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Review on Assessment of Quality Assurance Practices in the Production of Herbal Medicine

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ABSTRACT :

This review provides an overview of quality assurance (QA) practices during producing herbal medicines, including the importance of Good Agricultural and Collection Practices (GACP) and different quality control methods. GACP is particularly important in the initial stages of developing an herb, as it offers best practices to minimize risk associated with contamination, adulteration, and misidentification. Herbal products undergo these measures to assure quality and safety.

The review additionally covers several quality control measures employed in the herbal medicine industry. Thin-layer chromatography (TLC) and its derivative forms (namely, high-performance TLC) are extensively considered as a high-throughput chromatographic technique for botanic specimens scanning. Application of this approach is often required by regulatory agencies for the identity and quality assurance of herbal medicines. Also, in the food and plant industries, spectroscopic methodologies, especially in the infrared region of the spectrum, have also gained popularity for monitoring composition and verifying product consistency.

Mass spectrometry-based metabolomics has also been emphasized as a powerful tool for herbal medicine research. This approach allows sensitive detection of several hundreds of small-molecule metabolites in complex biological matrices of both in vivo and in vitro interventions, resulting in enhanced understanding of herbal drug composition and modification.

This review highlights the need for implementing stringent QA practices and utilization of sophisticated quality control tools in improving the safety, functionality and quality of herbal drugs. Making these adjustments is a key part of maintaining consumer trust and compliance with the regulations.

Keywords: Herbal Medicine, CGMP, Regulatory Collaboration, Quality Control Method, GACP

I. Introduction

Herbal medicine, as an indispensable part of traditional health care systems around the world, comprises different types of plant-based products used for therapeutic impact. The use of herbal medicine is one of the main health care sources for a large part of the population around the globe, particularly in developing countries, because quite a few important drugs are obtained from medical plant [1]. Herbal medicine is practiced with more than 53000 species, many of which are threatened with extinction due to overexploitation (Pan et al., 2014). About 80% of the earth's people depend on herbal formulations as the primary healthcare system, which is on the rise due to the ill effects created by modern allopathic drugs (Saggar et al., 2022). Data up to October 2023 have been used for developing the training systems.

Considering the growing global use of herbal medicine, the establishment of effective quality assurance at the production level is crucial. As the herbal medicine industry grows in respond to the ever demand for botanical products, so does the need for quality, efficacy, and safety (Jan & Abbas, 2018). Poor quality of raw materials or finished products accounts for the majority of the adverse events related to herbal medicines (Zhang et al., 2011). Sustainable raw material sourcing for herbal medicine production has shown to be a major challenge (Aziato et Odai, 2016).

This review evaluates existing quality assurance practices in HM production, along with challenges and improvement opportunities. The review will include an analysis of attributes of quality, including identity, purity, potency, and stability, current good manufacturing practices, and quality control methods. Additionally, the work emphasizes the need for research institutions and regulatory bodies to coordinate to ensure the efficacy and safety of herbal products (Aziato & Odai, 2016). Hence, this review attempts to consolidate around these issues in order to contribute toward the development and harmonization of regulatory framework addressing such herbal medicines at a global level (Ekor, 2014).

II. Quality Attributes of Herbal Medicines

Table 1: Key Quality Attributes of Herbal Medicines

Attribute	Definition	Methods for Assessment	Key Challenges
Identity	Accurate botanical identification of plant species	DNA barcoding, chromatography, microscopy, spectroscopy	Adulteration, morphological similarities between species
Purity	Absence of contaminants (heavy metals, pesticides, microbes)	Microbial testing, atomic absorption spectroscopy, HPLC	Environmental pollution, poor agricultural/manufacturing practices
Potency	Consistency in active compound concentration or biological activity	Marker compound quantification, bioassays	Phytochemical variability, synergistic interactions
Stability	Retention of therapeutic properties under storage conditions	Accelerated stability testing, degradation product analysis	Environmental factors (light, temperature, humidity), packaging limitations

Herbal medicines must possess and be monitored for key properties during production to ensure their safety and effectiveness.

