Modelling the Malaysian Herbal Domain Ontology for Standardizing the Safety of Herbal Medicine

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.9010289

Received: 14 January 2025; Accepted: 18 January 2025; Published: 19 February 2025

ABSTRACT

The increasing availability of online herbal medicine information has complicated the process for consumers and practitioners to locate pertinent data. Conventional resources such as textbooks and manuscripts are deficient in depth and order, hindering comprehension of herbal remedies and their interconnections. Ontology, as a systematic framework, can assist in resolving this challenge by offering a more lucid articulation of knowledge. Ontologies have demonstrated efficacy in domains such as biology, ecology, and biodiversity research, consolidating and augmenting data descriptions while improving data discovery. This study aims to develop and assess a domain ontology for Malaysian Herbal Medicine utilizing evidence-based data. The research has employed the Haghigi framework, which has three main phases: method of identification, ontology design and implementation, and ontology assessment. The ontology comprises 13 primary classes and properties, addressing competency questions regarding the safety and efficacy of herbal medicines through SPARQL query and prototype evaluations. The ontology provided correct answers to all competency questions through SPARQL query testing and has met the criteria in terms of its accuracy, appropriateness, comprehensiveness, consistency, extensibility, and completeness. The validation and verification results included the positive endorsement and constructive judgment of most of the ontology components. The established ontology may enhance compliance with regulatory standards by providing accurate definitions and classifications of pharmaceutical goods. The ontology may serve as an instructional tool, assisting students and professionals in understanding complex pharmacological concepts within a structured framework and, hence, enhancing learning outcomes and knowledge retention in pharmacology and related fields.

Keywords: herbal medicine, ontology, evaluation, evidence-based information

INTRODUCTION

Herbal medicine has been an integral part of traditional healing practices for centuries, offering natural remedies for various ailments. In Malaysia, with its rich biodiversity, a wide array of medicinal plants has been used for generations in both local and indigenous health systems. These plants have a profound cultural and historical significance and continue to play a crucial role in healthcare, especially in rural and underserved communities (Sahri et al., 2016). The increasing global interest in herbal medicine, due to its potential for treating chronic diseases and improving overall well-being, has also highlighted the need for scientific validation and standardized practices to ensure the safety, efficacy, and quality of herbal products (H. Wang et al., 2023).

In Malaysia, the herbal medicine industry has grown rapidly, contributing significantly to the economy.However, despite the wealth of plant species with therapeutic potential, there are several challenges regarding the standardization and safety of herbal medicines. One of the key obstacles is the lack of comprehensive, structured information that can be universally understood and applied by researchers, manufacturers, healthcare professionals, and policymakers (Shojaee-Mend et al., 2020). Many herbal medicines in use today are based on traditional knowledge, which, while valuable, often lacks the rigorous scientific validation required to ensure their safety and efficacy in modern healthcare settings (Dalamagka, 2024).

The World Health Organization (WHO) has long recognized the importance of herbal medicines and has advocated for the establishment of guidelines that ensure their safe and rational use. According to WHO, the global healthcare system can benefit from the integration of traditional medicine, provided it adheres to safety standards and scientific scrutiny (WHO, 2021). As part of these efforts, the need for a standardized framework to capture, evaluate, and disseminate herbal medicine data is critical. This is where the concept of ontology, particularly the development of an herbal domain ontology, becomes highly relevant (Afifa et al., 2022).

According to (Noy, 2005), ontology is a formal, structured framework that represents knowledge in a specific domain, facilitating information sharing and integration across systems. In the context of herbal medicine, a domain ontology can standardize the data related to the properties, uses, safety profiles, and efficacy of different herbs. By creating a comprehensive Malaysian Herbal Domain Ontology, it becomes possible to catalog the information about medicinal plants systematically, linking traditional knowledge with modern scientific research. This would facilitate better regulatory oversight, more reliable clinical research, and informed decision-making by healthcare professionals and consumers (Alkhatib & Briman, 2018).

Developing such an ontology is essential for ensuring the safety of herbal medicines. While many herbal treatments have been used for centuries, concerns regarding their safety, such as potential side effects, interactions with other medications, and improper usage, have emerged in recent years (Ekor, 2014). Standardizing the safety data through an explicit, evidence-based ontology can help address these concerns. It would provide a unified system to document the therapeutic properties, dosages, contraindications, and potential adverse effects of herbs, enabling both consumers and practitioners to make informed choices.

To model such an ontology, it is essential to collect and organize data from various sources, including traditional knowledge, scientific literature, regulatory frameworks, and clinical studies. This data must be systematically analyzed and integrated into a standardized format that ensures consistency and accessibility. Additionally, collaboration between government agencies, research institutions, and the private sector will be crucial to the successful implementation of the Malaysian Herbal Ontology (MHO).

The research aims to design and evaluate a domain ontology for Malaysian Herbal Ontology (MHO), utilizing evidence-based information to establish standardized guidelines for herbal medications, ensuring their safety and efficacy and facilitating the approval and monitoring processes of regulatory agencies.

LITERATURE REVIEW

Overview of herbal medicine

Since ancient times, plants have been used to treat and cure illnesses and to promote health and wellness. Medicinal plants serve as the foundation of both conventional and indigenous health systems, taking into account their long-standing history. The World Health Organization (WHO) has estimated that the majority of inhabitants in most poor nations continue to rely on these plants for their healthcare needs (WHO, 2019)

Medicinal and aromatic plants are crucial for addressing the needs of traditional medicine markets, both locally and internationally. Traditional medicine, such as Traditional Chinese Medicine (TCM), Arabic Unani medicine, Indian Ayurveda, and indigenous medicine, along with complementary or alternative medicine used in industrialized countries, is gaining increasing credibility worldwide (Ahmad & Othman, 2013).

