

A REVIEW ON QUALITY CONTROL PARAMETERS IN THE EVALUATION OF HERBAL CRUDE DRUG**Takeshwar Patel, Mrutyunjaya Bhanja*, Naimesh Nanda, Sandip Prasad Tiwari****Faculty of Pharmacy, Kalinga University, Naya Raipur, Chhattisgarh India (492101)***Corresponding Author's E mail: mrutyunjaya.bhanja@kalingauniversity.ac.in

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ABSTRACT

The use of herbal crude drugs in pharmaceuticals has gained significant attention due to their therapeutic properties and natural origins. However, ensuring the quality and safety of these drugs is essential for their effective utilization. This project explores the importance of quality control parameters in the evaluation of vegetable crude drugs. The study encompasses an extensive literature review to understand the current state of research in this field, focusing on physical, chemical, and biological parameters commonly used for quality assessment. Physical parameters such as organoleptic characteristics, chemical parameters including marker compounds and active constituents, and biological parameters like microbiological contamination are discussed in detail. Case studies are presented to demonstrate the application of quality control parameters in evaluating specific vegetable crude drugs. Moreover, challenges and limitations in the existing methods are analyzed, and potential improvements and future directions are proposed. This project highlights the significance of quality control in ensuring the efficacy, safety, and consistency of vegetable crude drugs in the pharmaceutical industry.

Keywords: Mycology, Fungal pathogens, Antifungal resistance, natural antifungal.

INTRODUCTION

The use of herbal crude drugs has surged globally due to their natural origin, perceived safety, and potential therapeutic benefits. However, to harness their full potential, rigorous quality control (QC) measures are imperative. Quality control ensures that herbal drugs are safe, effective, and consistent, thereby safeguarding public health and enhancing consumer trust ¹.

Safety is paramount when it comes to herbal crude drugs, as these are often consumed directly or used in formulations without extensive chemical processing. Quality control measures help identify and eliminate contaminants such as pesticides, heavy metals, and microbial organisms that can pose serious health risks. For instance, the presence of toxic metals like lead, mercury, and arsenic in herbal drugs can lead to severe poisoning and long-term health issues. QC protocols such as chromatography and

spectrometry can detect these contaminants at trace levels, ensuring that the final product is safe for consumption. Moreover, quality control helps in verifying the absence of adulterants and misidentified plant materials. Herbal drugs can sometimes be substituted with or contaminated by non-medicinal plants, which may not only reduce the efficacy but also introduce toxic effects. DNA barcoding and other molecular techniques are essential QC tools to authenticate the correct plant species, ensuring safety and consistency ².

The therapeutic efficacy of herbal drugs hinges on the presence and concentration of active constituents. Quality control measures are vital in quantifying these bioactive compounds and ensuring they are within the therapeutic range. For example, the efficacy of St. John's Wort (*Hypericum perforatum*) in treating depression is attributed to its hypericin content. Variability in the hypericin levels can lead to inconsistent therapeutic outcomes. High-performance liquid chromatography (HPLC) and mass spectrometry (MS) are commonly used QC techniques to measure these active ingredients precisely. Standardization, a crucial aspect of QC, involves setting specific guidelines and benchmarks for the concentration of active constituents. This process not only ensures that each batch of the herbal drug delivers the same therapeutic effect but also helps in maintaining the drug's overall reputation in the market ³.

Consistency in herbal crude drugs is challenging due to the natural variability in plant materials influenced by factors such as geography, climate, and cultivation practices. Quality control measures address this issue by implementing good agricultural and collection practices (GACP), which standardize the cultivation, harvest, and processing stages of medicinal plants. Consistent practices ensure that the raw materials are of uniform quality, which is crucial for producing reliable herbal drugs.

Additionally, QC protocols include rigorous testing at various stages of production, from raw material assessment to final product evaluation. Techniques such as thin-layer chromatography (TLC) and Fourier-transform infrared spectroscopy (FTIR) are employed to profile the phytochemical composition and ensure batch-to-batch uniformity. This consistency is vital for building consumer confidence and ensuring repeatability in therapeutic outcomes. Quality control is indispensable in the production of herbal crude drugs, serving as the backbone for ensuring safety, efficacy, and consistency. Through meticulous testing and standardization processes, QC measures protect consumers from potential health hazards, guarantee the therapeutic effectiveness of the drugs, and maintain product uniformity despite the inherent variability of natural materials. As the demand for herbal medicines continues to rise, robust quality control practices will be increasingly critical in sustaining their credibility and trustworthiness in the healthcare market ⁴.

