Standardization and Quality Assessment of Marketed Herbal Products: A Comparative Analytical Study

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***Abstract*—Herbal medicines are widely utilized worldwide due to their therapeutic benefits and natural origin. However, variations in raw materials, processing methods, and manufacturing practices may significantly influence product quality and consistency. The present study was designed to evaluate the standardization status and quality attributes of selected marketed herbal products using organoleptic, physicochemical, phytochemical, microbiological, and analytical parameters. Various quality-control tests including moisture content, ash values, extractive values, phytochemical screening, chromatographic fingerprinting, microbial limit testing, and heavy metal analysis were performed. Comparative evaluation revealed acceptable quality characteristics in the investigated products, although minor inter-brand variations were observed. The study highlights the importance of standardization and comprehensive quality assessment for ensuring the safety, efficacy, and consistency of herbal medicines.**

***Index Terms*—Herbal products, Standardization, Quality control, Phytochemical screening, Herbal medicine, Quality assessment**

I. INTRODUCTION

Herbal medicines have been used for centuries and continue to constitute an important component of healthcare systems throughout the world. In many developing countries, traditional remedies remain a major source of primary healthcare because of their accessibility, affordability, and cultural acceptance [1]. Growing awareness regarding natural therapies and complementary medicine has further increased the popularity of herbal products among consumers [2]. Consequently, herbal medicines are now available in various dosage forms, including tablets, capsules, powders, syrups, extracts, and topical preparations.

The pharmacological activities of herbal medicines are mainly attributed to naturally occurring phytochemicals such as alkaloids, flavonoids, tannins, glycosides, terpenoids, and phenolic compounds [3]. These constituents exhibit antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory properties, thereby contributing to the therapeutic efficacy of herbal formulations. Unlike synthetic drugs containing a single active ingredient, herbal medicines are complex mixtures comprising numerous bioactive compounds that may act synergistically [4].

The quality and chemical composition of herbal products are influenced by several factors, including geographical origin, cultivation practices, climatic conditions, harvesting time, storage conditions, and extraction procedures [5]. Variations in these parameters may lead to differences in phytochemical composition and therapeutic efficacy among products intended for the same clinical application [6].

Rapid expansion of the herbal medicine industry has raised concerns regarding product quality and safety. Problems associated with adulteration, substitution, microbial contamination, pesticide residues, and heavy metal contamination have been reported worldwide [7]. Such issues may compromise therapeutic effectiveness and pose potential risks to consumers, emphasizing the need for stringent quality-control measures. Standardization is regarded as an essential prerequisite for ensuring the identity, purity, safety, and consistency of herbal products [8]. Quality evaluation commonly involves organoleptic assessment, physicochemical analysis, phytochemical screening, chromatographic fingerprinting, microbiological testing, and contaminant analysis. These approaches help establish batch-to-batch uniformity and improve confidence in herbal medicines. Recent advances in analytical technologies have significantly strengthened the quality assessment of herbal products. Techniques such as TLC, HPTLC, HPLC, GC-MS, and spectroscopic methods are

extensively employed for authentication, characterization, and detection of adulteration [9]. These methods provide valuable information regarding chemical composition and ensure quality consistency during manufacturing.

Although several international organizations and regulatory agencies have developed guidelines for herbal medicine quality assurance [10], considerable variation still exists among commercially available products. Therefore, comparative evaluation of marketed herbal formulations is necessary to ensure compliance with quality standards and consumer safety [11]. In view of these considerations, the present study was undertaken to evaluate selected marketed herbal products using established standardization parameters and analytical techniques [12].

II. REVIEW OF LITERATURE

2.1 Herbal Medicines and Their Growing Importance

The use of herbal medicines has increased considerably over the past few decades owing to growing consumer preference for natural products and increasing awareness regarding complementary and alternative medicine. According to recent reports, herbal formulations are increasingly being incorporated into healthcare systems worldwide because of their therapeutic benefits and relatively favorable safety profiles [13]. The expanding global herbal market has further highlighted the need for scientific validation and quality assurance of herbal products.