A prerequisite to ensure the quality and safety of herbal medicines is the accurate botanical identification of source materials. This step is crucial to ensure, that the right species of plant is utilized to prevent the potential of adulteration or substitution that can result in negative health effects. Quality issues involve two general classes in respect of herbal medicines: external and internal factors (Zhang et al., 2011).

Another important quality attribute is purity, which describes the lack of microbiological pathogens, heavy metals and pesticides, as well. Contamination of herbal products may occur at several points, as a result of environmental pollution, bad farming and bad manufacturing practice.

Standardization to marker compounds (Yakovleva et al., 2012) or biological activity (Buchanan et al., 2011) allows for the assessment of potency that is important for ensuring consistency of therapeutic effect (Booker et al., 2015). Standardization assesses the concentration of selected constituents of the herbal extract or the biological effect exerted to guarantee that product batches are equal and efficacious.

The stability of herbal preparations, which affects the quality and efficacy of the product over time under various storage conditions, needs to be considered. Stability testing assesses the influence of environmental parameters such as temperature, humidity and light on chemical constituents and therapeutic function of herbs. High-level supervision of such essential quality attributes is vital for ensuring the manufacture of medications that are both effective and safe for patient consumption.

A. Identity

Botanical identification of source materials is a foundational first step in the quality and safety of herbal medicines. This essential aspect includes careful processes to ensure that the proper plant species is used, which if not could lead to down-products with adulteration or misidentification and result with products that not contain their demanded final product (Zhang et al., 2011). At the species level plants used as drugs, dietary supplements and herbal medicines are identified to ensure raw material authenticity and purity (Jan & Abbas, 2018). Methods, including macroscopic and microscopic analysis, as well as chemical profiling approaches (e.g., chromatography, spectroscopy), are used to verify the authenticity of plant sources and identify possible adulteration. These approaches are used to verify Indian medicinal plants to ensure the correct species is harvested to ensure safety and efficacy of the herbal preparations. Metabolomics plays an important role in the quality control of herbal medicine, being a versatile and comprehensive approach.

DNA barcoding has proven to be a very potent method of species identification and is capable of overcoming the limitations of traditional methods by allowing the identification of the vast majority of materials with similar morphologies and/or chemical structure [1 2 3 4]. Furthermore, accurate adulteration and authentication of herbal medicine plays a significant role in patients' safety and herbs' potential health benefits. This problem has been addressed by original, morphological, microscopic, physical and chemical identification (Chen et al., 2023). Introduction: Traditionally herb identification was based on morphology, which involves subjective interpretation of plant characteristics and therefore can have limitations (Chen et al., 2023).

Accurate identification of herbal materials is, therefore, not only a regulatory necessity but also a responsibility of public health and a hallmark of herbal medicine integrity.

B. Purity

The purity of herbal medicines is a crucial quality factor. The above includes reducing contaminants that may stem from environmental contamination, poor agricultural practices, or substandard manufacturing processes, such as heavy metals, pesticides, and microbial pathogens. These contaminants are undesirable to consumers due to their health risks.

Medicinal plants can absorb heavy metals such as lead, mercury, and arsenic from contaminated soil or water, causing toxicity and health problems in the consumer. Hence rigorous testing for heavy metals is crucial to establishing the quality control of herbal medicines. Likewise, pesticide contaminants originating from agricultural practice can contaminate herbal materials and cause endocrine disruption, neurotoxicity, and other health issues.

Another threat lies in the potential for microbial contamination, involving both bacteria and fungi and viruses. These substances can be used experiences at every level of the produce method, from farming to processing and storage.

These anxieties need to be met with rigorous measures of quality control. Those include careful selection of source material, solid processing methods, and stringent storage conditions. These steps are crucial for reducing contamination hazards of herbal goods for consumer consumption. Thus external problems like contamination, adulteration and misidentification are discussed in detail. Another internal problem is the complexity and heterogenous ingredients of herbal medicines.

C. Potency

Potency is one of the key quality attributes of herbal medicines. Potency is the concentration of active constituents in a herbal product and its resulting therapeutic effect. The main method of production in order to retain potency and consistency in herbal medicines is via standardization.

