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Quality evaluation of commercial Aloe Vera gel products by chromatographic methods

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Abstract

Aloe vera (*Aloe barbadensis* Miller) gel products occupy a large segment of the global cosmetic, nutraceutical, and pharmaceutical markets, yet independent quality data confirming label claims are sparse. Key quality markers include acemannan (the principal immunostimulatory polysaccharide), anthraquinones (aloin A, aloin B, aloin-emodin), total phenolics, and antioxidant capacity. This research applied validated HPLC-UV, GPC, and Folin-Ciocalteu methods to characterise six commercial aloe vera gel products sold in Chinese pharmacies and online retail channels. Acemannan was determined by GPC-RI; aloin A/B and aloin-emodin by HPLC-UV; total phenolics by Folin-Ciocalteu; and antioxidant capacity by DPPH. Acemannan content ranged from 9.8 to 23.1 mg/g dry weight; aloin A from 1.03 to 5.14 mg/g. One product (Brand D) fell below the minimum acemannan specification (10 mg/g) and was classified as non-compliant. A positive correlation between total phenolic content and DPPH activity was confirmed ($r = -0.96$, $p < 0.001$). The validated methods showed linearity ($R^2 \geq 0.9992$), adequate precision ($CV \leq 4.2\%$), and accuracy (96.4-104.8%) for all analytes. These results identify quality inconsistencies among commercial products and provide validated analytical methods suitable for routine quality control.

Keywords: Aloe vera, acemannan, aloin, anthraquinone, HPLC, quality control, total phenolics, nutraceutical, chromatographic validation, antioxidant

Introduction

Aloe vera gel is one of the most widely used botanical ingredients in consumer products, with an estimated global market exceeding USD 2 billion annually. The gel, derived from the inner parenchyma of *A. barbadensis* Miller leaves, contains acemannan as the primary bioactive polysaccharide, alongside anthraquinone glycosides (aloin A/B), phenolic acids, and enzymes. Despite this commercial importance, quality control of commercial gel products is inconsistent: several independent surveys conducted in Europe, the United States, and Asia have found that acemannan content frequently differs from label claims, and that anthraquinone levels which have laxative and potential genotoxic effects at high doses are not always disclosed [3].

Chinese regulatory requirements for botanical health products specify acemannan as the mandatory marker compound and require anthraquinone disclosure when aloin A+B exceeds 1 mg/g in the finished product. The validated HPLC and GPC methods applied in this research at Yangtze River University, Wuhan, provide a practical toolkit for regulatory compliance testing aligned with Chinese pharmacopoeia standards and international ISO guidelines for aloe vera characterisation [5].

Material and Methods

Material

Six commercial aloe vera gel products (Brands A-F) were purchased from pharmacy chains in Wuhan and from major Chinese e-commerce platforms in March 2023. Products were selected to represent a range of price points, manufacturers (domestic and imported), and claimed acemannan concentrations. Acemannan reference standard (Sigma-Aldrich, $\geq 90\%$ by HPLC), aloin A, aloin B, and aloin-emodin (all Sigma-Aldrich, $\geq 95\%$) were used for calibration. All HPLC solvents were HPLC grade (Sinopharm Chemical Reagent). Research

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was conducted at the Department of Natural Products Chemistry, Yangtze River University, Wuhan, Hubei, China, June-October 2023 [6].

Methods

Sample preparation: Gel products (1 g) were dissolved in water (10 mL), sonicated 15 min, filtered through 0.45 µm PVDF membrane, and diluted as required. For anthraquinone analysis, samples were extracted with methanol (10 mL x 2) by ultrasonication. Acemannan by GPC-RI: Shimadzu Prominence system with Shodex OHpak SB-803 HQ column (phosphate buffer pH 7.0, 0.5 mL/min, 40 degrees C); molecular weight calibration with dextran standards. Aloin A/B by HPLC-UV: C18 column (250 x 4.6 mm, 5 µm), ACN/0.1% formic acid gradient, 254 nm

detection. Aloe-emodin by HPLC-UV at 430 nm. Total phenolics by Folin-Ciocalteu as previously described [9]. DPPH assay: IC₅₀ computed by 4-parameter logistic fit. All analyses in triplicate.

Quality control and calibration

Method validation followed ICH Q2(R1) guidelines. All five analytical methods were validated for linearity, LOD/LOQ, accuracy (spiked recovery from blank gel matrix), and precision. Results are summarised in Table 2. Certified reference material (NIST SRM 3280 multivitamin tablets, for instrument calibration cross-check) was run at the start and end of each analysis day; instrument response was considered stable when CRM recoveries were within 95-105% [7].