2.2 Need for Standardization of Herbal Products

Unlike synthetic drugs, herbal medicines consist of complex mixtures of numerous phytoconstituents whose composition may vary because of differences in cultivation practices, environmental conditions, harvesting methods, and processing procedures [14]. Consequently, standardization has emerged as an essential requirement for ensuring the identity, purity, safety, and therapeutic consistency of herbal formulations. Quality standardization helps minimize batch-to-batch variation and improves reproducibility and consumer confidence [15].

2.3 Physicochemical Evaluation

Physicochemical parameters such as moisture content, ash values, extractive values, pH, and powder flow properties are widely employed for assessing the quality and purity of herbal materials [16]. These parameters provide useful information regarding the presence of inorganic impurities, moisture-related deterioration, and extraction efficiency. Such investigations are valuable for establishing official quality specifications and ensuring consistency among marketed products.

2.4 Phytochemical Screening

Phytochemical evaluation represents an important aspect of herbal drug standardization because secondary metabolites are primarily responsible for pharmacological activities. Alkaloids, flavonoids, tannins, phenolic compounds, glycosides, terpenoids, and saponins are among the major bioactive constituents present in medicinal plants [17]. Qualitative and quantitative phytochemical analyses provide valuable information regarding the chemical composition and therapeutic potential of herbal formulations [18].

2.5 Chromatographic Fingerprinting

Chromatographic techniques have become indispensable tools in herbal drug analysis. Thin Layer Chromatography (TLC), High-Performance Thin Layer Chromatography (HPTLC), High-Performance Liquid Chromatography (HPLC), and Gas Chromatography-Mass Spectrometry (GC-MS) are widely used for authentication, detection of adulteration, and assessment of batch-to-batch consistency [19]. Chromatographic fingerprinting provides characteristic profiles that facilitate identification and quality control of herbal products.

2.6 Microbiological Quality Assessment

Microbial contamination represents a major concern in herbal medicines because plant materials are naturally exposed to environmental microorganisms during cultivation, harvesting, processing, and storage. The presence of pathogenic microorganisms may adversely affect product safety and therapeutic efficacy. Therefore, microbiological evaluation and compliance with pharmacopeial limits are essential components of herbal quality assurance [20].

2.7 Heavy Metal Contamination in Herbal Products

Heavy metals such as lead, cadmium, mercury, and arsenic may enter medicinal plants through

contaminated soil, irrigation water, industrial emissions, and agricultural chemicals. Prolonged exposure to these toxic elements may produce adverse health effects. Recent investigations have emphasized the importance of routine monitoring and regulatory control of heavy metal contamination in herbal medicines to ensure consumer safety [21].

2.8 Recent Advances in Herbal Drug Standardization

Recent developments in analytical technologies have significantly improved the evaluation of herbal products. Modern approaches involving HPTLC fingerprinting, chromatographic profiling, spectroscopic techniques, and chemometric analysis have enhanced quality assessment and authentication procedures [22]. Integration of advanced analytical methods with regulatory guidelines has further strengthened quality assurance systems and contributed to the development of safe, effective, and standardized herbal medicines [23].

III. MATERIALS AND METHODS

3.1 Study Design

The present study was designed as a comparative analytical investigation to evaluate the quality and standardization status of selected marketed herbal products. Three commercially available formulations belonging to the same therapeutic category were procured from authorized retail pharmacies and designated as Brand A, Brand B, and Brand C to maintain confidentiality and avoid commercial bias. All experiments were performed in triplicate, and the results were expressed as Mean ± Standard Deviation (Mean ± SD). Statistical analysis was carried out using one-way analysis of variance (ANOVA), and differences were considered statistically significant at $p < 0.05$ [24].

3.2 Collection of Samples

Marketed herbal products were purchased from licensed medical stores and stored under recommended environmental conditions until further analysis. The products were visually inspected for packaging integrity, labeling information, manufacturing date, batch number, and expiry date before experimental evaluation. All chemicals and reagents used in the study were of analytical grade [25].