Herbal medicine ⁵

Herbal medicine, also known as phytotherapy or botanical medicine, refers to the use of plants or plant extracts for therapeutic purposes. This ancient form of medicine has been utilized by various cultures around the world for thousands of years. It encompasses a broad range of practices that include the use of whole plants, plant parts, and isolated phytochemicals to treat and prevent illnesses.

The foundations of herbal medicine are deeply rooted in traditional systems such as Traditional Chinese Medicine (TCM), Ayurveda from India, Native American healing practices, and European herbalism. Each system has its unique philosophies and methodologies, but all emphasize the natural healing properties of plants.

Global Use of Herbal Medicine ⁶

Herbal medicine enjoys widespread global use, driven by cultural traditions, personal preferences for natural therapies, and the growing popularity of holistic health approaches.

1. Traditional Chinese Medicine (TCM):

TCM is one of the oldest and most comprehensive systems of herbal medicine. It involves the use of herbs in combination with acupuncture, diet, and other modalities to restore balance and harmony within the body. Commonly used herbs include ginseng, astragalus, and licorice root, which are often prescribed in complex formulas tailored to the individual's needs.

2. Ayurveda:

Originating in India over 3,000 years ago, Ayurveda focuses on maintaining health through a balance of body, mind, and spirit. Herbal medicine is a cornerstone of Ayurveda, with plants like turmeric, ashwagandha, and holy basil (tulsi) used to promote health and treat various conditions. Ayurveda emphasizes personalized treatment based on an individual's dosha (body constitution) and the specific imbalance they are experiencing.

3. Western Herbalism:

In Western cultures, herbal medicine has a long history dating back to ancient Greece and Rome. Today, Western herbalism often integrates traditional knowledge with modern scientific research. Popular herbs such as echinacea, St. John's Wort, and chamomile are commonly used to support immune function, mood, and digestion, respectively.

4. African and Indigenous Practices:

Many African and Indigenous cultures have rich traditions of herbal medicine, using local plants for healing purposes. For example, African herbal medicine utilizes plants like devil's claw and African potato, while Native American medicine employs herbs such as echinacea and sage. These practices are often interwoven with spiritual and community rituals, highlighting the deep connection between nature and healing.

Modern Applications and Trends

In recent decades, the use of herbal medicine has experienced a resurgence in both developed and developing countries. This revival is fueled by several factors ^{7,8}:

1. Increased Awareness and Education:

The growing awareness of the side effects and limitations of synthetic drugs has led many people to explore natural alternatives. Education about the benefits and safety of herbal medicine has also increased through various media and health professionals.

2. Integration with Conventional Medicine:

Herbal medicine is increasingly being integrated into conventional healthcare systems. Many practitioners now adopt a complementary approach, combining herbs with conventional treatments to enhance efficacy and reduce side effects. Hospitals and clinics, especially in countries like Germany and China, routinely offer herbal therapies alongside conventional care.

3. Scientific Validation:

Advances in pharmacology and biotechnology have enabled scientists to study and validate the therapeutic properties of many herbs. This research has led to a better understanding of how herbal medicines work, their potential benefits, and safety profiles. Clinical trials and phytochemical analyses have provided evidence supporting the use of certain herbs for specific conditions.

4. Regulatory Developments:

To ensure the safety and quality of herbal products, regulatory frameworks have been established in many regions. For instance, the European Union has strict guidelines for the registration and marketing of herbal medicinal products, while the United States requires dietary supplements to meet Good Manufacturing Practices (GMP).

Standardization of Herbal Drugs ⁹

Standardization in the context of herbal drugs refers to the process of ensuring consistency, quality, purity, and efficacy of herbal products. This involves setting specific standards or benchmarks for the identity, potency, and purity of the raw materials and final products. The purpose of standardization is to ensure that each batch of the herbal product meets the established specifications, which is crucial for maintaining the therapeutic efficacy and safety of the herbal medicine (ASHP) (US Pharmacist).