In the last three decades, the herbal and herbal product market has seen substantial growth across the world. IRNA reports that the global market for medicinal herbs is estimated at $100 billion and is predicted to reach $500 billion in 2050. Medicinal and aromatic plants are offered a wide range of goods, from raw materials to refined and packaged products such as pharmaceuticals, herbal medicines, teas, cosmetics, snacks, nutritional

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025

supplements, varnishes and insecticides. Currently, 80% of the population in developing countries depends largely on plant-based medicines for their healthcare needs, and the WHO has predicted that a comparable percentage of the world's population will well depend on plant-based medicines in the coming decades (Asigbaase et al., 2023). Meanwhile, thirty percent of the drugs marketed worldwide contain compounds derived from plant material (Sahri et al., 2012).

As stated in several resolutions adopted by the World Health Assembly and the Regional Committee for the Western Pacific, the World Health Organization is well aware of the importance of herbal medicines to the health of many people worldwide. Herbal medicines have thus been recognized as a valuable and readily available resource for primary health care, and the WHO has endorsed their use for safety and efficacy. Due to a valuable resource for pharmaceutical products and a potential source of new drugs as well as for economic development, a comprehensive program has been developed for the identification, cultivation, preparation, evaluation, use and conservation of herbal drugs (Alamgir, 2017).

The WHO advocates the proper use of herbal medicines and supports the use of treatments that have been shown to be safe and reliable. A few herbal medicines have withstood scientific testing, but others are used simply for traditional reasons to protect, restore or improve health. It is still essential to scientifically research most herbal medicines, although the knowledge gained from their conventional use over the years should not be overlooked. Member States have pursued WHO collaboration in the identification of safe and effective herbal medicinal products for use in their national health care systems. As there is not enough evidence produced by common scientific approaches to answer questions of safety and efficacy about most of the herbal medicines now in use, the rational use and further development of herbal medicines will be supported by further appropriate scientific studies of these products, and thus the development of criteria for such studies (Hongting Wang et al., 2023).

Malaysia has been endowed with around 15,000 recognized plant species, out of which 3,700 are useful species and 2,000 have therapeutic potential. The other species have yet to be fully exploited. As a result, Malaysia has become a prominent study hub for its extensive biodiversity plantation. One of the focused research projects on Malaysian herb species is related to biotechnology in the food and medicine industry. In addition, Malaysia herbs are known with its medical value and economic importance with profits is more than RM 4.5 Billion a year in herbal based products (Sahri et al., 2016). Therefore, extensive research and development is needed in order to preserve the value of herbs.

According to (Tan et al., 2020), the most challenging part of developing the Malaysian Herbal Monograph (MHM) is identifying and gathering evidence-based information on medicinal herbs. This is due to the poorly documented data by the local practitioners, and the data was scattered, unstructured and stored in separate databases. The information retrieval process is carried out in a traditional way without the assistance of any system and is usually time-consuming. These will lead to major obstacles for the committee in updating the information annually and meeting the set standards by WHO.

Issues concerning herbal medicine

The issues surrounding herbal medicine in the world and Malaysia are generally multifaceted, reflecting the complexities of its cultural, regulatory, and scientific landscapes. Despite the growing popularity of herbal medicines, there is a significant lack of stringent regulatory frameworks to ensure their safety and efficacy. As is known, the regulatory status of herbal medicines varies widely across different countries. For instance, many herbal products are registered under less rigorous food supplement regulations compared to pharmaceuticals, leading to potential safety concerns due to the absence of comprehensive clinical evidence supporting their use. These issues pose significant challenges to consumer safety, product efficacy, and overall public health. Various reports and studies highlight the complexities and issues surrounding the regulation of herbal products globally. Manufacturers are also not required to prove the safety or efficacy of their products before marketing, leading to potential risks for consumers (Gatt et al., 2024).

The diverse regulatory status also contributes to diverse definitions and classifications. The definition of what constitutes herbal medicine can vary significantly, complicating regulatory efforts. A single herbal product might be categorized differently in various jurisdictions, either as a food supplement, dietary supplement, or traditional medicine, which may lead to confusion among consumers and healthcare providers.

In addition, in terms of quality control concerns, many herbal products lack adequate quality control measures, resulting in inconsistencies in potency and purity. The absence of rigorous testing can lead to contamination with harmful substances, such as heavy metals or toxic herbs, which can cause adverse health effects. Reports of adverse reactions to herbal medicines have increased, underscoring the need for better quality assurance practices. This situation becomes more challenging due to a lack of scientific evidence as a reference. The efficacy of many herbal medicines is often based on traditional use rather than scientific validation. Regulatory frameworks, such as the EU's Traditional Herbal Medicinal Products Directive (THMPD), require a history of use but do not always mandate the same level of clinical evidence as required for conventional pharmaceuticals. This can result in consumers using products that may not be effective or safe.

In terms of safety concerns, there is also a prevalent belief among the Malaysian population that herbal products are free from harmful chemicals and side effects. However, this perception is not always supported by scientific evidence. Many herbal medicines are used without proper supervision, particularly among pregnant women, raising concerns about potential adverse effects on both mothers and fetuses (Ramadhani et al., 2020). The increased use of herbal products, often driven by aggressive marketing, exacerbates these safety concerns. This is due to the fact that there are Inconsistent regulatory frameworks across countries, with many herbal products classified as dietary supplements subject to less stringent regulations and also a lack of scientific evidence for the efficacy of many herbal medicines, which are often based on traditional use rather than clinical trials (Shaikh Abdul Rahman & Aziz, 2020).