This is often realized by quantifying specific marker compounds or biological activity (Booker et al., 2015). Standardization usually refers to isolating target compounds that have been linked to particular clinical benefits, which can ensure that different batches of herbal medicine produce a consistent physiological response. Such information allows for the production of herbal medicines with known standard concentrations of active components, thus giving them constant and reproducible therapeutic values.

One avenue for herbal extract standardization lies with biological activity assays, which directly assess the pharmacological effects of the herbal extract. The assays can quantify the potencies of herbal products through their effects on relevant biological targets (receptor binding, enzyme inhibition, or cellular responses).

Standardized herbal medicines are challenging because the chemical composition of plant extracts is complex, and in particular, the chemical constituents have a potential for synergistic or antagonistic interactions with each other. Phytochemical profiles of herbal materials are often variable by nature, making it difficult to set standard quality in herbal medicines.

These challenges underline the importance of developing standardization protocols for herbal medicines to support their rational use and achieve consistent therapeutic outcomes. Standardisation aids both the quality and the efficacy and ensure the overall safety and efficiency of herbal medicine for the use of customers. Herbal medicines are complex; more than one active ingredient may be present, and the combination of multiple compounds may affect the overall therapeutic effect.

D. Stability

The stability of herbal preparations is important in order to guarantee their quality and effectiveness throughout time. Stability indicates the capability of an herbal product to maintain its intrinsic characteristics, including chemical composition, physical properties, and bioactivity throughout its shelf-life. The stability of herbal medicines can be affected by several environmental or storage conditions such as temperature, humidity, and light exposure, as well as the type of packaging materials used.

Temperature increases chemical reactions and decomposition of active substances, where degradation products are formed. Hydrolysis can be favored by humidity, leading to the decomposition of sensitive substances and microorganisms. Photochemical reactions caused by light exposure, especially ultraviolet radiation, can degrade active constituents and change the product appearance. Stability can also be helped by packaging material, which can act as a barrier to moisture, oxygen and light.

Stability studies must be performed by manufacturers to assess the effects of varied storage conditions on product quality. Such studies have included storing herbal preparations at controlled temperature and humidity, then periodically evaluating their chemical, physical, and microbiological attributes. These studies are used to inform appropriate storage conditions and expiry dates for herbal medicines, to ensure that herbal medicines are of a quality and efficacy until expiry (Nailius & Pote, 2023).

Appropriate preservation methods are important to ensure the stability of herbal preparations. These can include antioxidant utilization, antimicrobial use, or specialized packaging methods that guard against active compound degradation. When manufacturers implement suitable preservation techniques and conduct rigorous stability studies, herbal medicines can be assured of stability and efficacy until the end of their shelf life, thus protecting the health and well-being of consumers (Nailius & Pote, 2023). Implementing cold chain and adopting cutting-edge preservation technologies are required to serve wider range of markets (Ge et al., 2021). Novel approaches, used alone or with controlled temperatures during storage, can preserve the core characteristics of vegetables and fruits (Palumbo et al., 2022). Producers face a great challenge to maintain the stability and effectiveness of herbal medicines in a competitive market (Nailius & Pote, 2023). Shipping stability shall involve storage at all desirable temperatures and humidity conditions, as well as sensory and pH measurements.

III. Current QA Practices in Herbal Medicine Production

Table 2: Current QA Practices in Herbal Medicine Production

Practice	Objective	Methods/Techniques	Regulatory Relevance
Good Agricultural Practices (GACP)	Ensure sustainable cultivation and ethical harvesting	Soil testing, pest management, traceability systems	Aligns with WHO guidelines for raw material quality
cGMP Compliance	Standardize manufacturing processes for safety and consistency	Facility sanitation, batch documentation, personnel training	Mandatory for regulatory approval in most jurisdictions
Analytical Quality Control	Verify identity, purity, potency, and stability	HPLC, GC-MS, UV-Vis spectroscopy, microbial assays	Required for product certification and labeling accuracy

The quality control measures involved in the production of herbal medicine are currently diverse and cover the range of practices conducted from growing herbs to dispensing their preparations. Share thisSignificant developments in the herbal medicine field are leading to the utilization and implementation of guidance in these practices across the globe, ensuring the quality and safety of herbal medicines across all stages of the supply chain, from raw material sourcing through to dosage form deployment.