The necessity of standardization arises from the inherent variability in the chemical composition of herbal materials. Factors such as plant species, geographical location, harvesting season, and processing methods can significantly influence the quality of the herbal product. Without standardization, the variability can lead to inconsistent therapeutic outcomes and potentially pose risks to patient safety. Therefore, standardization is fundamental to establishing the reliability and reproducibility of herbal medicines in clinical practice ¹⁰.

Standardization Techniques

Various techniques are employed in the standardization of herbal drugs, ensuring comprehensive evaluation from raw materials to final products. These techniques include morphological, microscopic, and chromatographic methods, each contributing uniquely to the overall standardization process ¹¹.

1. Morphological Evaluation

Morphological evaluation involves the macroscopic examination of the herbal material, assessing its physical characteristics such as size, shape, color, texture, and odor. This initial examination helps in the identification and authentication of the plant material, ensuring it matches the description of the desired species. Morphological characteristics are often detailed in pharmacopoeias, which provide standard references for comparison.

2. Microscopic Evaluation

Microscopic evaluation complements morphological analysis by examining the microscopic features of the herbal material. This technique involves the use of light microscopy to identify cellular structures, tissue arrangements, and unique characteristics such as trichomes, stomata, and vascular bundles. Microscopic evaluation is particularly useful for identifying adulterants and contaminants that are not visible to the naked eye. This level of detail enhances the accuracy of the identification process and ensures the purity of the herbal material (US Pharmacist).

3. Chromatographic Techniques

Chromatographic techniques are critical in the chemical standardization of herbal drugs. These methods separate and quantify the individual chemical constituents within the herbal material, providing a detailed chemical profile. Common chromatographic techniques used in herbal drug standardization include ¹²:

Thin Layer Chromatography (TLC): TLC is a simple, cost-effective method used to separate and identify compounds based on their movement on a stationary phase under the influence of a solvent. It provides a visual representation of the chemical composition, which can be compared against standard reference compounds.

High-Performance Liquid Chromatography (HPLC): HPLC is a more advanced technique that offers high resolution and sensitivity in separating and quantifying chemical constituents. It is widely used to ensure the consistency and potency of active ingredients in herbal products.

Gas Chromatography (GC): GC is used for the analysis of volatile compounds within herbal materials. It provides detailed information about the composition and concentration of essential oils and other volatile constituents.

These chromatographic methods are essential for detecting variations in the chemical composition of herbal materials, ensuring that each batch meets the established quality standards.

Biological Evaluation ^{13,14}

The evaluation of biological activity and ensuring microbial quality are critical aspects of the quality control process for herbal crude drugs. This section delves into the significance of bioassays and methods for detecting microbial contamination to ensure the safety and efficacy of herbal medicines.

Bioassays: Evaluating Biological Activity

Bioassays are essential tools in the evaluation of the biological activity of herbal drugs. They provide a means to measure the effects of herbal extracts on living organisms or cells, thereby assessing the therapeutic potential and efficacy of the herbal products.

Importance of Bioassays: ¹⁵⁻¹⁷

Determining Therapeutic Efficacy:

Bioassays help in quantifying the biological activity of herbal drugs. They are used to identify and measure the potency of active compounds within a herbal preparation. For instance, bioassays can

determine the anti-inflammatory, antioxidant, or antimicrobial properties of an herb, providing crucial information about its therapeutic potential.

Standardization:

By evaluating the biological activity of herbal drugs, bioassays contribute to the standardization of herbal products. Consistent bioassay results help in establishing benchmarks for the potency and efficacy of the herbs, ensuring that each batch meets the required therapeutic standards.

Quality Assurance:

Bioassays serve as a quality assurance measure, detecting variations in the biological activity of different batches of herbal drugs. This ensures that the final product is not only effective but also consistent in its action, which is vital for maintaining consumer trust and regulatory compliance.

Safety Assessment:

Bioassays also play a crucial role in the safety assessment of herbal drugs. They can identify potential toxic effects of herbal compounds on biological systems, ensuring that the herbal products are safe for consumption.

Common Bioassay Methods: ¹⁸

In Vitro Assays:

These involve testing the herbal extracts on cultured cells or microorganisms. Examples include cell viability assays, antioxidant assays (e.g., DPPH assay), and antimicrobial assays.

In Vivo Assays:

These involve testing the herbal extracts on live animals to study their effects on whole biological systems. Examples include animal models for studying anti-inflammatory or analgesic effects.