Apart from that, herbal medicines could also cause adverse effects, including contamination with toxic substances, misidentification, or substitution of herbs. Many herbal medicines are used concurrently with conventional drugs, leading to potential pharmacokinetic interactions and adverse events (Dwivedi & Chopra, 2013). A retrospective study by (Shaikh Abdul Rahman & Aziz, 2020) reported 242 (26%) serious adverse drug reactions (ADRs) in Malaysia, including 36 deaths as a result of complementary and alternative medicines use. From 2010 to 2016, 140 cases of acute kidney injury were associated with the consumption of traditional and complementary medicines in Malaysia (Lee et al., 2017).

Although both studies show that the majority of adverse reactions are caused by unregistered natural products, there are still reports of adverse reactions caused by licensed products that need to be addressed. This is due to the significant portion of the population has limited knowledge about the safe use of herbal medicines. Studies indicate that many users rely on anecdotal information from family and traditional practitioners rather than scientific evidence, which can lead to unsafe practices and misuse of herbal products (WHO, 2019). Besides that, the concurrent use of herbal products with prescription medications can lead to unpredictable adverse reactions, particularly with drugs that have a narrow therapeutic index. This unpredictability is also due to the lack of standardization and regulation of herbal products, which often leads to variability in their composition and potency (Mirzaeian et al., 2019).

In the context of the herbal industry, it is also essential to consider the challenges posed by the market and the economy. Although the Malaysian government acknowledges the economic prospects of the herbal business, there are still obstacles to overcome in creating high-value herbal products that adhere to global standards. Currently, most products available in the market are low-claim herbal supplements, lacking the rigorous research and development needed to establish their efficacy. This is due to the lack of comprehensive regulatory frameworks governing the herbal medicine sector (Salini & Kamarulzaman, 2023).

This absence can lead to product quality, safety, and efficacy inconsistencies, which undermines consumer confidence and hinders market growth. Standardized regulations are critical to ensure that herbal products meet safety and quality standards. Besides that, the herbal industry suffers from insufficient investment in research and development (R&D). This gap limits the ability to validate traditional claims scientifically and to innovate new products. Without robust R&D, the industry struggles to keep pace with advancements in herbal medicine seen in other countries, such as India and China, where traditional practices are supported by modern scientific research (Rahimah, 2019).

In addition to the aforementioned aspects, (Park et al., 2022) have emphasized the significance of cultural elements as an additional key factor that must be considered. The integration of various traditional medicinal systems, such as Malay, Chinese, and Indian herbal practices, creates a rich but complex landscape for herbal medicine. Furthermore, it is associated with a strong ethnic identity and is regarded as a cultural heritage. This diversity can lead to inconsistencies in quality and efficacy, as well as challenges in standardizing practices across different cultural contexts (Rajendran & Kamarulzaman, 2023). In summary, the issues in herbal medicine in Malaysia encompass regulatory challenges, safety concerns, knowledge gaps among users, economic barriers, cultural diversity, and environmental sustainability. Addressing these challenges is crucial for the safe and effective use of herbal medicines in the country. As emphasized by (Tan et al., 2020), this issue can be addressed by developing a standard guideline that can serve as a reference in/for the herbal industry.

Furthermore, it is imperative to prioritize the establishment of a comprehensive herbal medicine knowledge database to effectively tackle the emerging issues. A database of knowledge of herbal medicine on medicinal plants has been widely developed around the world. World Wide Web (www) consisting a large volume of information related to medicinal plants. However, the study conducted by (Zhang et al., 2022),(Hamiz et al., 2014) and(Hartono Wijaya et al., 2016) found that the problems faced by the biological domain were the data generated in large numbers stored in separate databases, scattered, in text form, unstructured and cannot be reached by the public. Search engines are not quite efficient and require excessive manual processing. This problem was also highlighted by (Tan et al., 2020) in their challenge to develop the Materia medica of Malaysian herbs. This condition will lead to ineffectiveness and difficulties in information sharing, making it difficult for researchers to make more informed decisions. Since herbal knowledge is part of biological knowledge, then there is a need to address the problem of scattered information in the various databases. (Kassani & Kassani, 2018) Proposed the implementation of an ontology and the development of a standardized framework or structure to effectively manage the expanding knowledge in the field of herbal medicine.

Herbal knowledge repository

The adoption of semantic technology for representing herbal medicine knowledge has grown rapidly, driven by the need to conserve and utilize biological resources effectively. The vast and ever-expanding body of herbal medicine knowledge has led to efforts to integrate multiple sources to meet the demands of experts across various fields. Unfortunately, most existing repositories focus solely on basic information about herbal medicine, neglecting critical aspects such as pharmacology, safety, and efficacy. This omission is concerning, as herbs can produce a range of undesirable or even life-threatening adverse reactions (Ekor, 2014). Therefore, it is imperative to merge foundational knowledge with insights into pharmacological processes and herbal drug discovery (Wainwright et al., 2022).

(Lim-Cheng et al., 2014) Emphasize the importance of populating herbal ontologies, particularly in Malaysia, which hosts extensive databases of local herbal knowledge for medical applications and research programs. However, the ontology population in the herbal medicine domain presents challenges due to ambiguous terms in source texts. These terms often stem from varied information formats spread across websites, portals, journals, and books, as well as the multilingual nature of these texts, where each language conveys unique nuances. (Devine et al., 2022) Note that the specialized nature of herbal knowledge and complex sentence structures hinder the effectiveness of rules applied during the ontology population.

Given the critical role of the rapid ontology population in application development, adopting automated or semi-automated approaches has become a pressing need. Techniques such as Hearst patterns for extracting semantic relations (Hearst, 1998), as adapted by (Ibrahim et al., 2018) in herbal research, have shown promise but remain limited in accuracy due to challenges in identifying semantic relationships between concepts (Lubani et al., 2019). Thus, future efforts should focus on refining semantic connection rules to enhance the domain of medicinal herbs.

