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Ontologies of Herbal Medicine: A thematic review analysis from 2011-2022

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Abstract

This study examines various approaches for ontology construction and evaluation in medicinal plant ontology, focusing on the challenges associated with this domain. Thirty review articles on three databases revealed five alternative approaches for ontology generation in herbal medicine: well-structured methodology, customized methodology, semiautomatic approach, socio-technical approach, domain expert techniques, and top-level approach. However, 68% of the research did not include ontology evaluation. Ontology quality was often assessed using competency questions, expert opinion, and automated error detection. The study provides ontology developers with a better understanding of established methodologies for developing and evaluating standard ontologies in this area and identifies gaps in existing research for future studies.

Keywords : Ontology ,Herbal Medicine ,Ontology Development ,Ontology Evaluation

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1.0 Introduction

The utilization of herbal medicines has been a practice deeply rooted in human history. Across cultures, continents, and epochs, incorporating herbal remedies into healthcare regimens has remained a prevalent and enduring tradition. This age-old custom demonstrates the profound connection between humanity and the natural world, as well as the valuable knowledge passed down through generations. The widespread use of herbal medicines speaks to their significance in promoting health and well-being, echoing a timeless pursuit of holistic approaches to healing (Sahri et al., 2016).

Herbal medicinal knowledge, especially the use of ethnomedicinal plants in developing countries, has been passed down for generations through informal practices and self-experiences. Today, quite often we can obtain this knowledge of herbal medicine on the web. This knowledge is often unstructured and usually scattered on various data sources (Shojaee-Mend et al., 2019). Thus, the understanding of their usage relies heavily on humans Mustaffa et al., (2012), and due to the exponential growth of articles and literature existence, it is difficult for the user or the practitioners to find relevant and useful information from this large amount of data (Gayathri & Jagadeesh Kannan, 2018).

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Meanwhile, some knowledge like Thai Traditional Medicine (TTM), which is well documented in textbooks and traditional manuscripts, is often presented in flat knowledge form, where it lacks depth in taxonomies and hierarchy and is not well-organized. The practice and functions in the textbooks are only used as a frame of reference and typically involve practice but frequently do not dictate the theoretical framework (Tungkwampian et al., 2015). The relationships between herbs or herbal formulations with treatments are still unclear in Herbal Medicine. This lack of taxonomies and hierarchy in traditional knowledge makes it difficult for practitioners to find relevant information. One potential solution is the utilization of ontology, a method of representing information in a structured and semi-structured manner (Berners-Lee et al., 2001). Ontologies bridge the gap between application systems and facilitate interoperability by providing a shared understanding of a domain and enabling data integration across systems with similar domains (Bhargava & Mukherjee, 2015).

Various techniques have been suggested for building ontologies, including well-structured approaches and semiautomatic methodologies. These methods aim to balance human expertise with computational efficiency, allowing researchers to create their own unique ontology. Semiautomatic methodologies strike a balance between human expertise and computational efficiency, allowing for more efficient and accurate ontology development (Altea et al., 2020). However, automated ontology construction requires domain experts' input, making it challenging for researchers to have the necessary knowledge in specific domains. Meanwhile, Top-level ontologies facilitate semantic interoperability, harmonizing knowledge between different ontologies. This approach improves knowledge representation quality and promotes standardization in the ontology development process (Shojaee-Mend et al., 2019). Meanwhile, the socio-technical approach integrates social factors and technical aspects at every stage of ontology production (Silalahi et al., 2015). Once the Ontology has been constructed, it is imperative to evaluate both its consistency and quality to ensure the avoidance of excessiveness concepts, terminological ambiguity, and incompatible subclass relationships

Ontology evaluation is the systematic examination and assessment of an ontology's quality, efficacy, and suitability, serving as a structured representation of knowledge within a specific domain (Raad et al., 2018). Competency questions, domain experts, metrics, and automatic reasoners are four prominent methods used in ontology evaluation. Competency questions provide unambiguous criteria for evaluating an ontology's structure, content, and capacity to meet its intended aims (Ren et al., 2014), while the expert review method involves domain experts assessing the ontology to identify inconsistencies, errors, and ambiguities (Baker & Cheung, 2007). Automatic evaluation metrics quantitatively assess distinct attributes of an ontology, such as the number of concepts, properties, instances, and axioms. Meanwhile, automated reasoning evaluation addresses logical reasoning and inference concepts (Lantow, 2016).