A. Good Agricultural and Collection Practices

From the very beginning of herb cultivation and harvesting, GHCP and GACP are essential in producing quality herbal medicine. Guiding principles on sustainability of herbal raw materials. The GACP guidelines assist in minimizing the risk of contamination, adulteration, and misidentification of herbal materials, which ultimately plays an important role in the quality and safety of the final herbal product (Jan & Abbas, 2018).

Though the implementation of GACP is vital, it has its challenges. The compositional variability of medicinal plants, geographical differences in cultivation practices, and the absence of standardised protocols can present serious obstacles for producers. Now, establishing the concepts of GACP for herbal medicines is necessary to develop sustainable sourcing and to maintain the quality and safety of herbal medicines.

Such high-quality herbal products are dependent upon proper cultivation, collection, drying, storage, and processing techniques (Jan & Abbas, 2018). Acquiring sustainable resources to produce herbal medicine can be challenging, especially in poorer nations (Aziato & Odai, 2016). These challenges must be addressed if quality considerations are to include input from research institutions as well as the regulatory body to ensure that herbal products are safe and that herbalists receive formal training (Aziato & Odai, 2016).

No wonder, herbal medicines are safe and effective because they are attuned to contemporary healthcare through research and formal training. In doing so, GACP promotes conservation of the medicinal plant resource base and the sustainable development of the herbal medicine industry (Aziato & Odai, 2016). GACP is a comprehensive approach considering environmental, social and economic factors to guarantee the sustainable production of high-quality herbal raw materials.

B. Current Good Manufacturing Practices (cGMP)

Maintaining Current Good Manufacturing Practices (cGMP) during the processing, packaging and storage stages is crucial for the quality and safety of herbal medicines. The above guidelines are guided and further implemented in the herbal medicine manufacturing space to back production process and control quality as per standards.

By following cGMP principles, manufacturers can reduce the likelihood of contamination, mistakes, and deviations in the manufacturing process, resulting in herbal medicines with consistent quality and safety.

All these challenges render medicinal herbs are quite limited to the immediate application of cGMP in the ground of herbal medicine manufacturing process. Standardising the manufacturing processes and quality control specifications for herbal medicines must take into account the specific nature of each plant species, and its chemical components. However, all these obstacles should not negate the necessity of adopting cGMP that is a precursor to ensure quality, safety, and efficacy of herbal medicines and thus to build confidence among consumers and regulatory authorities (McChesney, 2001).

Good Manufacturing Practices (GMPs) are vital to the herbal medicine market to improve standardization and manufacturing for the betterment of consumer health and well-being (McChesney, 2001). Furthermore, the application of cGMP necessitates a comprehensive quality management framework that covers all elements of the production process, including the raw materials procurement and the final product launching. The system provides detailed procedures for documentation, training, equipment maintenance, and sanitation to promote consistency and standardization in operations.

The principles of cGMP cover these aspects and set out guidelines that help in quality assurance of herbal drugs and increased consumer confidence and regulatory compliance (Reis et al., 2015). We hope this underscored the importance of cGMPs in the pharmaceutical industry as it helps to ensure product quality as well as overall efficiency and effectiveness of the manufacturing process.

GMP manufacturing requires extensive knowledge of critical quality attributes and processes parameters, documented properly and strict control through training, facilities, equipment, and operations to ensure uniform product quality (Hodge, 2018). These are monitored at every stage of the facility's lifecycle by a number of systems to ensure consistent product quality – as shown in (Hodge, 2018)

Compliance with good manufacturing practice guidelines is a legal requirement for the issuance of manufacturing authorization and for obtaining market authorization, underscoring its importance in the pharmaceutical sector (Korčok et al., 2020).

This measure will provide the basis for the establishment of a high-quality medicine, with the guarantee of safety, effectiveness and sanitary-improve in accordance with quality standards (Xu, 2022). Ultimately, risk-based cGMP expectations are designed to achieve medicinal product quality standards that do not inhibit pharmaceutical industry innovation and the implementation of new manufacturing technologies (Reis et al., 2015).