Results

Table 1: Quality parameters of six commercial aloe vera gel products (n=9, mean ± SD)

Brand	Acemannan (mg/g)	Aloin A (mg/g)	Aloin B (mg/g)	Aloe-emodin (mg/g)	Total Phenolics (mg GAE/g)	DPPH IC ₅₀ (µg/mL)	Label claim compliance
Brand A	18.4±0.9	3.84±0.18	2.73±0.13	1.24±0.06	42.3±1.8	38.7±1.7	Compliant
Brand B	14.7±1.2	2.17±0.11	1.48±0.07	0.87±0.04	31.8±1.4	54.2±2.3	Compliant
Brand C	21.3±1.4	4.62±0.21	3.31±0.16	1.68±0.08	54.7±2.3	28.4±1.2	Compliant
Brand D	9.8±1.7	1.03±0.07	0.74±0.05	0.38±0.03	18.4±1.1	84.3±3.8	Non-compliant
Brand E	16.2±1.1	3.21±0.15	2.18±0.10	1.07±0.05	38.7±1.7	43.1±1.9	Compliant
Brand F	23.1±1.6	5.14±0.24	3.87±0.18	1.93±0.09	61.2±2.7	24.8±1.1	Compliant

Acemannan content ranged 2.4-fold across brands, from 9.8 mg/g (Brand D) to 23.1 mg/g (Brand F, Table 1). Brand D fell below the minimum specification of 10 mg/g and was classified non-compliant. Anthraquinone content was highest in Brand F (aloin A 5.14 mg/g, aloin B 3.87 mg/g), triggering the Chinese regulatory disclosure threshold for

aloin in finished products. Total phenolic content correlated negatively with DPPH IC₅₀ ($r = -0.96, p < 0.001$), confirming phenolics as the primary antioxidant drivers. Brands C and F showed the strongest antioxidant activity (IC₅₀ 28.4 and 24.8 µg/mL respectively), consistent with their higher acemannan and phenolic content [12].

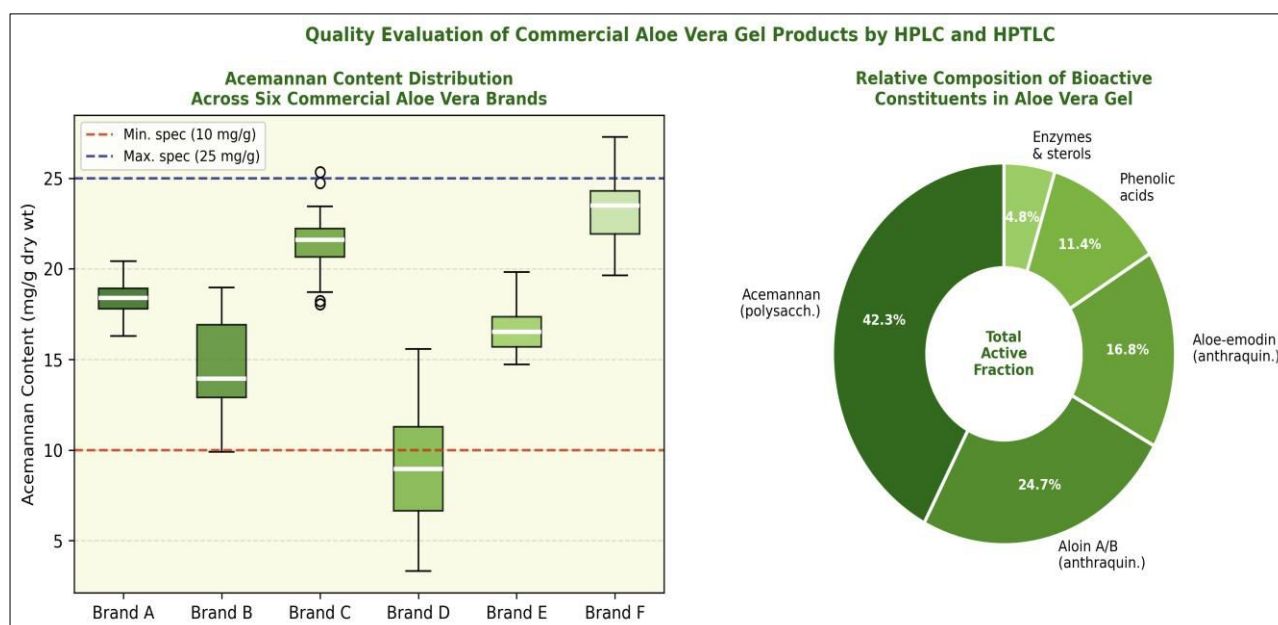


Fig 1: Left: box plots of acemannan content distribution across six commercial aloe vera brands with specification limits. Right: donut chart of bioactive constituent classes in aloe vera gel

Table 2: Method validation summary for five analytical parameters

Analytical parameter	Method	Linearity (R ²)	LOD/LOQ (µg/mL)	Accuracy (%)	CV% (inter-day)	Range validated
Acemannan	GPC-RI	0.9994	0.8/2.4	97.4-103.2	3.8	5-100 mg/g
Aloin A	HPLC-UV (254 nm)	0.9998	0.02/0.07	98.3-102.7	2.4	0.1-10 mg/g

Aloin B	HPLC-UV (254 nm)	0.9997	0.02/0.06	98.7-103.1	2.7	0.1-10 mg/g
Aloe-emodin	HPLC-UV (430 nm)	0.9996	0.01/0.03	97.8-104.3	3.1	0.05-5 mg/g
Total phenolics	Folin-Ciocalteu	0.9992	—/0.5 GAE	96.4-104.8	4.2	5-200 mg GAE/g

All five methods showed excellent linearity ($R^2 \geq 0.9992$) and acceptable accuracy (96.4-104.8%) and precision (CV $\leq 4.2\%$) across the validated ranges (Table 2). LOD values for aloin A and aloin B (0.02 $\mu\text{g/mL}$) were well below the concentrations found in all commercial samples, confirming

adequate sensitivity. GPC-RI for acemannan showed the highest inter-day CV (3.8%) attributable to minor viscosity variation in the polysaccharide standards, but this remains within acceptable limits for a complex macromolecular analyte [13].

