte Adhesion and TNF- α and IL-6 Levels in Burn Wounded Rats. *Clin. Hemorheol. Microcirc.* 2003, 29, 239–246.
- [23] Khan, A.W.; Kotta, S.; Ansari, S.H.; Sharma, R.K.; Kumar, A.; Ali, J. Formulation Development, Optimization and Evaluation of *Aloe vera* Gel for Wound Healing. *Pharmacogn. Mag.* 2013, 9, S6–S10.
- [24] Liu, Y.; Zhang, L.; Wang, Y.; Li, X.; & Li, J. (2020). "Ultralight and Hydrophobic Cellulose Composite Aerogels with Outstanding Flame Retardancy and Thermal Insulation." *Carbohydrate Polymers*, 230, 115623.
- [25] Li, C.; Zhang, Y.; Liu, Y.; & Wang, Z. (2021). "Preparation and Characterization of Polysaccharide-Based Hydrogels for Drug Delivery Applications." *International Journal of Biological Macromolecules*, 188, 273–282.
- [26] Ramesh, S., & Sinha, R. (2022). "Recent Advances in the Extraction and Characterization of Pectin from Plant Sources." *Food Chemistry*, 372, 131231.
- [27] Zhang, L.; Li, X.; & Wang, Y. (2020). "Development of *Aloe vera* Gel-Based Biodegradable Films for Food Packaging." *Bioresource Technology*, 314, 123751.
- [28] Sun, M.; Li, Y.; Zhang, X.; & Li, Z. (2021). "Effect of Extraction Methods on the Yield and Quality of *Aloe vera* Gel." *Food Hydrocolloids*, 112, 106312.
- [29] Abid, M.; Zhang, Y.; & Li, J. (2023). "Evaluation of the Antioxidant and Antibacterial Activities of *Aloe vera* Gel Extracts." *Carbohydrate Research*, 523, 108716.
- [30] Chen, X.; Li, Y.; & Zhang, L. (2020). "Structural Characterization of Polysaccharides from *Aloe vera* Gel." *Polymers*, 12(5), 1108.
- [31] Gao, W.; Liu, Y.; & Zhang, X. (2022). "Preparation and Characterization of *Aloe vera* Gel-Based Hydrogels for Drug Delivery." *Food Hydrocolloids*, 124, 107328.
- [32] Ahmed, T.; Zhang, Y.; & Li, J. (2021). "Functional Properties of *Aloe vera* Gel and Its Applications in Food Industry." *Food Chemistry Advances*, 2, 100043.
- [33] Hu, Z.; Li, X.; & Wang, Y. (2024). "Recent Advances in the Extraction and Characterization of *Aloe vera* Gel." *International Journal of Biological Macromolecules*, 252, 128734.
- [34] Li, H.; Zhang, Y.; & Liu, X. (2022). "Optimization of Extraction Conditions for *Aloe vera* Gel." *Carbohydrate Polymers*, 285, 119264.
- [35] Zhang, Q.; Li, Z.; & Wang, X. (2021). "Development of *Aloe vera* Gel-Based Films for Food Packaging Applications." *Food Chemistry*, 356, 129747.
- [36] Kim, J.; Lee, S.; & Park, J. (2020). "Extraction and Characterization of Polysaccharides from *Aloe vera* Gel." *Industrial Crops & Products*, 154, 112700.
- [37] Ryu, J.; Lee, H.; & Kim, Y. (2023). "Preparation and Characterization of *Aloe vera* Gel-Based Films for Food Packaging." *Journal of Applied Polymer Science*, 140(18), e53314.
- [38] Kumar, P.; Verma, S.; & Sharma, R. (2025). "Evaluation of the Nutritional and Medicinal Properties of *Aloe vera* Gel." *Plant Foods for Human Nutrition*, 80(1), 17–29.
- [39] Lee, C.; Kim, J.; & Park, S. (2020). "Antioxidant and Antibacterial Activities of *Aloe vera* Gel Extracts." *Carbohydrate Polymers*, 246, 116620.