In addition, acquiring pharmacological knowledge is vital, particularly for ensuring the safe prescribing and administration of drugs. Pharmacology knowledge is integral to healthcare, influencing drug safety, the development of new therapies, and the education of healthcare professionals in understanding drug interactions, side effects, and appropriate dosages (Abougalambou & Alenezi, 2023). Inadequate pharmacological knowledge contributes significantly to medication errors, a leading cause of mortality in healthcare settings (Hipskind et al., 2024).

While medicinal plants have demonstrated therapeutic potential, they require thorough pharmacological analysis to understand their composition, adverse effects, and contraindications fully. Unlike synthetic medications, adverse reactions to herbal therapies are generally less frequent when used cautiously (Thomford et al., 2018). Nonetheless, a deeper understanding of potential conflicts and adverse effects is essential to maximize their safe usage (Afifa et al., 2022). (Chandra & Natalia, 2019) highlighted that although the global herbal medicine market is significant, only 15% of plants have undergone phytochemical study, and a mere 6% have been biologically tested.

To address these gaps, (Devine et al., 2022) and (Ratsamano & Chairungsee, 2019) propose integrating herbal medicine into existing healthcare systems to ensure safety and efficacy. This integration fosters semantic interoperability by aligning medical knowledge structures with those of traditional medicine. (Supiah et al., 2012) identified four essential categories for constructing herbal domain ontologies: herb knowledge, traditional medicine, herbal preparation processes, and pharmacology knowledge. Building on this framework, (Lim-Cheng et al., 2014) enhanced the ontology by including therapeutic characteristics, types of illnesses, affected body parts, preparation methods, and plant parts used. Additional insights, such as drug dosages aligned with meridians and clinical use scenarios for toxic herbal drugs, could further enrich Malaysia's herbal pharmacopeia.

Beyond ontology development, the importance of drug discovery must also be emphasized. Drug discovery involves identifying chemical entities with therapeutic potential to address unmet medical needs. Herbal medicines comprising herbs, herbal materials, preparations, and products are vital sources for novel therapies (Gajanan & Suresh, 2021). However, the lack of comprehensive, accessible knowledge and expert guidance hampers the general public's effective use of herbal remedies (Hassen et al., 2022). (Alkhatib & Briman, 2018) stress the importance of developing comprehensive knowledge bases and ontologies for medicinal plants to facilitate the creation of new drugs and therapies. Machine learning techniques have further enabled the analysis of herbal compounds' molecular properties, offering more profound insights into their therapeutic potential. The development and application of exhaustive ontologies for medicinal plants thus represent a transformative step toward advancing drug discovery and healthcare.

RESEARCH METHODOLOGY

In the process of ontology development, various methodologies have been employed to construct effective and meaningful ontologies. Methodology, 101 Method, TOVE Methodology, and the ENTERPRISE Methodology are considered among the leading frameworks for building ontologies, each offering unique features and advantages in representing domain knowledge. According to (Haridy et al., 2023), different methodologies may be suited to other purposes, contexts, and types of domains, reflecting the flexible nature of ontology creation. Some research notes that ontology development remains an area of innovation and exploration where multiple approaches can coexist and offer complementary benefits.

The construction of the MHO ontology draws significant inspiration from the methodologies outlined by (Delir Haghighi et al., 2013). It also incorporates specific insights from (Nguyen, 2018), adhering closely to the guidelines provided in the Protégé practical guide by (Horridge et al., 2011). This comprehensive approach is especially effective for presenting detailed information on large biomedical ontology, ensuring clarity and precision in knowledge representation.

Overall, Haghighi’s method is divided into three major parts: the identification phase of ontology development methodologies, ontology design and implementation, and the evaluation phase. The first phase relates to reviewing and aims to identify methodologies within past research work, while the second phase merely deals with ontology development for MHP. The final phase is for the evaluation of ontology as a whole. Figure 1 depicts the visual representation of the Research Method.

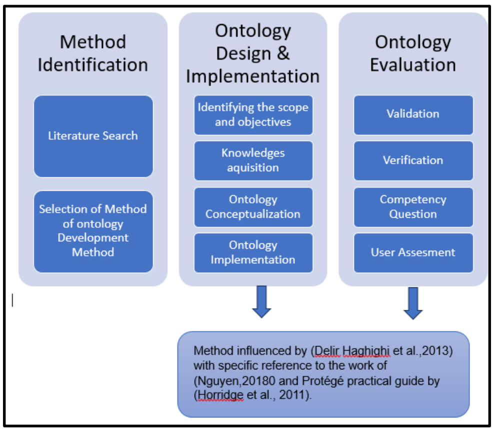

Fig. 1 Research Method

Method of identification:

The first stage of the identification process is derived to some degree from the systematic literature review. This phase has used a systematic literature study to identify the ontology development techniques and evaluation approaches based on previous studies. The Haghihi approach is believed to be appropriate for enhancing decision-making in the biomedical area.

Ontology Design and Implementation:

The second phase comprises of four main steps namely:

Identifying the scope and objectives:

The first step in building the ontology is to identify the scope and objectives of the proposed ontology in order to provide a better understanding of the domain knowledge for study and analysis. This step consists of domain identification, the ontology's aim, and the users.

The basic questions elucidate the purpose of the ontology and limit the scope of the intended ontology development. The standard basic questions asked are as follows:

What domain would the ontology cover?

The ontology domain will cover the herbal medicinal plant perspective for the constructing of Malaysian Herbal Pharmacopeia domain ontology.