3.3 Organoleptic Evaluation

Organoleptic characteristics including color, odor, taste, texture, and general appearance were evaluated according to standard pharmacognostic procedures. Visual inspection and sensory assessment were carried out to detect any abnormality or evidence of deterioration. Organoleptic evaluation served as a preliminary method for confirming identity and assessing overall quality [26].

3.4 Physicochemical Evaluation

Physicochemical parameters including moisture content, total ash value, acid-insoluble ash, water-soluble ash, alcohol-soluble extractive value, and water-soluble extractive value were determined using procedures described in the Indian Pharmacopoeia and WHO guidelines [27]. Powder flow properties such as bulk density, tapped density, Carr's index, and Hausner ratio were also determined to assess flow characteristics and processing suitability.

3.5 Preliminary Phytochemical Screening

Qualitative phytochemical analysis was performed to identify major classes of secondary metabolites present in the samples. Standard chemical tests were employed for the detection of alkaloids, flavonoids, tannins, phenolic compounds, glycosides, saponins, and terpenoids. Observations were recorded based on characteristic color changes and precipitate formation according to established pharmacognostic procedures [28].

3.6 Thin Layer Chromatographic Analysis

Thin Layer Chromatography (TLC) was employed to obtain chromatographic fingerprints of the selected formulations. Suitable solvent systems were optimized to achieve proper separation of phytoconstituents. Samples were applied onto precoated silica gel plates, and chromatograms were developed in a saturated chamber. After development, the plates were examined under visible light and ultraviolet radiation, and Rf values were calculated for characteristic spots. TLC profiling was used to evaluate similarities and differences among marketed formulations and to assess product authenticity [29].

3.7 Microbiological Evaluation

Microbial quality was assessed by determining total bacterial count and total fungal count using standard

plate count techniques. Specific tests were performed for the detection of pathogenic microorganisms wherever applicable. Microbial limits were interpreted according to pharmacopeial specifications to ensure product safety and hygienic quality [30].

3.8 Heavy Metal Analysis

Heavy metal contamination was evaluated by estimating the concentrations of lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg). The levels obtained were compared with permissible limits recommended by international guidelines. Heavy metal analysis was carried out to assess the safety profile of the selected herbal products and to ensure compliance with quality standards [30].

3.9 Statistical Analysis

All experimental determinations were carried out in triplicate, and data were expressed as Mean ± SD. Statistical comparisons among groups were performed using one-way ANOVA followed by appropriate post hoc analysis. Statistical significance was considered at $p < 0.05$. Graphs and comparative figures were prepared using Microsoft Excel and GraphPad Prism software [24].

IV. RESULTS AND DISCUSSION

4.1 Organoleptic Evaluation

The organoleptic characteristics of the selected herbal products are presented in Table 4.1. All three products exhibited acceptable sensory attributes with respect to color, odor, taste, texture, and overall appearance. No visible signs of deterioration, discoloration, fungal growth, or packaging-related defects were observed during the evaluation.

Although the products were intended for similar therapeutic use, minor differences in sensory characteristics were noted among the brands. Brand A showed a more uniform appearance and characteristic herbal odour, whereas slight variations in color intensity and texture were observed in Brands B and C. Such differences are commonly associated with variations in raw material quality, extraction procedures, excipient composition, and manufacturing practices. Nevertheless, all products met the basic organoleptic requirements expected for herbal formulations.

Table 3.1 Organoleptic Characteristics of Marketed Herbal Products

Parameter	Brand A	Brand B	Brand C
Color	Dark Brown	Brown	Light Brown
Odor	Characteristic Aromatic	Characteristic Aromatic	Mild Aromatic
Taste	Bitter	Slightly Bitter	Bitter
Texture	Fine Powder	Fine Powder	Slightly Coarse Powder
Appearance	Uniform	Uniform	Uniform