Ex Vivo Assays:

These involve testing the herbal extracts on isolated organs or tissues from animals. Examples include using isolated rat ileum to study the spasmolytic effects of herbal extracts.

Microbial Contamination: Detection and Ensuring Quality

Ensuring the microbial quality of herbal crude drugs is vital to prevent health risks associated with microbial contamination. Microbial contamination can arise from various sources during the cultivation,

harvesting, processing, and storage of herbal materials. Effective methods for detecting and controlling microbial contamination are essential components of quality control.

Methods for Detecting Microbial Contamination: ^{19,20}

Total Viable Count (TVC):

TVC is a commonly used method to estimate the number of viable microorganisms in a sample. It involves plating a diluted sample on nutrient agar and counting the colonies formed after incubation.

Pathogen Detection:

Specific tests are conducted to detect pathogenic microorganisms such as *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus*, and molds like *Aspergillus* spp. These tests often involve selective media and biochemical tests to identify pathogens.

Rapid Microbial Detection Methods:

Advanced techniques such as polymerase chain reaction (PCR), enzyme-linked immunosorbent assay (ELISA), and ATP bioluminescence offer rapid and sensitive detection of microbial contamination. These methods are particularly useful for detecting low levels of contamination and specific pathogens.

Ensuring Microbial Quality: ^{21,22}

Good Manufacturing Practices (GMP):

Adhering to GMP guidelines helps in minimizing the risk of microbial contamination during the production process. This includes maintaining a clean environment, using sterilized equipment, and ensuring proper hygiene among personnel.

Proper Storage Conditions:

Storing herbal crude drugs under appropriate conditions (e.g., controlled temperature and humidity) helps in preventing microbial growth. Packaging materials should also protect against contamination.

Use of Preservatives:

Natural or synthetic preservatives can be added to herbal products to inhibit microbial growth. However, the use of preservatives must comply with regulatory standards to ensure safety.

Regular Monitoring:

Routine microbial testing of raw materials, intermediate products, and final products is essential to ensure ongoing compliance with microbial quality standards.

Innovations in Quality Control ²³

The field of quality control in herbal drug evaluation has seen significant advancements in recent years. Innovations such as DNA barcoding and metabolomics have revolutionized the way herbal medicines are authenticated, standardized, and monitored for quality. This section explores these technological advances and discusses future trends and emerging methodologies in the quality control of herbal medicines.

Technological Advances ²⁴

1. DNA Barcoding:

DNA barcoding is a molecular technique that uses a short genetic sequence from a standardized region of the genome to identify plant species. This method has become an invaluable tool in the quality control of herbal drugs for several reasons:

Authentication:

DNA barcoding provides accurate identification of plant species used in herbal medicines, preventing adulteration and misidentification. This is particularly important in ensuring that the correct plant species with the desired therapeutic properties are used.

Traceability:

This technique enables traceability of herbal materials from the source to the final product, ensuring that the supply chain is free from contamination and substitution.

Standardization:

By providing precise species identification, DNA barcoding helps in the standardization of herbal products, ensuring consistency in their therapeutic efficacy.

Regulatory Compliance:

Regulatory authorities increasingly recognize DNA barcoding as a reliable method for ensuring the authenticity and safety of herbal drugs, aiding in compliance with quality standards.

2. Metabolomics:

Metabolomics involves the comprehensive analysis of metabolites in a biological sample. It provides a detailed chemical profile of herbal extracts, which is crucial for quality control ²⁵:

Chemical Fingerprinting:

Metabolomics generates a chemical fingerprint of herbal drugs, capturing the complexity of their phytochemical composition. This fingerprint can be used to compare different batches of the same product, ensuring consistency and quality.

Detection of Adulteration:

The detailed metabolic profiles obtained through metabolomics can identify adulteration and contamination in herbal products, enhancing their safety and efficacy.

Phytochemical Profiling:

Metabolomics allows for the identification and quantification of bioactive compounds, supporting the standardization and therapeutic efficacy of herbal medicines.

Predictive Quality Control:

By analyzing the metabolic profiles, manufacturers can predict the quality and potency of herbal products, ensuring they meet the required standards before reaching the market.