The selection of evaluation methods depends on factors such as the ontology's intended purpose, complexity, available resources, and target user community. Integrating multiple methodologies can lead to a more comprehensive understanding of the ontology's benefits, limitations, and overall quality. Besides addressing the topics of ontology construction and ontology evaluation, this article also centers its attention on issues and problems during the process of developing a herbal ontology. Furthermore, this study also explores the topic of drug discoveries, as well as the safety and efficacy of herbal medicine, to elicit experts' perspectives on these matters. In conclusion, these methodologies and approaches are crucial in developing high-quality ontologies that bridge traditional herbal knowledge and modern scientific investigation for effective medicinal solutions. Hence, this paper aims to do a systematic review of the literature from 2011 to 2022 on the current trends in developing and evaluating medicinal herbs ontology and to discuss the most common issues in herbal medicine ontology based on the following question:

1) What are the current trends in developing medicinal herbs ontology?
2) What are the most common issues in herbal medicine ontology?

Nomenclature

A	WHO/ World Health Organization
B	CQ /Competency Question
C	HIV / Human Immunodeficiency Virus
D	AIDS/Acquired immunodeficiency syndrome

2.0 Methodology

Table 1: Search strings from Scopus, Mendeley and Web of Science (Wos)

SCOPUS	("herbal" OR "herbal medicine" OR "herbs" OR "medicinal herbs" OR "herbal plant") AND ("ontology" OR "ontology construction" OR "ontology development" OR "ontology modelling") "herb" AND "ontology" AND "domain"	76 articles
Mendeley	"herb" AND "ontology" AND "domain"	61 articles
WoS	**herbal medicine OR herbs OR medicinal herbs** (All Fields) and **ontology construction OR ontology development OR ontology modelling** (All Fields) and **domain ontology OR ontology OR domain** (All Fields) and **2022** or **2021** or **2020** or **2019** or **2018** or **2017** or **2011** or **2012** or **2013** or **2014** or **2015** or **2016** or **2010** or (Publication Years)	113 articles

This study uses the thematic review method using ATLAS.ti 22, introduced by Zairul (2020), to identify patterns and construct themes in the development of herbal medicine ontology. The term thematic review is implemented because the method of this study applies a

thematic analysis procedure in a literature review. Clarke & Braun (2012) define thematic analysis as a process of identifying the pattern and constructing themes over thorough reading on the subject. The following step identifies the pattern and constructs a category to understand the trend in developing herbal medicine domain ontology. The tenets of the research are to analyze and interpret the findings for the recommendation of future research in the herbal medicine domain subject. The selection of literature was performed according to several selection criteria: 1) Publication from 2011- 2022, 2) Have at least keyword(s) ontology or herbal medicine or herbal plants, 3) Focus on the method of ontology development. Table 1 shows the search results from Scopus, Mendeley, and Web of Science (WoS) databases.

2.1 Materials and Methods

The literature search was conducted using Scopus, WoS, and Mendeley, resulting in 76 articles from Scopus, 113 from WoS, and 61 from Mendeley. However, 220 articles were removed due to premature results, anecdotes, or non-focus on herbal ontology. Some articles were incomplete, broken links, or overlapped. The final paper was reviewed down to 30 articles. The articles were uploaded to ATLAS.ti 22 as primary documents and grouped by author, issue number, periodical, publisher, volume, and year of publication. This allowed for analysis of the articles' year of publication and discussion patterns. Figure 1 demonstrates the procedure of identifying the articles for thematic review.