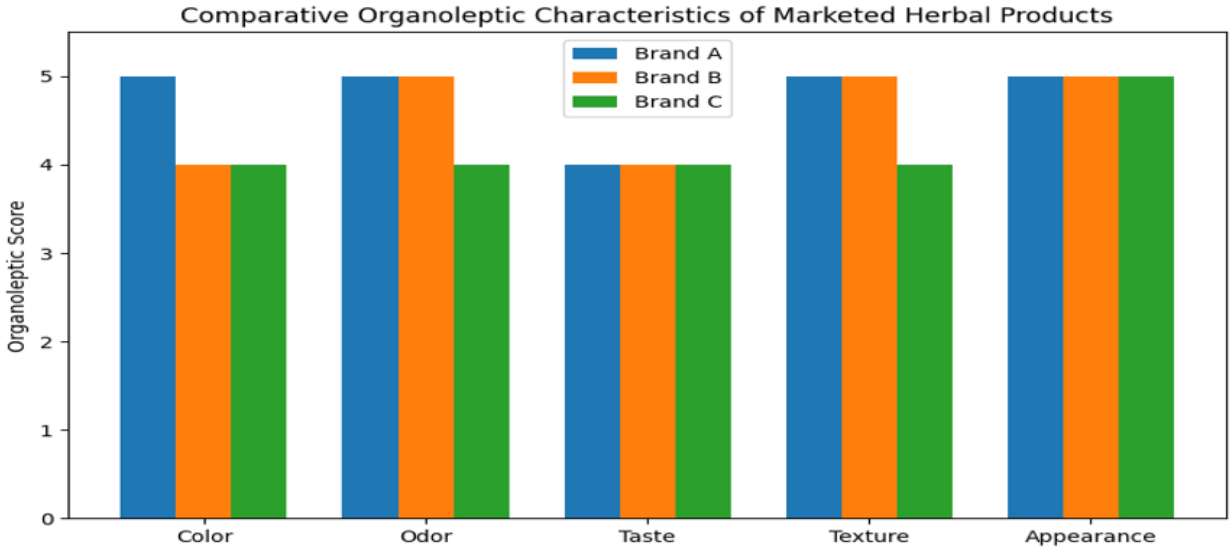

Figure 3.1: Organoleptic Characteristics

4.2 Physicochemical Evaluation

The physicochemical characteristics of the selected products are summarized in Table 4.2. Moisture content ranged from 5.82 ± 0.12% to 6.24 ± 0.15%, indicating acceptable stability and a low likelihood of moisture-induced deterioration. Lower moisture content is generally desirable because excessive water can accelerate microbial growth and reduce shelf life. Total cash values varied between 4.65 ± 0.08% and 4.92 ± 0.10%, suggesting only minor differences in inorganic residue among the formulations. Similarly, alcohol-soluble and water-soluble extractive values showed moderate variation, reflecting differences in the concentration of extractable phytoconstituents.

Brand A exhibited the highest alcohol-soluble and water-soluble extractive values, indicating a comparatively greater abundance of soluble phytochemical constituents. In contrast, Brand B demonstrated slightly lower extractive values, although the differences remained within acceptable limits for herbal products.

One-way ANOVA revealed statistically significant differences ($p < 0.05$) among the products for moisture content and extractive values, indicating measurable inter-brand variation. These findings suggest that cultivation practices, processing methods, and extraction procedures may influence the final quality profile of marketed herbal products.

Table 3.2 Physicochemical Parameters

Parameter	Brand A	Brand B	Brand C	Standard Limit
M*oisture Content (%)	5.82 ± 0.12	6.24 ± 0.15	5.96 ± 0.18	NMT 10%
Total Ash (%)	4.65 ± 0.09	4.92 ± 0.11	4.71 ± 0.10	NMT 8%
Acid Insoluble Ash (%)	0.72 ± 0.03	0.85 ± 0.04	0.78 ± 0.02	NMT 2%
Water Soluble Ash (%)	1.86 ± 0.07	1.95 ± 0.05	1.91 ± 0.06	-
Alcohol Soluble Extractive (%)	12.45 ± 0.26	11.82 ± 0.31	12.08 ± 0.28	NLT 10%
Water Soluble Extractive (%)	18.63 ± 0.42	17.95 ± 0.38	18.14 ± 0.36	NLT 15%