Future Trends and Emerging Methodologies

As the field of herbal drug quality control continues to evolve, several future trends and emerging methodologies are poised to enhance the reliability, accuracy, and efficiency of quality control processes ²⁶:

1. Integration of Omics Technologies:

Genomics, Proteomics, and Transcriptomics:

Integrating genomics, proteomics, and transcriptomics with metabolomics can provide a holistic understanding of the quality and efficacy of herbal drugs. This multi-omics approach enables comprehensive quality control by considering genetic, protein, and metabolic data.

2. Artificial Intelligence (AI) and Machine Learning (ML):

Predictive Modeling:

AI and ML can be used to develop predictive models for quality control, identifying patterns and correlations in large datasets to predict the quality and efficacy of herbal products.

Automation:

These technologies can automate the analysis of complex data from DNA barcoding, metabolomics, and other techniques, increasing the speed and accuracy of quality control processes.

3. Advanced Analytical Techniques:

Nuclear Magnetic Resonance (NMR) Spectroscopy:

NMR spectroscopy provides detailed information about the molecular structure and composition of herbal extracts, supporting their authentication and standardization.

Mass Spectrometry Imaging (MSI):

MSI allows for the spatial mapping of metabolites within plant tissues, providing insights into the distribution of bioactive compounds and potential contaminants.

4. Blockchain Technology:

Supply Chain Transparency:

Blockchain technology can be used to create transparent and tamper-proof records of the entire supply chain of herbal medicines, from cultivation to final product. This ensures traceability and accountability, enhancing the overall quality control process.

5. Regulatory Harmonization:

Global Standards:

Future trends may include the harmonization of quality control standards for herbal medicines across different countries and regulatory bodies. This would facilitate international trade and ensure consistent quality and safety of herbal products worldwide.

CONCLUSION

The evaluation of herbal crude drugs through stringent quality control parameters is essential for ensuring their safety, efficacy, and consistency. This review highlights the critical aspects of quality control, encompassing macroscopic and microscopic examination, physicochemical analysis, and phytochemical

screening. Advanced techniques such as chromatography and spectroscopy play a pivotal role in identifying and quantifying the bioactive constituents, ensuring the authenticity and purity of herbal drugs. Regulatory guidelines and standardization protocols are fundamental in minimizing the variability in herbal products, thereby enhancing consumer trust and market acceptance. Despite the challenges posed by the inherent complexity and variability of herbal materials, continued advancements in analytical methodologies and collaborative efforts between researchers, industry, and regulatory bodies can significantly improve the quality assurance of herbal crude drugs. Ultimately, integrating traditional knowledge with modern scientific approaches is crucial for the sustainable development of the herbal medicine industry. This synergistic approach will not only uphold the therapeutic potential of herbal medicines but also pave the way for their global acceptance and utilization in contemporary healthcare systems.

REFERENCES:

1. Sen S, Chakraborty R, De B. Challenges and opportunities in the advancement of herbal medicine: India's position and role in a global context. *Journal of Herbal medicine*. 2011 Dec 1;1(3-4):67-75.
2. Barkat MA, Goyal A, Barkat HA, Salauddin M, Pottoo FH, Anwer ET. Herbal medicine: Clinical perspective and regulatory status. *Combinatorial chemistry & high throughput screening*. 2021 Nov 1;24(10):1573-82.
3. Balkrishna A, Sharma N, Srivastava D, Kukreti A, Srivastava S, Arya V. Exploring the Safety, Efficacy, and Bioactivity of Herbal Medicines: Bridging Traditional Wisdom and Modern Science in Healthcare. *Future Integrative Medicine*. 2024 Mar 25;3(1):35-49.
4. Paul T, Kumar KJ. Standardization of Herbal Medicines for Lifestyle Diseases. In *Role of Herbal Medicines: Management of Lifestyle Diseases* 2024 Feb 27 (pp. 545-557). Singapore: Springer Nature Singapore.
5. Kopp T, Abdel-Tawab M, Mizaikoff B. Extracting and analyzing pyrrolizidine alkaloids in medicinal plants: A review. *Toxins*. 2020 May 13;12(5):320.
6. Ahad B, Shahri W, Rasool H, Reshi ZA, Rasool S, Hussain T. Medicinal plants and herbal drugs: An overview. *Medicinal and aromatic plants: healthcare and industrial applications*. 2021:1-40.
7. Govindaraghavan S. Quality assurance of herbal raw materials in supply chain: challenges and opportunities. *Journal of dietary supplements*. 2008 Jan 1;5(2):176-212.