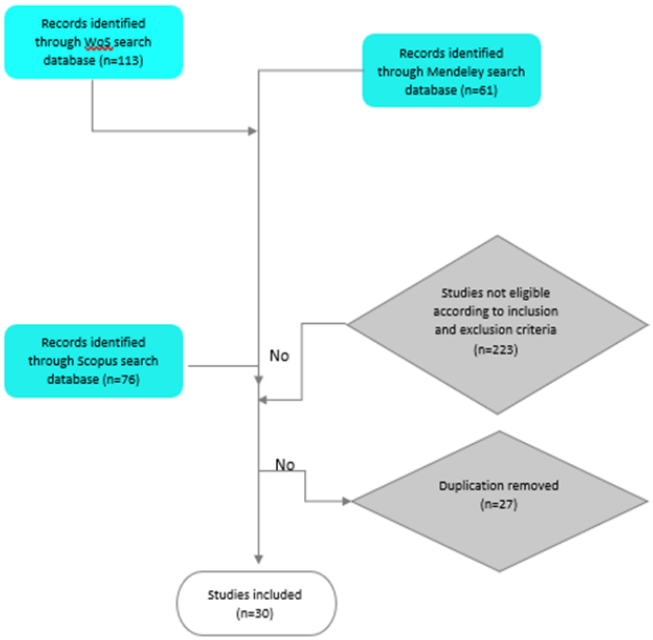

Fig 1. The procedure of identifying the articles for thematic review

3.0 Finding and Discussion

3.1 Quantitative findings

Based on Figure 2, the word cloud from 30 articles revealed that "ontology" was used 940 times, "knowledge" 188 times, and "information" 600 times. Based on the thematic analysis of the selected articles and sequence of frequency, the present discussion is conducted based on the following themes: 1) Development method; 2) Drug Discoveries; 3) Evaluation Method; 4) Issues and problems and 5) Safety and Efficacy.

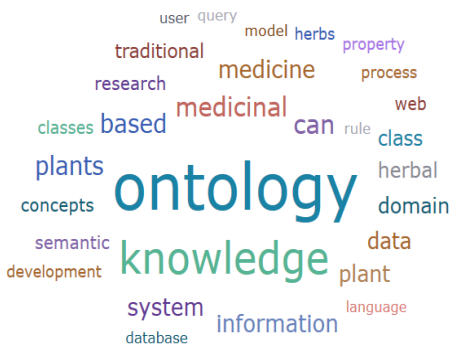

Fig 2: Word cloud generated from 30 articles

Figure 3 displays a Sankey diagram illustrating the countries worldwide that participate in the study of herbal medicines' ontology. The majority of studies are carried out in Malaysia and Indonesia. The study also analysed publications from diverse countries such as Africa, Brazil, Pakistan, Thailand, the United States, Germany, Taiwan, India, China, and the Philippines. Based on the publication trend by year, the majority of research papers were published in 2012, totalling six publications, followed by 2018 with five publications

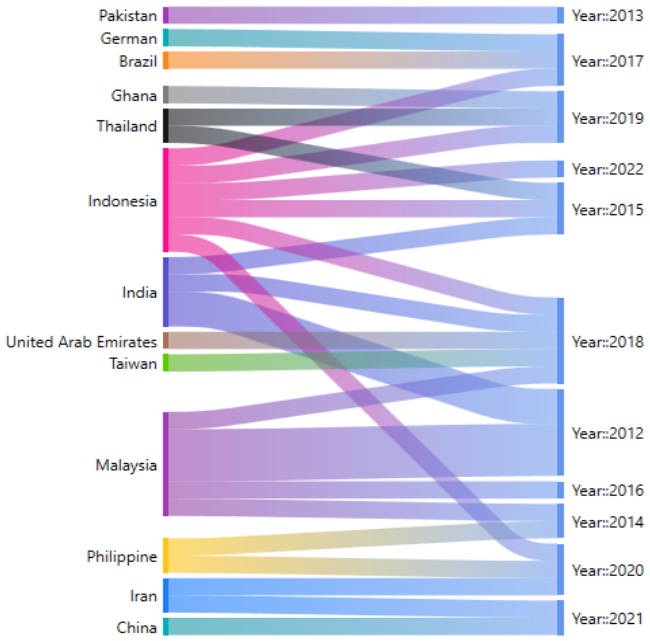

Fig 3 : The distribution of articles according to country and year of publication

3.2 Qualitative findings

This study examines the structure and trajectory of ontology in herbal medicine through a rigorous iterative process of comparing 30 research articles. The initial set of 135 codes was merged into five primary themes: Safety and Efficacy, Issues and Problems, Development Method, Evaluation Method, and Drug Discoveries. The aim was to ensure consistency in the final subcategories. A list of publications and their allocation into the subcategories can be found in Table 2.