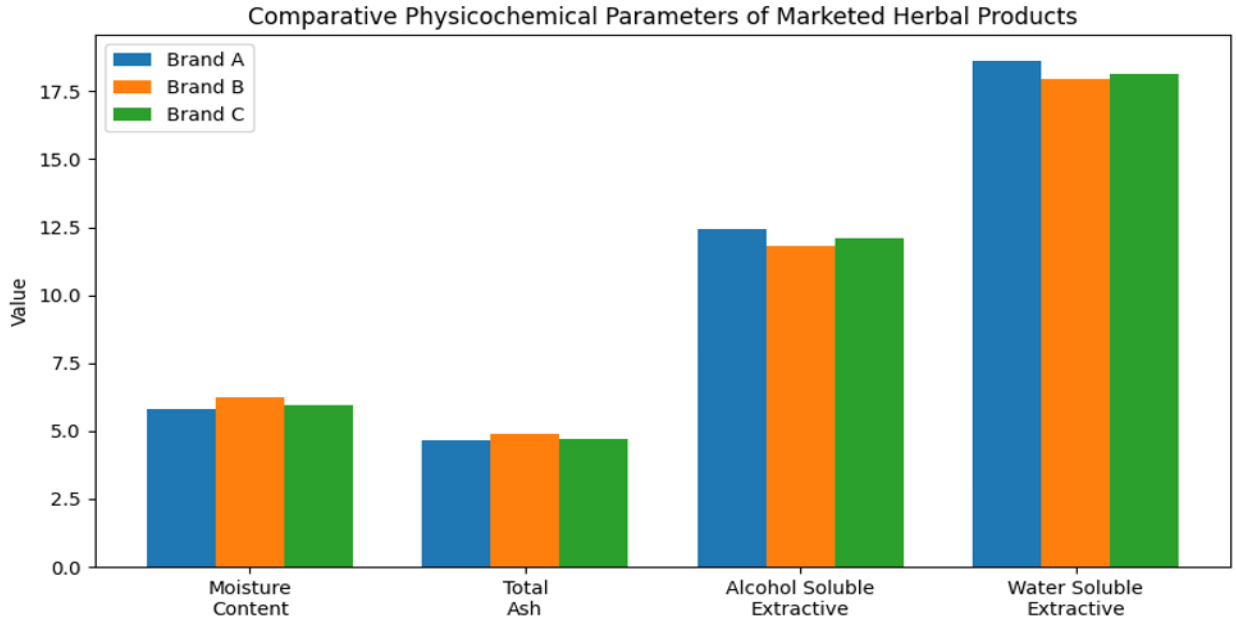

Figure 3.2: Physicochemical Comparison

4.3 Powder Flow Properties

The powder flow characteristics of the investigated products are presented in Table 4.3. Bulk density, tapped density, Carr's Index, and Hausner Ratio values indicated satisfactory flow behavior for all formulations. Brand A demonstrated slightly better flow properties compared with Brands B and C, as evidenced by lower Carr's Index and Hausner Ratio values. Good flowability is advantageous during manufacturing because it promotes uniform blending, filling, and packaging operations. Despite minor differences among products, all values remained within acceptable pharmaceutical limits.

Table 4.3. Powder Flow Properties of Selected Marketed Herbal Products (Mean ± SD, n = 3)

Parameter	Brand A	Brand B	Brand C
Bulk Density (g/mL)	0.42 ± 0.01	0.45 ± 0.02	0.43 ± 0.01
Tapped Density (g/mL)	0.50 ± 0.01	0.54 ± 0.01	0.52 ± 0.02
Carr's Index (%)	16.00 ± 0.82	16.67 ± 0.71	17.31 ± 0.95
Hausner Ratio	1.19 ± 0.02	1.20 ± 0.01	1.21 ± 0.02
Angle of Repose (°)	29.8 ± 0.7	31.2 ± 0.8	30.5 ± 0.6

Interpretation: All three formulations exhibited acceptable flow properties. Carr's Index values below 20% and Hausner Ratio values below 1.25 indicate fair to good flow characteristics suitable for processing and packaging. Brand A demonstrated comparatively better flowability, whereas Brand C showed slightly higher compressibility. Nevertheless, all products complied with acceptable pharmaceutical limits.