Compliance with current good manufacturing practices (cGMP) is ensured, as analytical development and quality control analysts assure data validity, traceability, and reproducibility (Doneski & Dong, 2023), protecting the safety and efficacy of a product. Compliance activities are heterogeneous and dynamic, largely governed by the company's standard operating procedures, resources, and compliance culture (Doneski & Dong, 2023).

C. Quality Control Methods

Diverse analytical techniques play a crucial role in comprehensive quality assessment of herbal medicines and contribute to ensure safety, efficacy, and consistency. Various analytical methodologies are applied for herbal materials and finished products to assess identity, purity, potency, and stability through chromatographic, spectroscopic and microscopic techniques.

Chromatographic techniques (such as high-performance liquid chromatography and gas chromatography-mass spectrometry) have been applied for separation, identification, and quantification of multiple chemical compounds in herbal extracts and formulations. The use of these techniques allows for accurate and reliable analysis of the chemical composition of herbal samples, as well as the possibility of identifying potential adulterants or contaminants.

Ultraviolet-visible spectroscopy, infrared spectroscopy, nuclear magnetic resonance spectroscopy, and other spectroscopic techniques help get information regarding both the chemical structure and composition of herbal raw materials (Sahoo & Umashankara, 2022). Methods to do this also

exist, and they can be used to fingerprint the right chemical profiles of herbal samples, allowing for the proper identification of the plant species themselves.

Microphotographic analysis is used for assessing morphological features of plant materials which helps in identifying adulterants and contaminants. This approach is especially valuable for the verification of crude pharmaceuticals to confirm their botanical identity and inform about contaminants.

The relatively recent advent of metabolomics provides, in principle, a global approach to the simultaneous study of classes of plant metabolites, or phytochemicals, present in a given herbal specimen, and is attracting increasing attention as a potential holistic quality control tool for herbal drugs (Sahoo & Umashankara, 2022). Metabolomics studies present broad-spectrum analysis, characterization, identification, and quantification of metabolites at multiple levels, which enables more elaborate understanding concerning quality, safety, and authenticity of herbal medicines.

High-performance liquid chromatography is a common and simple technique for natural product analysis because of its simplicity, broad applicability, and high accuracy (Je et al., 2015). To ensure the consistency and quality of herbal medicines, this technique is extensively applied for separating, identifying, and quantifying bioactive compounds in herbal extracts and formulations.

Thin-layer chromatography (TLC, including high-performance TLC) is a general and high-throughput liquid chromatographic method with application to above-mentioned screening of botanicals. Often, such practical applications are requested by various regulatory agencies involved in authentication and quality assurance of herbal medicines, alimentary herbs and spices, and even forensic control of these ethnobotanicals. Further, spectroscopic methods in the infrared spectroscopic domain have found an increasingly broader application in the food industry revealed through monitoring and evaluation of foods composition becoming one of the most attractive and wide spread method for plant analysis last 10 years (Smyth and Cozzolino, 2011). Metabolomics based on mass spectrometry has been extensively employed to profile the constituents of these herbal medicines in vivo and in vitro, bringing new insights into the comprehension and modification of herbal medicine from the perspective of small-molecule metabolism (Wang et al., 2019). Integrating metabolomics techniques with agricultural biotechnology is a cross-disciplinary study that is very useful for basic and applied medical research (Kowalska & Sajewicz 2022; Sahoo & Umashankara 2022; Shyur & Yang 2008; Wang et al. 2019).

IV. Challenges and Opportunities in Implementing Quality Assurance

There are significant challenges to implementing sound quality assurance practices in the production of herbal medicines:

A. Raw Material Variability: Because herbal medicines are obtained from natural plant sources, they naturally exhibit derivative differences in chemical composition, physical properties, and biological activity. This raw material variation presents a primary challenge to the uniform quality, safety, and efficacy of herbal products.

B. Supply chain complexities: Global and fragmented supply chains for the sourcing, processing, and distribution of herbal materials introduce further risks related to adulteration, contamination, and traceability. Maintaining the quality standards of supply chain requires integrity and transparency.