Table 2: Thematic review of herbal medicinal ontology from 2011-2022

No	Article	Issues & Problem	Development Method	Evaluation Method	Drug Discoveries	Safety & Efficacy
1	Lim-cheng (2014)		√		√	√
2	Silalahi (2015)	√	√	√		√
3	Promkot (2019)					√
4	Sahri (2012)	√				
5	Bu (2021)		√			
6	Gayathri (2018)	√				
7	Alkhatib (2018)				√	√
8	Yulianti (2018)			√		
9	Chien (2018)	√		√		
10	Devine (2019)	√	√	√		√
11	Tungkwampian (2015)		√			
12	Ibrahim (2018)		√			
13	Oladosu (2012)	√				
14	Raja Mohan (2012)		√	√		
15	Chandra (2019)		√			
16	Jairo Jr (2017)		√			
17	Altea (2020)				√	√

18	Vadivu (2012)	√				
19	Mustaffa (2012)	√	√	√		
20	Naghizadeh (2021)			√	√	
21	Bhargava (2015)					
22	Ayimdji (2011)		√			
23	Surendro (2020)		√		√	
24	Tahar (2017)					√
25	Sulaiman (2014)					
26	Sahri (2016)	√				
27	Waheed (2013)		√			
28	Gunawan (2017)					
29	Afifa (2022)		√			√
30	Supiah M (2012)	√				√

3.3 Theme 1: Issues and problems in herbal ontology

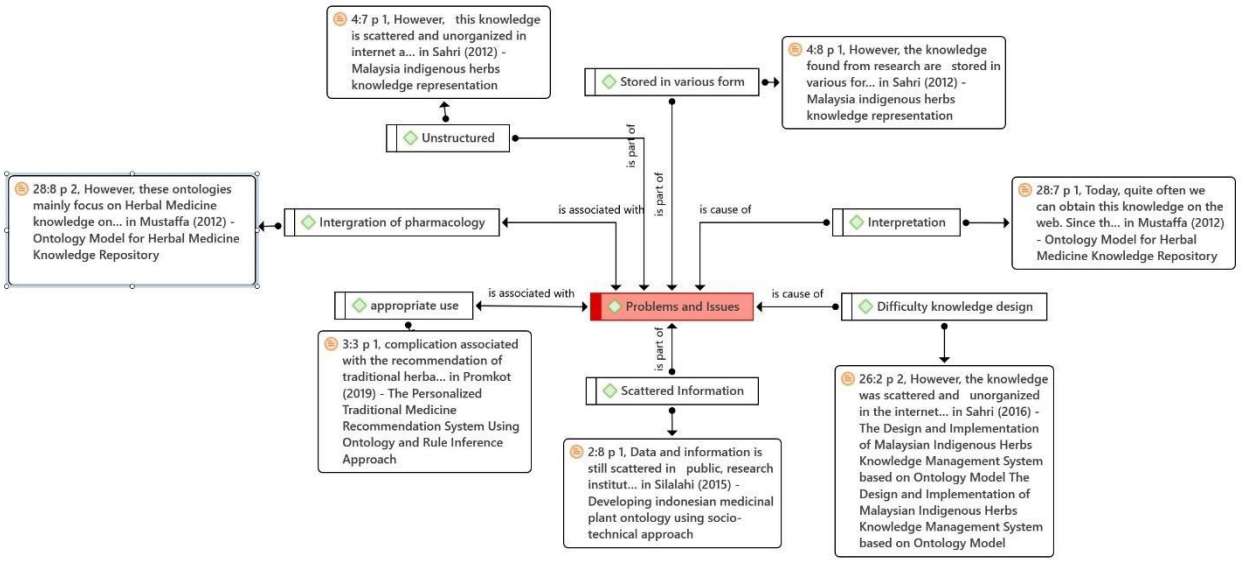

Figure 4: Network view on Issues and problems in herbal ontology

Traditional medicine, as defined by the World Health Organization (WHO), is based on indigenous theories, beliefs, and experiences used for maintaining health and preventing, diagnosing, improving, or treating physical and mental illnesses (WHO, 2013). In some regions, most people rely on traditional medicine for primary health care. However, this knowledge is often lost or not developed over time, leading to practitioners passing away with it (Devine et al., 2019). The value of indigenous plants extends beyond their medicinal properties to include local and traditional knowledge of each plant. The dispersion and organization of this knowledge on the internet and its local ownership make it difficult to design a knowledge-based system. Herbal medicine and products derived from botanicals are currently easily accessible. However, without access to comprehensive knowledge or expert assistance, it remains challenging for the general public to implement them in their daily life (Vadivu & Hopper, 2012).