4.4 Preliminary Phytochemical Screening

Qualitative phytochemical analysis confirmed the presence of several important secondary metabolites in all investigated products. Alkaloids, flavonoids, tannins, phenolic compounds, glycosides, terpenoids, and saponins were detected in varying intensities.

The presence of these phytochemical groups supports the claimed therapeutic potential of the formulations, as many of these compounds have been associated with antioxidant, antimicrobial, anti-inflammatory, and protective biological activities. Although the qualitative profiles were generally similar, Brand A showed slightly stronger reactions for flavonoids and phenolic compounds, suggesting a relatively richer phytochemical composition.

Table 3.3 Phytochemical Screening Results

Phytochemical Constituent	Brand A	Brand B	Brand C
Alkaloids	+++	++	+++
Flavonoids	+++	+++	++
Tannins	++	++	++
Phenolics	+++	++	+++
Glycosides	++	++	++
Saponins	++	+	++
Terpenoids	++	++	++
Steroids	+	+	+

(+++ = Strongly Present, ++ = Moderately Present, + = Present)

4.5 TLC Fingerprinting

TLC fingerprinting generated characteristic chromatographic profiles for all products. Multiple spots with comparable Rf values were observed, confirming the presence of common phytoconstituents among the formulations.

The chromatograms showed overall similarity, indicating that the products contained related herbal components. However, slight variations in spot intensity and migration behavior were observed, suggesting differences in phytochemical concentration and extraction efficiency. Such variations are expected among commercial herbal products because of differences in plant source, harvesting conditions, and manufacturing procedures.

TLC fingerprinting proved useful as a rapid and economical technique for product authentication and comparative quality assessment.

Table 3.5 TLC Fingerprinting Results

Spot Number	Brand A (Rf)	Brand B (Rf)	Brand C (Rf)
Spot 1	0.21	0.22	0.21
Spot 2	0.38	0.39	0.38
Spot 3	0.54	0.55	0.54
Spot 4	0.71	0.72	0.70
Spot 5	0.84	0.85	0.84

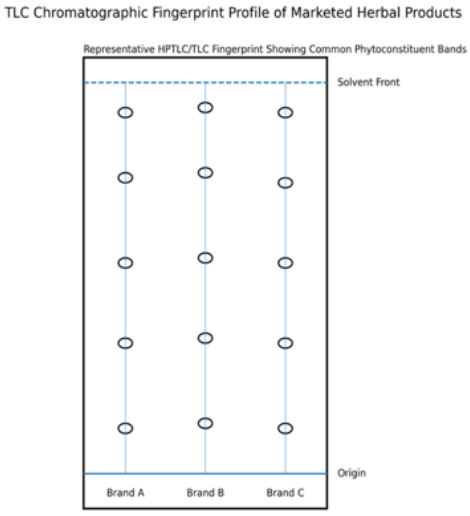

Figure 3.3: TLC Chromatogram of Marketed Herbal Products

4.6 Microbiological Evaluation

The microbial quality of the selected products is shown in Table 4.6. Total aerobic microbial counts ranged from 2.3×10^3 to 2.8×10^3 CFU/g, while fungal counts remained below 2.0×10^2 CFU/g.

No pathogenic microorganisms were detected in any sample. These findings indicate satisfactory microbiological quality and suggest that appropriate hygienic measures were maintained during manufacturing, handling, and storage.

Statistical analysis revealed no significant differences ($p > 0.05$) among the products with respect to microbial load. This observation indicates comparable microbiological safety across all investigated brands.