For what purpose was the ontology used?

Primarily, the ontology was constructed with the aim to encourage the responsible use of the highest possible degree of efficacy and protection of herbal medicinal products through the establishment of botanical identification, purity and analysis standards, including the examination of traditional and scientific evidence on their efficacy and safety. This ontology should the safe and effective use of herbal medicines and encourages the use of treatments that have been proven to work.

What types requirements and competency questions should the ontology answers?

The ontology aims to provide safety and efficacy information on medicinal herbs and propose effective treatments based on disease and symptoms. It analyzes requirements and competency questions based on problem identification and ontology development. The ontology design addresses these pre-established competency questions, which are a list of questions that the ontology must answer. The finalized competency questions are formalized in a query language for ontology querying. The following are possible competency questions to envision the end results of the ontology, as shown in Table 1.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025

Table I Competency questions

	Herbal medicine knowledge	Competency Question
1	**Plant identification** In terms of plant identification, the competency question should determine the plant's name based on its local, synonym, or scientific name. Furthermore, it may provide information about the plant's family and genus based on other relevant characteristics or morphological findings. It also helps to offer information on the best climatic conditions and natural habitats for plant development.	*What are the scientific name and synonyms for the herbal plant?* *What is the genera for the herbal plant?* *What is the climate requirement for herbal plant?*
2	**Chemical Constituents** For chemical constituents, the competency question can identify and classify the major classes of herbal constituents by describing the biosynthetic pathways and chemical structures of key phytochemicals and explaining the relationship between chemical constituents and the pharmacological activities of herbs.	*What are the chemical constituents found in the herbal plant?*
3	**Pharmacological information** In terms of pharmacological information, the competency question will demonstrate a comprehensive understanding of the pharmacological basis for the therapeutic applications of herbal medicines, including their active constituents, mechanisms of action, pharmacokinetic properties, and clinical evidence.	*What is the recommended dosage to be used for herbal plants in treating the disease?* *Which herbal plants have high antioxidants?*
4	**Medicinal Used** In term of medicinal use, the competency question can demonstrate a comprehensive understanding of modern and traditional herbal medicine practices grounded in knowledge of herbal constituents, modern and traditional therapeutic principles, and safety considerations.	*Are there any clinical studies or information available for herbal plant?* *What precautions should be taken if taking the herbal plant?*
5	**Safety and efficacy** For safety and efficacy, the competency question will provide information to demonstrate a comprehensive understanding of the complex interplay between herbal medicines' safety, quality, and efficacy and the ability to critically apply this knowledge to real-world situations in herbal medicine practice and research.	*Does the herbal plant show high levels of toxicity?* *Can the herbal plant cause illness to patients?*
6	**Cultivation** In term of cultivation, the competency question will provide an information on the best practices for cultivating medicinal herbs.	*What is the soil suitability for the herbal plant?*

7	**Disease** In terms of diseases, competency questions can address the symptoms associated with the disease and available herbal remedies associated with managing the disease	*Can malaria be treated using herbal plants?* *Which parts of the herbal plants are used for the treatment of high blood pressure?*

Knowledge Acquisition

The knowledge acquisition process involves discovering, eliciting and extracting knowledge from the domain of interest. The resource needs to be identified when gathering concepts extracted from the literature. Each concept must be discussed, defined, and documented with the experts, including the reference sources. In addition to the above resources, it is important to gather the domain knowledge and key concepts and elements from domain experts and researchers. Two critical activities involved within this stage are content capture and content analysis.

The information acquired from ontology modeling originated from two separate sources. The primary sources are from the thorough information collection conducted throughout the interview with 12 domain experts in herbal medicine that involved researchers, medical professionals, pharmacologists, botanists and pharmacies. This participant was chosen based on their expertise in medical herbs, including therapeutic indications, medication interactions, dosage, active constituents, and herbal product precautions. Meanwhile, the secondary sources originate from the Malaysian Herbal Monograph, which served as a guideline and reference for the herbal business in producing high-quality herbal goods. The monograph provides scientific information about medicinal plant species' identification, purity, and safety. The process of knowledge mapping was used in the development of the ontology for designated objectives.

Content Analysis

The respondent proposed a comprehensive selection of 35 plants to serve as herbal sources for advancing MHO. The herbal plant is believed to possess substantial value and considerable promise for drug discovery activity. The data on the herbal detail was compiled from the texts "Compendium Herbal Malaysia" and "Malaysia Herbal Monograph 2016" and reviewed by the expert during the focus group discussion. The graft is shown in Figure 2.

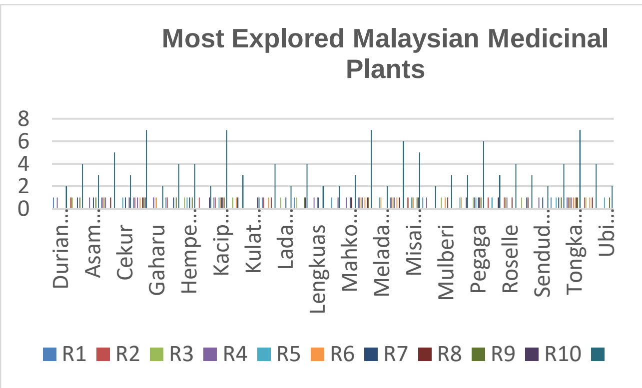

Fig. 2 Most Explored Malaysian Medicinal Plants

Ontology Conceptualization

Conceptualizing and implementing ontologies are fundamental components of the ontology development process. Throughout the ontology conceptualization process, the fundamental concepts that constitute the core content of the ontology are structure and design. An ontological development tool will precisely define and explain the ideas (classes), subclasses, attributes, and related connections within the specific field of interest. The slots, characteristics, instances, and relations are specified for the ideas to enhance comprehension and facilitate querying and reasoning associated with the concepts. This stage involves defining and structuring fundamental concepts, relationships, and entities within a specific domain or knowledge area. A well-designed ontology can improve information retrieval, data sharing, and knowledge management in complex and data-rich domains. The main objectives of ontology conceptualization include:

i. Identifying Concepts: Determining the key concepts and entities relevant to the domain.