According to Tungkwampian et al., 2015, medicinal herb data published online lacks semantic value and has multiple structures and formats, making it difficult to understand disease and treatment comprehensively. This results in inefficient search engines and manual processing, making it more challenging for common Internet users to search for medicinal uses of herbal plants (Vadivu & Hopper, 2012).

Establishing herbal database systems incorporating a thorough taxonomy hierarchy and structured knowledge regarding herbs is paramount in facilitating efficient and prompt prescription (Oladosu et al., 2012). Furthermore, understanding medicinal applications heavily relies on human interpretations. A potential strategy for addressing this issue involves creating diverse data sources meticulously annotated through standardized and collectively accepted extensions to existing vocabulary, commonly referred to as ontology. This will help extract the semantic significance of the data and define the precise parameters of herbal medicine knowledge (Silalahi et al., 2015). Figure 4 represents the network view of medicinal ontology issues and problems.

3.4 Theme 2: Framework of ontology development

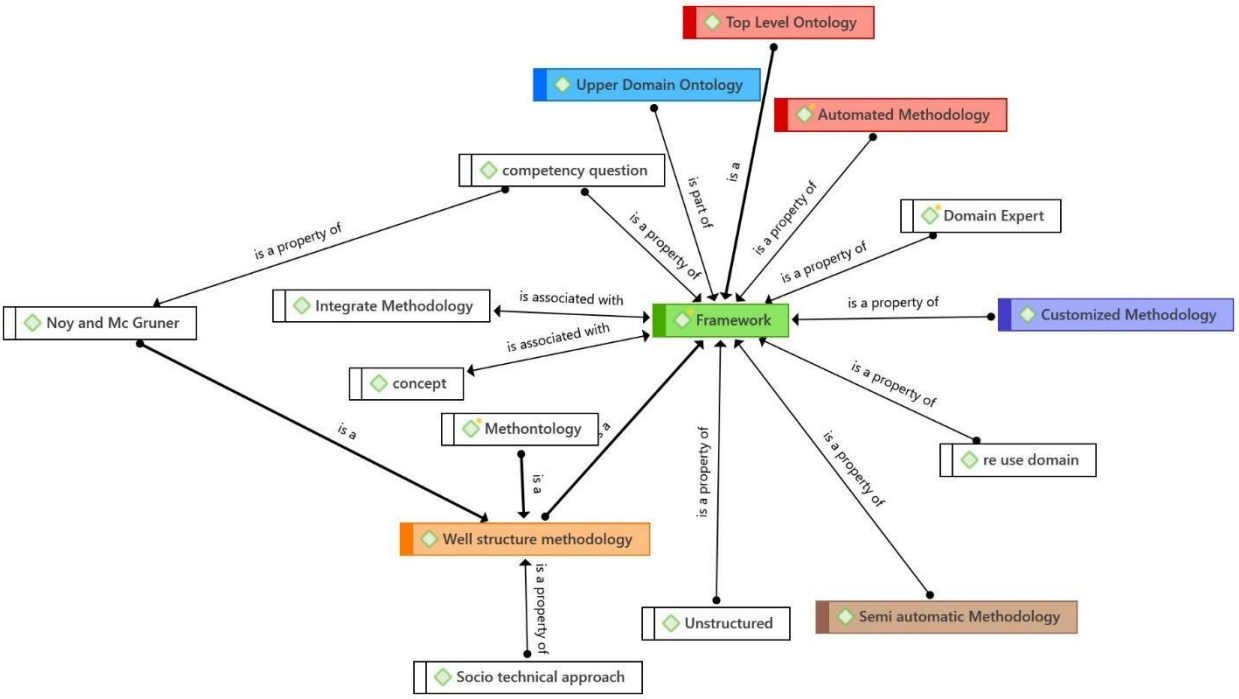

Fig 5. Network view on the framework ontology development

The methodological framework is one of the themes discussed in this article. Under this theme, five different methods were proposed for developing ontology that can be categorized into well-structured methodology, customized methodology, socio-technical approach technology, Domain Expert, automatic ontology, and top-level ontology (Shojaee-Mend et al., 2019). Ontology engineering methodology provides guidance to build, manage, and maintain the ontology. The methodology approach will aid in outlining the various stages of the ontology engineering process and recommending actions and tasks to be carried out for each phase (Silalahi et al., 2015).