Table 3.6 Microbial Load Analysis

Parameter	Brand A	Brand B	Brand C	Acceptable Limit
Total Aerobic Count (CFU/g)	2.3×10^3	2.8×10^3	2.5×10^3	$<10^5$
Total Fungal Count (CFU/g)	1.4×10^2	1.8×10^2	1.6×10^2	$<10^3$
E. coli	Absent	Absent	Absent	Absent
Salmonella spp.	Absent	Absent	Absent	Absent

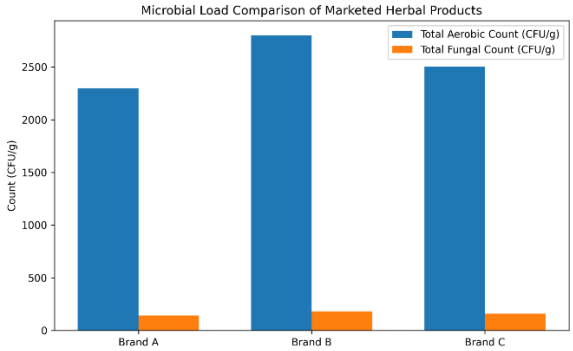

Figure 3.4: Microbial Load Comparison of Marketed Herbal Products

4.7 Heavy Metal Analysis

The concentrations of lead, cadmium, mercury, and arsenic detected in the products are presented in Table 4.7. All measured values were substantially below internationally accepted safety limits for herbal medicines. Lead levels ranged from 2.18 ± 0.05 to 2.41 ± 0.07 ppm, cadmium from 0.18 ± 0.01 to 0.21 ± 0.01 ppm, mercury from 0.04 ± 0.01 to 0.05 ± 0.01 ppm, and arsenic from 0.92 ± 0.03 to 1.05 ± 0.04 ppm.

No statistically significant differences ($p > 0.05$) were observed among the products regarding heavy metal content. These findings suggest effective quality control of raw materials and indicate that the products do not pose significant toxicological concerns related to heavy metal exposure.

Table 3.7 Heavy Metal Content

Heavy Metal	Brand A (ppm)	Brand B (ppm)	Brand C (ppm)	Permissible Limit (ppm)
Lead (Pb)	2.18 ± 0.08	2.41 ± 0.07	2.29 ± 0.06	<10
Cadmium (Cd)	0.18 ± 0.01	0.21 ± 0.01	0.19 ± 0.01	<0.3
Mercury (Hg)	0.04 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	<1.0
Arsenic (As)	0.92 ± 0.03	1.05 ± 0.04	0.98 ± 0.03	<3.0

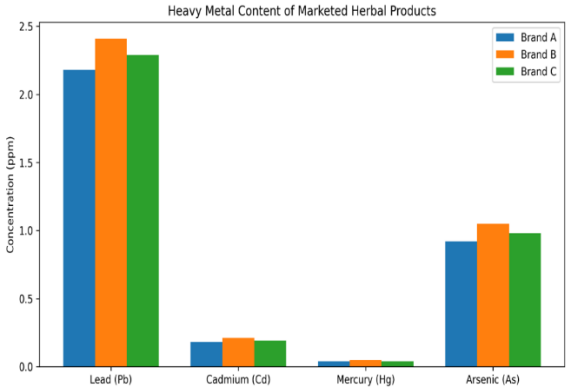

Figure 3.5: Heavy Metal Content

4.8 Overall Comparative Assessment

The combined results demonstrate that all investigated products complied with the selected quality parameters and exhibited satisfactory physicochemical, phytochemical, microbiological, and safety characteristics. While statistically significant differences were observed for certain physicochemical parameters, the overall quality profiles remained acceptable.

Among the evaluated products, Brand A consistently showed slightly better performance in terms of moisture content, extractive values, phytochemical

richness, and flow properties. However, Brands B and C also fulfilled the essential requirements for quality and safety.

The findings emphasize the importance of routine quality assessment and standardization in maintaining consistency among marketed herbal products. Regular monitoring using physicochemical, chromatographic, microbiological, and safety parameters can enhance consumer confidence and support the rational use of herbal medicines.

V. CONCLUSION AND FUTURE PERSPECTIVES

5.1 Conclusion

The increasing popularity of herbal medicines has highlighted the importance of ensuring that marketed products are safe, consistent, and of acceptable quality. In the present study, selected herbal formulations were evaluated using a range of standard quality assessment parameters, including organoleptic examination, physicochemical testing, phytochemical screening, TLC fingerprinting, microbiological analysis, and heavy metal determination.