C. Regulatory Harmonization: Overcoming the inadequacy of global harmonised regulatory frameworks and quality standards for herbal medicines to facilitate harmonisation of QA across diverse markets and jurisdictions. Streamlining regulations and harmonizing quality requirements can ease the establishment of effective quality assurance programs.

D. Analytical Limitations: The diverse phytochemicals that herbal materials often elicit could pose challenges in developing robust analytical methods that are important for comprehensive quality assessment and control. Therefore, novel analytical methods such as metabolomic platforms are required to integrate the inherent complexity of herbal medicines.

E. Knowledge Gaps: The limited scientific understanding of the active compounds, mechanisms of action, and structure-activity relationships of many herbal medicines hinders the development of optimal QA strategies. Filling knowledge gaps through collaborative research can contribute to the development of better QA practices.

Nonetheless, some solutions and best practices can help to enhance quality assurance in herbal medicine production:

A. Implement the following GMPs (Good Manufacturing Practices): Good Agricultural and Collection Practices to ensure consistency from cultivation to a final product.

B. Develop sophisticated analytical approaches (chromatographic, spectroscopic, metabolomic), which are needed to characterize herbal materials and finished products to assure quality, safety, and efficacy.

C. Encourage worldwide synergy of regulatory frameworks and quality standards surrounding herbal medicines to promote a cohesive strategy for QA implementation across markets and jurisdictions.

D. Facilitate collaboration between academic institutions, private sector industry, and development of regulatory approaches to improve understanding and implement appropriate quality assurance strategies suited to the distinctive nature of herbal medicines.

E. Enhance supply chain management via traceability systems and supplier qualification programs to guarantee the integrity and transparency of the herbal material supply chain (Booker et al., 2015).

Herbal medicine has a promise in health and well being, although the standardization and production needs improvement (McChesney, 2001). The absence of sustainable raw materials is an issue, requiring research institutions and regulatory bodies to ensure safe herbal products and provide adequate training for herbalists (Aziato & Odai, 2016). These aspects must be carefully considered when integrating herbal medicine into a broader healthcare framework (Aziato & Odai, 2016). Quality is affected externally by contamination, adulteration, and misidentification (misidentification); and internal (eg, complexity and non-uniformity of ingredients).

There is a great variability in raw materials that presents a challenge for the consistent quality to be maintained and requires active quality controls at all the levels of the value chain (Booker, 2015). Quality of herbal materials is crucial, particularly to countries with strict entrance barriers (Booker et al., 2015) Objective measurement of herbal material quality is particularly important for exports. Quality-driven interventions across the value chain lead to better product standards for consumers (Booker et al., 2015). When quality control measures are effective at every stage of the value chain, value is intrinsically tied to the final product (Booker et al., 2015).

V. Solutions and Best Practices

Table 3: Challenges and Solutions in Herbal Medicine QA

Challenge	Proposed Solution	Expected Benefit
Raw material variability	Standardized cultivation protocols and DNA authentication	Consistent phytochemical profiles and reduced adulteration
Regulatory fragmentation	Harmonization of global QA frameworks (e.g., ICH, WHO guidelines)	Streamlined market access and improved consumer trust
Analytical complexity	Adoption of metabolomics and AI-driven quality prediction models	Enhanced detection of contaminants and bioactive compounds
Supply chain opacity	Blockchain-based traceability systems	Improved transparency and accountability in sourcing

Quality assurance practices are critical in herbal medicine production; ensuring product safety, efficacy, and consistency in the final therapeutic preparation. The need for quality assurance is paramount in the increasing acceptance of herbal medicines, which can only be ensured through comprehensive quality measures across the entire production chain.

A. Good Agricultural and Collection Practices: GACP is essential for the production of high quality herbal materials starting from the cultivation stage to harvesting (McChesney, 2001). It has been suggested that sustainable sourcing practices are also needed to protect biodiversity and /034 M. Du et al. ensure a reliable supply of good quality raw materials (Aziato & Odai, 2016). This goes from practicing safety-oriented farming and harvesting approaches as well as implementing traceability systems to ensure raw material quality.

B. Current Good Manufacturing Practices: CGMP principles are adaptable to herbal medicine processing manufacture to ensure quality control during processing, packaging, and storage. cGMP guidelines can help minimize contamination risk and ensure product consistency. cGMP is a set of quality assurance principles that ensures chemical pollutants are eliminated from herbal products while producing a human-safe product.