3.4.1 Well-structured Methodology

The Methontology framework, established by Fernández et al. in 1997, provides accurate descriptions of activities in ontology development. This systematic methodology consists of activities, techniques, and deliverables. It addresses the complexities and challenges of ontology development by providing a well-defined process. Raja Mohan & Arumugam (2012) found that ontology construction is an iterative and dynamic process that requires analytical and abstract thinking. Noy and McGuiness's method offers a structured framework for ontology development, encouraging collaboration, resource reuse, and decision documentation(Noy & McGuinness, 2001). It is particularly beneficial for beginners as it provides a clear roadmap and structure for ontology development (Waheed et al., 2013).

3.4.2 Customized Methodology

The study reveals eleven studies used distinct ontology development methods, starting with a well-structured methodology but being customized based on the specific project or domain's needs and goals. Ayimdji et al. (2011) developed a specialized ontology construction methodology involving comprehensive definitions of concepts and relationships. Tungkwampian et al. (2015) proposed a six-step strategy involving identifying domain ideas, establishing a class hierarchy, and defining data and object attributes. A database was generated, and the Ontology Application Management (OAM) software was used to map the ontology to the database architecture, facilitating the creation of a knowledge base in the Resource Description Framework (RDF) format. Gunawan & Mustofa (2017) used SWRL rules to enhance information accessibility, involving planning, requirements analysis, ontology design, and evaluation. The domain rules were established using SWRL, and a webpage was created to facilitate access to the ontology.

3.4.3 Social Technical Approach

A different way of developing ontologies is the socio-technical approach. According to Silalahi et al., (2015), the primary objective of this methodology is to integrate social factors with technical features at every level of ontology building, from early design to implementation and evaluation. This technique frequently creates a feedback loop that captures user requirements and assures universal acceptance of the resulting ontologies while developing complex technical systems. This research addresses the existing gap by formulating a strategy that effectively addresses both the technical and social aspects of ontology engineering.

3.4.4 Domain Expert.

The "Domain Expert" technique in ontology development involves collaborating with experts to ensure the ontology accurately represents the domain's semantics and meets stakeholder needs (Sulaiman et al., 2014). This comprehensive technique simplifies knowledge engineering by assembling domain-specific information in relational propositions. Consensus is crucial, and a cross-literature review with a subject matter expert is suggested to achieve mutual comprehension and consensus (Devine et al., 2019).

3.4.5 Top Level Methodology

Creating a high-level framework that may guide various ontology projects is part of designing a Top-Level approach for ontology development. Top-level ontology describes very basic concepts that are independent of a particular domain (Raja Mohan & Arumugam, 2012). This framework offers an organized approach to ontology development, encompassing the major phases and considerations independent of domain or application. A top-level ontology enables semantic interoperability, allowing knowledge to be harmonized across ontologies (Tahar et al., 2017).

3.4.6 Semiautomatic and Automatic Methodology.

Semiautomatic ontology development is a method that combines automated tools and human intervention to create formal knowledge representations within a specific domain. This approach minimizes the need for domain expertise and ensures efficient data integration. Ontology development is an iterative process that involves input from domain experts, oncologists, and potential users (Lim-cheng et al., 2014). The resulting ontology serves as a valuable resource for knowledge representation, data integration, search, reasoning, and decision-making within the specified domain (Ibrahim et al., 2018).