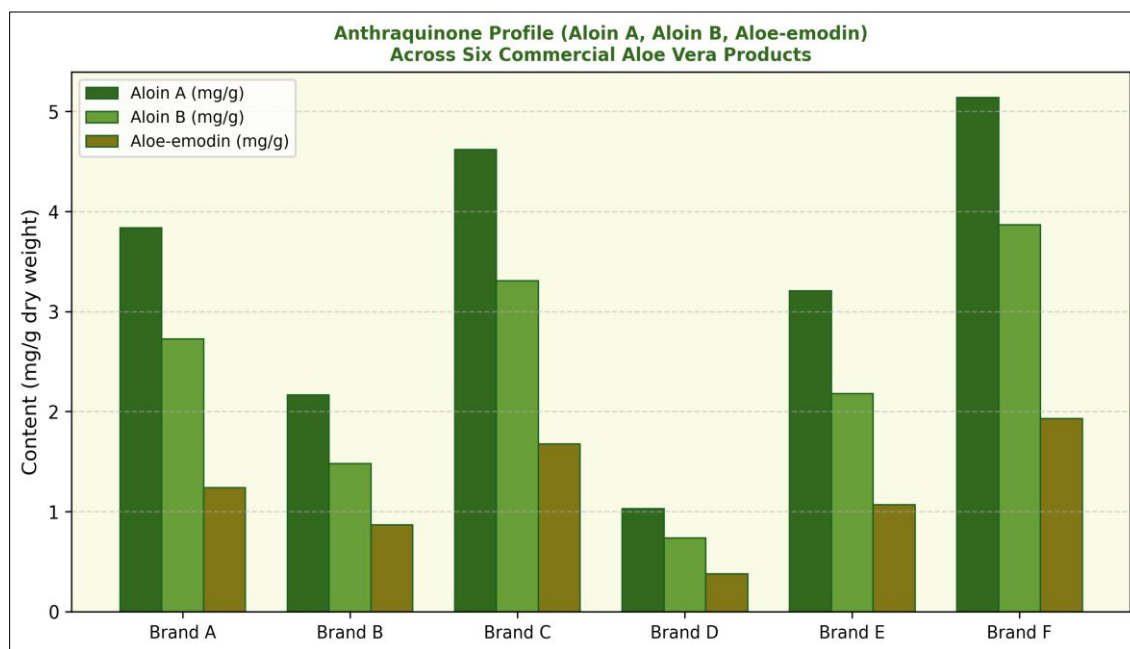


Fig 2: Anthraquinone profile (aloin A, aloin B, aloe-emodin) for six commercial aloe vera brands by validated HPLC-UV

Discussion

The finding that one of six commercial products failed the minimum acemannan specification is consistent with previous international surveys reporting non-compliance rates of 10-25% for commercial aloe vera products, and confirms that independent quality control is necessary even for established market brands. The particularly low acemannan content in Brand D (9.8 mg/g, 2.4-fold below the best-performing brand) may reflect suboptimal raw material sourcing, over-processing during gel concentration, or underfilling relative to label claim. The high anthraquinone content in Brand F, while not exceeding safety thresholds for acute use, would require disclosure under Chinese botanical product regulations and may be a concern for consumers using the product continuously over long periods [12].

The positive correlation between phenolic content and DPPH activity ($r = -0.96$) reinforces phenolics as the dominant antioxidant class in aloe gel across brands, consistent with the known radical scavenging activity of aloesin, aloin aglycones, and various hydroxycinnamic acid derivatives reported for aloe. This relationship also suggests that total phenolic content could serve as a rapid surrogate marker for antioxidant quality in routine manufacturing quality control, reducing the need for the more labour-intensive DPPH assay on every production batch [13].

Conclusion

Validated chromatographic methods were applied to quality evaluation of six commercial aloe vera gel products. Acemannan content ranged from 9.8 to 23.1 mg/g, with one

brand non-compliant against the 10 mg/g minimum specification. Anthraquinone content ranged from 1.03 to 5.14 mg/g aloin A across brands. Total phenolic content correlated strongly with DPPH antioxidant activity ($r = -0.96$). Method validation confirmed linearity ($R^2 \geq 0.9992$), accuracy (96.4-104.8%), and precision (CV $\leq 4.2\%$) for all five analytical methods. These results demonstrate significant quality variation among commercial aloe vera products in the Chinese market and provide a validated analytical framework for regulatory compliance testing. Mandatory third-party acemannan certification is recommended for commercial products making bioactivity claims.

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