C. Quality Control Methods: There is a series of analytical techniques (e.g., chromatographic, spectroscopic and microscopic methods) that are essential to be used for quality evaluation of herbal raw materials and their final products (Booker et al., 2015). This allows for the identification and quantification of active compounds, contaminants, and other quality indicators. This results in a reliable evaluation of herbal medicines when a comprehensive quality control program incorporating multiple analytical techniques is implemented.

D. Regulatory Collaboration: In order to enable the implementation of coherent QA practices, the harmonization of regulatory frameworks and quality standards across regions and countries will play a major role. Creating internationally recognized standards requires collaboration between regulatory authorities, industry representatives, and research institutions. This work may serve as a starting point for a more harmonized approach to quality assurance for herbal medicines across the globe.

E. Research and Development: Better understanding of active compounds, mechanisms of action, and stability of herbal medicines through research will guide the development of effective QA strategies. Such research may enhance the recognition of new quality markers and development of better analytical methods. Regular innovations and scientific breakthroughs in the assurance of quality herbal drug can continuously upgrade scientific production technology and provide consumers high-quality herbal products.

VI. Future Directions

There is a greater appreciation for the need for robust quality assurance practices surrounding the manufacture of herbal medicines. Future efforts will need to concentrate on continued standardization, safety, and efficacy of herbal medicines, utilizing a variety of regulatory best practice and scientific approaches (Xu, 2022).

A. Advance Analytical Methods: Describing and validating new analytical techniques to perform robust and high-throughput evaluation of the quality, safety, and efficacy of herbal medicines, such as omics technology, are essential (Booker et al., 2015).

B. Implement Advanced Metabolomics: Deploy Metabolomics for Quality Control of Herbal Drugs: Metabolomics provides a powerful platform for quality control of herbal drugs, since this platform can be used to study plant metabolites and phytochemicals in herbal samples.

C. Strengthen Regulatory Frameworks: Standardize regulatory adherence across the globe regarding herbal and natural medicines to help provide consistent quality and issuance of health benefits.

D. Sustainable sourcing: Encouraging sustainable agricultural/collection practices of plant material to ensure the ongoing availability of high quality plant resources.

E. Educate Healthcare Professionals and Consumers: Accurate, evidence-based information to promote appropriate and safe use of herbal medicines can be disseminated to healthcare professionals and consumers.

F. Integrate Traditional Knowledge: Combiner les connaissances et pratiques traditionnelles avec les approches scientifiques modernes pour améliorer le développement et lassurance qualité des médicaments à base de plantes.

Conclusion

The authors discuss some of the established herbal medicine that need to be recognized as medicine and enforced with an effective quality control, to guarantee their safety and efficacy. It underlines important areas to strengthen quality assurance (QA) of herbal medicines.

First is the need for Good Agricultural and Collection Practices (GACP), guidelines that keep herb consistency and quality intact from cultivation to the final product. Compliance with GACP effectively minimises the risks of contamination and adulteration that are still common issues facing the herbal medicine sector.

Moreover, improved quality control processes are essential for verifying that products meet authenticity and regulatory standards. Techniques like thin-layer chromatography (TLC) and spectroscopic methods help in correctly identifying plant species and ensuring product quality.

Metabolomics, which uses mass spectrometry to investigate herbal constituents, is also playing an increasingly significant role according to the review. This strategy yields greater evolving information through the metabolic profiling of herbs, thereby helping to better reinforce their pharmacological implications and associated toxicity risks.

Additionally, filling currently existing knowledge gaps is vital to advance QA in herbal medicine manufacture. Consumer awareness and education about both the benefits and risks as well as the implementation of best practices will help to improve consumer trust in herbal products as well as their safety and efficacy.

Last but not least, unanimous effort by stakeholders involved in herbal medicine is needed to ensure implementation of holistic QA practices. This allows the entire sector to better the quality of their products, increase patient safety, and build more trust for herbal treatments.

Conflicts of Interest

The authors declare that there are no conflicts of interest, whether financial or otherwise.

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