3.5 Theme 3: Evaluation Method

The evaluation of ontology is an essential procedure that aims to analyze an ontology's quality, efficacy, and suitability. The process encompasses a range of methodologies and standards to guarantee that the ontology effectively captures and reflects domain-specific knowledge while fulfilling its intended objectives (Naghizadeh et al., 2021). Ontologies frequently exhibit intricate structures, and assessments are typically carried out to ensure accuracy, consistency, completeness, conciseness, clarity, and computing efficiency are evaluated independently. Additional areas encompass the evaluation of class appropriateness, subclass delineation, and property identification, as well as the assessment of ontology correctness and reusability. The validation process is of utmost importance in guaranteeing the precision and excellence of the constructed ontology (Raad et al., 2018).

The usefulness and comprehensiveness of an ontology were evaluated by Silalahi et al. (2015), Supiah et al. (2012) and Wardani et al.(2014) through the utilization of Competency Questions (CQs). The CQ assessment methodology evaluates the degree to which the ontology adequately addresses the information needs of its users. The automated detection of inconsistency issues in ontologies is of utmost importance in ensuring the integrity and reliability of these knowledge representation systems. Automated reasoning engines employ algorithms and logical principles to derive inferences from the axioms and norms of the ontology.

The utilization of metric assessment presents a valuable methodology for evaluating the caliber of a built ontology. Surendro et al. (2020) employ a complete methodology that integrates assessment and metrics to examine and differentiate areas needing improvement, identify problematic elements, and enable comparisons. According to Yulianti & Surendro (2018), an approach to improve the quality of herbal knowledge ontology involves the division of the ontology into many modules. This division facilitates the accurate measurement and evaluation of the distance between modules, ensures the independence of each module, and identifies and eliminates redundant duplicate axioms. The process of evaluating ontology is characterized by iteration, wherein feedback is utilized to enhance and modify its quality. As the ontology undergoes development and is implemented in practical contexts, continuous assessment is conducted to assure its sustained efficacy.

The evaluation of ontologies poses significant challenges due to their subjective nature, absence of a definitive reference, wide range of applications, intricate structure, and dynamic characteristics. The presence of subjectivity poses challenges in reaching objective assessments, while the absence of a definitive "ground truth" complicates the process of making comparisons. The utilization of ontologies spans across diverse applications, resulting in considerable variations in evaluation criteria. The presence of a multitude of classes, attributes, and relationships contributes to the intricacy of evaluating the comprehensiveness, accuracy, and coherence of these structures. The evolution of knowledge domains over time is a significant challenge in the process of evaluation(Raad et al., 2018).

3.6 Theme 4: Safety and efficacy

Pharmacology knowledge is important as an evaluation may be carried out to prove scientifically the traditional experience on the safety and efficacy of herbal medicines. It may also be conducted to validate a new-found plant material, a new combination of herbal medicines, a new indication, a new dosage form or a new administrative route for an existing herbal medicine. Plants contain a variety of components, some of which are exceedingly hazardous. However, compared to synthetic medications, the adverse responses associated with most herbal therapies are less common if these remedies are used carefully (Promkot et al., 2019). Understanding medical plants goes beyond their benefits, demanding a thorough pharmacological investigation that includes potential side effects, contradictions, and the ingredients of medicinal plant chemicals. Since a medicinal plant might have various pharmacological effects, analyzing its chemical makeup is critical for determining its biological activity. To use medicinal plants with greater caution, a greater wealth of information on potential side effects and contradictions is required (Afifa et al., 2022).

Among the popular subjects covered by researchers while building the ontology of herbal medicine was the safety and efficacy of herbal medication. This theme was chosen to summarize the writer's interest in the field. Three researchers, Lim-cheng et al.(2014), Supiah et al.(2012) and Devine et al.(2019), employ an approach based on the relationship process between symptoms and diseases to construct an ontology of herbal medicine. Chandra & Natalia (2019), Gunawan & Mustofa (2017) and Afifa et al. (2022) have directed their attention towards the examination of toxicity and adverse effects. Meanwhile, Jairo Cambraia Junior (2017) and Silalahi et al.(2015) proposed that modern medical knowledge frameworks must be aligned with traditional knowledge structures.

According to Chandra & Natalia (2019), the global herbal medicine market is relatively significant, but only 15% of plants have undergone phytochemical study, and only 6% have passed biological testing. Furthermore, some consumers regularly dispute the efficiency of these treatments due to a lack of sufficient documentation on the selection of ingredients, methods of drug manufacturing and administration (Devine et al.,2019). Silalahi et al.(2015) proposed that the best way to ensure the safety and efficacy of herbal

medicine is to incorporate it into the existing healthcare system, which can improve the follow-up procedure. This integration can accomplish semantic interoperability by matching medical knowledge structures with traditional medicine knowledge structures.