8. Ameh SJ, Obodozie OO, Inyang US, Abubakar MS, Garba M. Current phytotherapy-A perspective on the science and regulation of herbal medicine. *Journal of Medicinal Plants Research*. 2010 Jan 18;4(2):072-81.
9. Kumar V, Kumar V. An overview of herbal medicine. *Int. J. Ph. Sci.* 2009 May;1(1):1-20.
10. Miraldi E, Baini G. Medicinal plants and health in human history: From empirical use to modern phytotherapy. *Journal of the Siena academy of Sciences*. 2018;10(1).
11. Sen S, Chakraborty R. Revival, modernization and integration of Indian traditional herbal medicine in clinical practice: Importance, challenges and future. *Journal of traditional and complementary medicine*. 2017 Apr 1;7(2):234-44.
12. Gilani AH. Trends in ethnopharmacology. *Journal of ethnopharmacology*. 2005 Aug 22;100(1-2):43-9.
13. Pan SY, Litscher G, Gao SH, Zhou SF, Yu ZL, Chen HQ, Zhang SF, Tang MK, Sun JN, Ko KM. Historical perspective of traditional indigenous medical practices: the current renaissance and conservation of herbal resources. *Evidence-Based Complementary and Alternative Medicine*. 2014;2014(1):525340.
14. Shinde VM, Dhalwal K, Potdar M, Mahadik KR. Application of quality control principles to herbal drugs. *International Journal of Phytomedicine*. 2009 Jan 1;1(1):4-8.
15. Indrayanto G, Putra GS, Suhud F. Validation of in-vitro bioassay methods: Application in herbal drug research. *Profiles of drug substances, excipients and related methodology*. 2021 Jan 1;46:273-307.
16. Barba-Ostria C, Carrera-Pacheco SE, Gonzalez-Pastor R, Heredia-Moya J, Mayorga-Ramos A, Rodríguez-Pólit C, Zúñiga-Miranda J, Arias-Almeida B, Guamán LP. Evaluation of biological activity of natural compounds: current trends and methods. *Molecules*. 2022 Jul 13;27(14):4490.
17. Wu X, Zhang H, Fan S, Zhang Y, Yang Z, Fan S, Zhuang P, Zhang Y. Quality markers based on biological activity: a new strategy for the quality control of traditional Chinese medicine. *Phytomedicine*. 2018 May 15;44:103-8.
18. Nwachukwu ID, Sarteshnizi RA, Udenigwe CC, Aluko RE. A concise review of current in vitro chemical and cell-based antioxidant assay methods. *Molecules*. 2021 Aug 11;26(16):4865.

19. Ediriweera MK, Tennekoon KH, Samarakoon SR. In vitro assays and techniques utilized in anticancer drug discovery. *Journal of Applied Toxicology*. 2019 Jan;39(1):38-71.
20. Stanley MC, Ifeanyi OE, Ifediora AC, Uzoma UG. Isolation and identification of microorganisms involved in the spoilage of soymilk. *Journal of Pharmacy and Biological Sciences*. 2014;9(5):29-36.
21. Sanders ER. Aseptic laboratory techniques: plating methods. *JoVE (Journal of Visualized Experiments)*. 2012 May 11(63):e3064.
22. Li X, Yang Y, Henry RJ, Rossetto M, Wang Y, Chen S. Plant DNA barcoding: from gene to genome. *Biological Reviews*. 2015 Feb;90(1):157-66.
23. Sarvananda L. Short introduction of DNA barcoding. *International Journal of Research*. 2018 Feb;5(4):673-85.
24. Tehen N, Parveen I, Pan Z, Khan IA. DNA barcoding of medicinal plant material for identification. *Current opinion in Biotechnology*. 2014 Feb 1;25:103-10.
25. Zhu X, Yao Q, Yang P, Zhao D, Yang R, Bai H, Ning K. Multi-omics approaches for in-depth understanding of therapeutic mechanism for Traditional Chinese Medicine. *Frontiers in pharmacology*. 2022 Nov 25;13:1031051.
26. Pinu FR, Beale DJ, Paten AM, Kouremenos K, Swarup S, Schirra HJ, Wishart D. Systems biology and multi-omics integration: viewpoints from the metabolomics research community. *Metabolites*. 2019 Apr 18;9(4):76.