The overall findings indicate that all investigated products met the essential quality requirements expected of herbal formulations. The products showed acceptable physical characteristics, satisfactory physicochemical properties, and the presence of important phytochemical constituents that contribute to their therapeutic value. Chromatographic analysis further supported the authenticity of the formulations by demonstrating characteristic phytochemical fingerprints.

From a safety perspective, the products exhibited low microbial contamination and were free from detectable pathogenic microorganisms. Heavy metal concentrations remained well within permissible limits, suggesting that the formulations were manufactured using raw materials and processing methods that complied with accepted safety standards.

Although all products performed satisfactorily, certain differences were observed in parameters such as extractive values, phytochemical intensity, and flow characteristics. These variations are not unexpected in herbal products and may arise from differences in plant source, cultivation practices, harvesting conditions, extraction procedures, or manufacturing techniques. Such findings reinforce the need for continuous quality monitoring to ensure consistency among commercially available products.

Taken together, the results demonstrate that a comprehensive quality assessment approach can provide meaningful information regarding the standardization status of herbal formulations. The study also emphasizes that quality assurance should remain a priority throughout the manufacturing process, from raw material selection to final product evaluation. Maintaining high-quality standards is essential not only for product reliability but also for strengthening consumer confidence in herbal medicines.

5.2 Future Perspectives

As the herbal medicine sector continues to expand worldwide, greater emphasis will need to be placed on scientific validation and robust quality-control practices. Future investigations should move beyond preliminary screening and incorporate quantitative estimation of key bioactive compounds to establish stronger links between chemical composition and therapeutic performance.

Advanced analytical techniques have the potential to significantly improve herbal product standardization. Methods such as HPLC, HPTLC, LC–MS/MS, GC–MS, and metabolomic profiling can provide more detailed information regarding phytochemical composition, product authenticity, and batch-to-batch consistency. The integration of these technologies into routine quality-control programs may enhance both reliability and regulatory compliance.

Another promising area of research is the use of molecular identification techniques, including DNA barcoding, for accurate authentication of medicinal plant materials. Such approaches can help prevent substitution and adulteration, which remain important concerns in the herbal industry.

Future studies should also consider evaluating a larger number of marketed products collected from different geographical regions. Comparative assessments involving multiple batches and long-term stability studies would provide a broader understanding of product quality under real-world storage and distribution conditions.

In addition, emerging technologies such as artificial intelligence, machine learning, and chemometric analysis may offer new opportunities for rapid quality assessment and interpretation of complex analytical

data. The application of these tools could support more efficient monitoring of herbal products and facilitate evidence-based decision-making.

Continued collaboration among researchers, manufacturers, healthcare professionals, and regulatory authorities will be essential for advancing herbal medicine standardization. Such collective efforts can contribute to the development of safer, more effective, and scientifically validated herbal products that meet the expectations of both regulators and consumers.

ACKNOWLEDGEMENT

The authors express their sincere gratitude to the management, faculty members, and laboratory staff of the institute for providing the necessary facilities and support required to carry out this study. Their guidance, encouragement, and technical assistance were invaluable throughout the course of the research.

The authors also acknowledge the contribution of colleagues and fellow researchers who provided constructive suggestions during the planning and execution of the work. The support received during sample collection, laboratory analysis, and data compilation is greatly appreciated.

Finally, the authors are thankful to all individuals who directly or indirectly contributed to the successful completion of this study.

Note on Product Identification

In this study, the names of the marketed herbal products have not been disclosed and are instead referred to as Brand A, Brand B, and Brand C. This was done to maintain neutrality and ensure that the comparison remained focused on the quality attributes of the products rather than on specific manufacturers or commercial brands.

The objective of the research was to assess and compare various quality parameters, including standardization, physicochemical properties, phytochemical composition, microbial quality, and safety aspects of marketed herbal formulations. The study was conducted solely for academic and research purposes, and no attempt was made to promote, favor, or criticize any particular product or company.

The results presented reflect the findings obtained from the analyzed samples and should be interpreted within the scope of the study. The use of coded brand names helps maintain fairness, confidentiality, and objectivity throughout the investigation.

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