ii. Defining Relationships: Specifying the relationships and associations that exist among the identified concepts.

iii. Defining properties and attributes associated with concepts.

iv. Define instance

The insights gained from the survey served as a crucial guideline during the specification process for developing the Malaysian Herbal Ontology (MHO). The information obtained is as follows:

i. Plant Profile: A Plant Profile is a comprehensive description or summary of a specific plant, providing key details about the plant name and its characteristics. Plant profiles are commonly used to document a plant's therapeutic value and scientific understanding. The data provided by specialists will be subjected to a verification process on the plant list website https://wfoplantlist.org to ascertain the accuracy of the local name, scientific name, family name and genera.

ii. Geographical Information: Defines the geographic region or habitat where the plant grows or is cultivated. Information about where the plant naturally grows or is cultivated. This section includes geographic locations, climate preferences, and the type of environment.

iii. Plant Identification: A physical description of the plant, including its size, shape, color, and distinguishing features such as the structure of its leaves, flowers, fruits, or roots.

iv. Research and Clinical Studies: Scientific research or clinical trials conducted on the plant to support its medicinal claims.

v. Plant Part Used: The specific parts of the plant that are used for medicinal purposes. Plant parts were used to create remedies, predominantly centered around leaves and roots, rhizomes, flowers, bulbs, barks, stems, latex, seeds, tubers, sap, bulbs, fruits, whole plants and stems.

vi. Disease: A pathological condition of the body or mind that disrupts normal functioning, typically manifested by identifiable symptoms and signs.

vii. Safety and Efficacy: Indicates cautionary details about herbs or formulations related to contraindications, precautions, side effects, adverse reactions, and case studies.

viii. Symptoms: Represents all potential signs and symptoms associated with illnesses.

ix. Medicinal used: Refers to the application of herbs or plant-based substances to prevent, treat, or alleviate health conditions. A description of the plant's therapeutic applications, including traditional uses and modern scientific evidence supporting its use. This section highlights the conditions or ailments the plant can treat, prevent, or alleviate.

x. Pharmacological properties: Effects and actions a substance, such as a drug or medicinal herb, has on the body.

xi. Chemical constituent: A list of the main active compounds found in the plant that contribute to its medicinal effects.

xii. Preparation Method: Information on how the plant is typically prepared for medicinal use, such as in teas, tinctures, capsules, or topical applications.

Ontology Implementation

The next phase involves the implementation of the ontology. The objective of this phase is to implement formalized ontology in a formal knowledge representation language. Implementation refers to the act of constructing the formal ontology model using a machine-programmable ontology language. This work utilizes the formal ontology language Web Ontology Language (OWL) with the Resource Description Framework (RDF), which is available and supported. Furthermore, Protégé version 5.2 is used as ontology editors at this stage. The visualization of an ontology is achieved by utilizing the OntoGraf Plugin in Protégé to provide clear and visible representations of the findings.

RESULT

Class Implementation

Figure 3 illustrates that thirteen (13) concepts have been identified to facilitate the modelling of the Malaysia Herbal Ontology (MHO). The formulation of this notion has been guided by the findings of an interview and insights derived from an extensive review of relevant literature. The recognized elements include plant profile, used plant parts, associated diseases, symptoms, pharmacological qualities, dosage, preparation methods, medicinal applications, safety and effectiveness, cultivation, and storage.

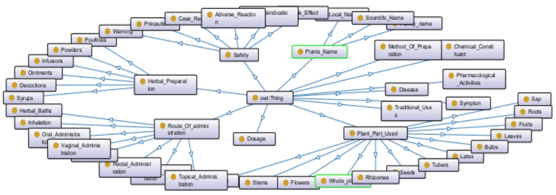

Fig. 3 Most Explored Malaysian Medicinal Plants

Properties Implementation

The hierarchy of classes must be comprehensive to capture the full semantics of the domain. To achieve this, every class instance is associated with properties or attributes. The MHO ontology uses two distinct types of properties: object properties and data properties. The implementation includes 15 object properties and six data properties, as shown in Figure 4. Object properties establish generic relationships between two individuals in the ontology, whereas data properties define specific alphanumeric relationships that connect individuals to data values. In ontology, object properties link two or more classes or concepts and their associated objects. These properties can also exist independently within the ontology. Object properties are crucial for defining relationships between different concepts or classes when designing an ontology for herbal medicine. They explain how instances of one class relate to instances of another. Below are some relevant object properties for an herbal medicine ontology:

The Objective Properties

i. has_Name associated the herbal Name

ii. has_Disease associated symptoms with its diseases.

iii. has_property relates chemical compounds and pharmacological activities to the specific plants

iv. has_symptoms related to the patient's disease and associated symptoms.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025

v. has_medicinal_used suggests treatment for diseases.

vi. has_associated_with associated the plant with safety information.

vii. has_treat suggested plants for the specific treatment.

viii. has_cause associated with the side effect of taking the herbal plant

ix. has_ interacts_with is interactions between a chemical constituent of a plant and pharmaceutical drugs.

x. has_grows_in defines the geographic region or habitat where the plant grows or is cultivated

xi. administered_via specifies how the herbal preparation is administered to a patient.

xii. has_induces_effect defines the physiological effects induced by an herbal preparation on the body.

xiii. contraindicated_for Indicates the health conditions for which a specific herb or preparation is not recommended.