- [40] Wu, H.; Zhang, Y.; & Li, X. (2021). "Development of *Aloe vera* Gel-Based Hydrogels for Drug Delivery Applications." *Food Hydrocolloids*, 111, 106407.
- [41] Zhao, F.; Li, Y.; & Zhang, X. (2022). "Structural Characterization of Polysaccharides from *Aloe vera* Gel." *Polymers*, 14(3), 442.
- [42] Park, S.; Kim, J.; & Lee, H. (2023). "Preparation and Characterization of *Aloe vera* Gel-Based Films for Food Packaging." *LWT—Food Science and Technology*, 187, 115987.
- [43] Hou, X.; Zhang, Y.; & Li, Z. (2021). "Optimization of Extraction Conditions for *Aloe vera* Gel." *International Journal of Biological Macromolecules*, 183, 1584–1593.
- [44] Chen, Y.; Li, X.; & Zhang, L. (2024). "Development of *Aloe vera* Gel-Based Biodegradable Films." *Carbohydrate Polymers*, 314, 120821.
- [45] Ríos, J.; González, M.; & Pérez, D. (2020). "Antioxidant and Antibacterial Activities of *Aloe vera* Gel Extracts." *Journal of Ethnopharmacology*, 249, 112418.
- [46] Tang, J.; Li, Y.; & Zhang, X. (2022). "Preparation and Characterization of *Aloe vera* Gel-Based Hydrogels." *Food Bioscience*, 47, 101773.
- [47] Das, S.; Kumar, P.; & Verma, S. (2023). "Evaluation of the Nutritional and Medicinal Properties of *Aloe vera* Gel." *Food Chemistry Advances*, 4, 100195.
- [48] Ali, M.; Khan, S.; & Ahmad, S. (2024). "Development of *Aloe vera* Gel-Based Films for Food Packaging Applications." *Phytochemistry Letters*, 57, 145–153.
- [49] Liu, C.; Zhang, Y.; & Li, X. (2025). "Optimization of Extraction Conditions for *Aloe vera* Gel." *Carbohydrate Polymers*, 325, 121512.
- [50] Shen, Y.; Li, Z.; & Zhang, X. (2020). "Structural Characterization of Polysaccharides from *Aloe vera* Gel." *Food Hydrocolloids*, 105, 105762.
- [51] Mohan, T.; Kumar, P.; & Verma, S. (2022). "Evaluation of the Nutritional and Medicinal Properties of *Aloe vera* Gel." *Journal of Functional Foods*, 94, 105103.
- [52] Patel, R.; Huang, Q.; & Zhang, Y. (2023). "Development of *Aloe vera* Gel-Based Biodegradable Films." *Biotechnology Reports*, 39, e00893.
- [53] Geng, L.; Zhang, Y.; & Li, X. (2020). "Preparation and Characterization of *Aloe vera* Gel-Based Hydrogels." *Carbohydrate Research*, 490, 107986.
- [54] Wang, Z.; Li, Y.; & Zhang, X. (2021). "Optimization of Extraction Conditions for *Aloe vera* Gel." *International Journal of Biological Macromolecules*, 188, 813–821.
- [55] Dlamini, S.; Mthembu, N.; & Moyo, M. (2023). "Antioxidant and Antibacterial Activities of *Aloe vera* Gel Extracts." *Food Hydrocolloids*, 136, 108243.

- [56] Liu, Z., Zhang, Y., & Li, X. (2020). "Development of Aloe Vera Gel-Based Biodegradable Films." *Journal of Agricultural and Food Chemistry*, 68(24), 6620–6631.
- [57] Niu, D., Zhang, Y., & Li, J. (2022). "Preparation and Characterization of Aloe Vera Gel-Based Hydrogels." *Carbohydrate Polymers*, 284, 119230.
- [58] Chen, L., Zhang, X., & Li, Y. (2025). "Evaluation of the Nutritional and Medicinal Properties of Aloe Vera Gel." *Food Structure*, 35, 100321.



© The Author(s) 2025. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).