The Data Properties

The proposed ontology has eight (8) simple data properties as shown in Fig. 4.

i. Disease: This property is of string type and maintains the disease's full name in English.

ii. Local_Name. It is also of string type and saves the herb's full name in local languages.

iii. Scientific_ Name: It saves the herb's scientific name in English.

iv. Pharmacological_Property_ID: This property is of string type and maintains the pharmacological activities of plants.

v. Medicinal_Uses: It contain health approaches to treat illnesses or maintain well-being.

vi. Grows_In the geographic region or habitat where the plant grows or is cultivated.

vii. Symptom: This property is of string type and maintains the disease's full name in English.

viii. Chemical_Constituent_ID: This property is of string type and maintains the chemical constituent property of plants.

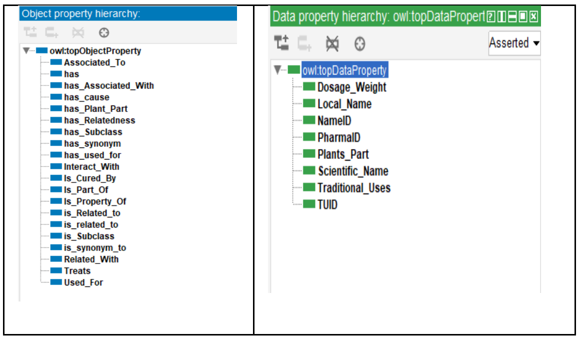

Fig. 4 The data property and object property of MHO

Individual Implementation

Every category is made up of individuals, also known as Instances. Within the 13 different classes of MHO, a total of three hundred eighty-nine (389) individuals were constructed. Figure 5 illustrates the presence of a person who belongs to the class of Pharmacological Activities.

Fig. 5 Individual of Pharmacological Activities.

Ontology Evaluation

The ontology evaluation comprises four important processes involving validation and verification, which are the first parts of internal evaluation. Experts perform the first part of the evaluation after the ontology conceptualization stage is completed. The second part of the evaluation, which is the external evaluation, is conducted after the ontology implementation is accomplished through the execution of competency questions in SPARQL Query in the Protégé ontology editor. Users' assessments are distributed to prospective users to evaluate the effectiveness of MHP ontology in fulfilling their requirements.

In addition, a prototype was created to confirm that ontologies are well-crafted, dependable, and suitable for their intended use. The prototype showcases the practicality of the ontology and establishes a basis for further advancements towards a resilient and implementable knowledge representation.

Users Assessment: SPARQL Query

After constructing the ontology, the Apache Jena Fuseki Server, an HTTP-based query engine, was employed to evaluate the SPARQL query prior to its evaluation on the developed prototype. This query is constructed based on the suggested competence question during the first stages, as shown in Figure 6.

Competency Question 1: Which plant exhibits antidiabetic properties?

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX MHPO: <http://www.semanticweb.org/user/ontologies/2023/5/MHPO#>
SELECT ?Scientific_Name?Pharmacological_Activities? Antidiabetic
 WHERE {
?Pharmacological_Activities MHPO:Is_Property_Of?Scientific_Name
}
```

Fig. 6 SPARQL Query

As shown in Figure 7, the execution of this competency question has yielded seven (7) results from the SPARQL query execution and successfully addressed the submitted question for the competency question.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025


http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Andrographis_paniculata
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Curcuma_longa_L.
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Zingiber_officinale
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Eurycoma_longifolia_Jack
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Zingiber-zurumbet
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Alpinia_galangga
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Brucea_javanica
http://www.semanticweb.org/user/ontologies/2023/5/untitled-ontology-12#Antidiabetic_Activity

Fig. 7 The execution results of this competency question

The execution results of plants that exhibit antidiabetic properties are visualized using OntoGraf, as depicted in Figure 8. The figure corresponds to the seven (7) results obtained from the execution of the SPARQL Query.

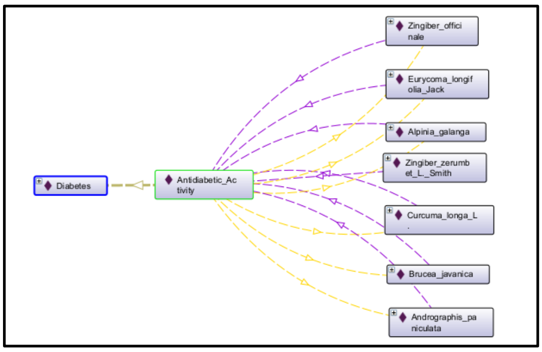

Fig. 8 The result of SPARQL query execution

Users Assessment result for SPARQL Query

The participating users rated the generated result from the SPARQL Query execution based on the Correctness of the suggested answer given and its correspondence to the relatedness of medicinal herb with disease. Their assessment was conducted using a three-point scale of categories: Accurate, Partially Accurate, and Not Accurate.

All 34 competency questions were tested by qualified users for user assessment. Out of 34 questions, 95% of the results were categorized as Accurate. Another 2, equivalent to 5% of the results, were categorized as Partially Accurate, and none were categorized as Not Accurate. Thus, most of the information and relationships provided by ontology have reached a promising and significant level of ontology usefulness from the user's point of view. The validity rate of 90% falls within the range recommended by (Nguyen, 2018) and (Shojaee-Mend et al., 2020) for domains involving decision-making in the biomedical domain.

The competency questions that remark as ***Partially Accurate*** by user:

Competency Question 1: Which plant should be cautiously approached by a nursing mother?

The result only gives two suggested plants that can harm nursing mothers from the relationship *can_cause*. Results only show warnings and side effects from Safety Information. There is no result from safety caution for nursing mothers / breastfeeds from a traditional perspective. This is due to the absence of concepts and relationships offered by conventional medicine regarding the cautions and hazards associated with the use of specific herbs during pregnancy and breastfeeding.

According to the conventional perspective, it is advised against the use of *Kemfaria galanga* and *Brucea Javanica* by lactating and breastfeeding mothers, in addition to Carica papaya and *Centella asiatica*. The absence of a link between traditionally used and safety information accounts for this emergence.

Competency Question 2: Which plant has the potential to be utilized in the treatment of diabetes?

The result fails to answer all the identified relationships between disease and the potential plant to treat diabetes. This is attributed to the absence of any established correlation between wound healing properties, hypoglycemic properties, and hyperglycaemic activity in the context of diabetes treatment. This is due to the inability to demonstrate the property's full potential as a diabetic preventive agent.

Suggested given: Besides antidiabetic activity, other plants with listed wound-healing properties, hypoglycemic properties, and hyperglycemic activity can potentially be used in the treatment of diabetic patients.

i. Wound-healing properties: The ability to replace devitalized and missing cellular structures and tissue layers

ii. Hyperglycemic activity: The ability to lower blood sugar levels in hyperglycemia or high blood sugar.

iii. Hypoglycemic activity: The ability to lower blood sugar levels in hypoglycemia or low blood sugar.

Prototype validation through case reference

The system's validity refers to whether the system can meet the requirements of both the domain experts and the individuals. The system validity is assessed by three criteria: domain accuracy, completeness and appropriateness. Domain accuracy and completeness were assessed by experts, while appropriateness was assessed by individuals.

In this study, the semi-structured interview method was used to collect participants' views about the system's validity. This enables getting complete information on system validity because participants can express their views in-depth and widely. The system prototype of the MHO was implemented by integrating multiple technologies. The system uses PHP and JavaScript (AJAX) communication between the user's browser and the server, enabling dynamic updates without requiring a page reload. The interface of the prototype is shown in Figure 9:

Fig.9 The interface of the MHO prototype

The selected plant for the case study of the evaluation process is Labisia pumila. A compilation of 24 questions was constructed for user assessment in prototype testing. The questions began with simple searches and progressed to more complex ones to ensure the prototype could satisfy the user's requirements. Users can perform inquiries-driven searches and assess the responses acquired from those inquiries. The Assessment result for the case study can be seen in Figure 10.

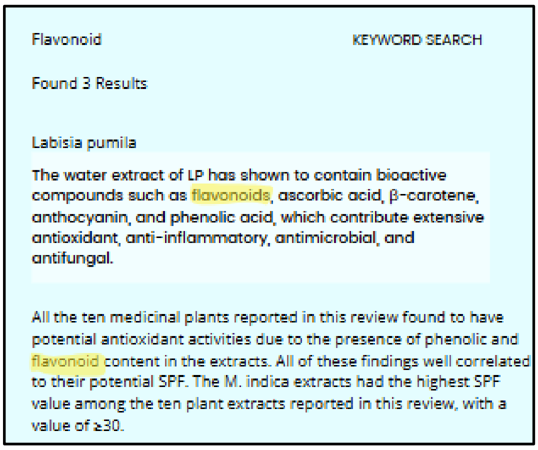

Fig. 10 Result of Keyword Search

Results derived from user assessments

Accuracy

All participants (100%) agreed that the system provides accurate information and hence can be used as a source of reference.

Completeness

All experts indicated that the system provides 100% complete information about possible plants and diseases. This means that information on the system can be used as a guideline in modeling MHO.

Appropriateness

Upon evaluation of the system, all participants deemed the data 100% entirely relevant and beneficial to them. This signifies that the system is suitable.

CONCLUSIONS

In conclusion, this research successfully developed the Malaysian Herbal Ontology (MHO), a robust and practical knowledge base for medicinal plant information. By employing credible sources, competency questions, and expert feedback, the ontology effectively addressed key inquiries concerning the safety, efficacy, and utilization of herbal medicine. Tested using Java and the JENA framework, the MHO demonstrated reliability and utility in managing and applying knowledge of traditional medicine.

An ontology for Malaysian herbal medicine can provide a structured knowledge base for education, interdisciplinary learning, and digital learning tools. It promotes cultural preservation, aids policy-making, and supports evidence-based regulations. It also aids biodiversity conservation, healthcare integration, and intellectual property protection. The ontology supports product development, supply chain transparency, market expansion, research and innovation, and collaboration across sectors. Challenges include digital transformation, stakeholder involvement, and global recognition. By creating a robust ontology, Malaysia can contribute to sustainable growth and the global recognition of its herbal heritage.

The study highlights critical areas for further exploration, including expanding traditional medicine concepts to encompass treatment methods, dosage, and harvesting techniques, thereby enriching the ontology's scope. Additionally, extending the chemical constituents' domain to include bioavailability analysis and molecular linkage can enhance drug discovery efforts. Integrating the MHO with existing ontologies, such as the drug target and chemical constituent ontologies, further supports a comprehensive framework for drug development.

Despite its success, the research acknowledges limitations, particularly the challenges of integrating complex concepts like traditional medicine knowledge and plant chemical composition. Addressing these limitations is essential for establishing correlations between plant compositions and their therapeutic applications, ultimately improving the efficacy and safety of traditional treatments.

By building on these recommendations, future studies can refine the MHO, contributing to advancing traditional medicine and facilitating the development of targeted, effective therapies through semantic technology. This work represents a significant step in leveraging ontology for knowledge management and search systems of herbal medicine.

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