Additionally, previous efforts failed to establish a link with various herbal medicine ontologies that accurately delineated the constituents of herbal remedies. The active ingredient is commonly found in herbal medicines. As a result, the potential adverse reactions to the remedy might be predicted by evaluating the constituent plants utilized in creating an herbal cure. Therefore, Alkhatib & Briman (2018) propose integrating treatment data into traditional and contemporary medical science disease ontologies. This linkage is crucial to ensure the relevance of traditional medical therapies.

Mustaffa et al. (2012) identified four key knowledge categories for developing herbal domain ontology: herb knowledge, traditional medicine, the process of generating herbal medicine, and pharmacology knowledge. Meanwhile, Lim-cheng et al. (2014) suggested that all ontologies should focus on the therapeutic characteristics of the plant, types of illnesses, body parts affected, preparation instructions, and plant parts used. In addition, Altea et al. (2020) highlighted the need for more information on drug dosage compatibility with meridians and clinical use scenarios. Supiah et al. (2012) emphasized ingredient registration with food and drug authorities to address safety issues and formula efficacy.

3.7 Theme 5: Drug Discoveries

The topic of drug discoveries was selected to demonstrate the author's interest in the subject area. Only four articles discuss the significance of developing information on medicinal plants for drug discovery. The process of identifying chemical entities with the potential to become therapeutic agents is known as drug discovery. Plants have therapeutic properties and have been used to treat pathological conditions. However, modern medicine requires the isolation and purification of active compounds to address global health challenges like cancer, degenerative diseases, HIV/AIDS, and diabetes. Drug discovery is a multidimensional problem requiring safety, pharmacokinetics, and efficacy evaluations. One of the primary goals of drug discovery initiatives is to identify new and innovative chemical compounds that have the potential to effectively address medical conditions without adequate therapeutic options (Thomford et al., 2018).

Although herbs and various herb-related products, such as nutritional supplements, are now readily available, the dearth of readily accessible comprehensive knowledge and expert guidance makes it difficult for the general public to effectively incorporate them into their daily lives (Lim-cheng et al., 2014), (Altea et al., 2020). Ongoing research and exploration into the benefits of Traditional Medical Knowledge enable the potential use of information within traditional medical knowledge concerning practices and benefits in studies supporting modern healing methods (Surendro et al., 2020).

Alkhatib & Briman (2018) emphasize the significance of developing comprehensive knowledge and ontologies of medicinal plants to facilitate the creation of novel drugs and therapies. Traditional medicine knowledge, such as herbal medicine, has the potential to inform modern therapeutic methods and reduce the time and cost of drug discovery. Ontology-based approaches can facilitate the organization and standardization of traditional medicine knowledge, thereby increasing its accessibility to researchers and the general public. The molecular properties of herbal compounds and their associations with traditional medical systems have been studied using machine-learning techniques, yielding greater insight into their potential therapeutic properties. Overall, the development and application of exhaustive knowledge and ontologies of medicinal plants have the potential to significantly advance drug discovery (Naghizadeh et al., 2021).

5.0 Conclusion & Recommendations

The article explores the development of ontologies for medicinal herbs in the traditional medicine industry, focusing on issues, methodological development, evaluation methods, safety and efficacy, and drug discovery. Ontologies are crucial for providing a formal semantic structure for traditional medicine knowledge, facilitating common understanding among stakeholders and technologies. The study identified various ontology development methods, including conventional, customized, top-level, semiautomatic, and large-scale approaches. Few studies have included evaluation methods in the process of constructing ontologies. The review highlights a need for pharmaceutical innovations and safety assessment in herbal medicine. A novel ontological framework is needed to address these concerns and enhance the current ontology by incorporating additional safety and effectiveness data. This would promote the secure utilization of herbal items and facilitate the progression of medical research. However, this study is restricted in scope as it just focuses on research related to herbal medicine. Future research should also integrate ethnobotanical studies and alternative medicine to obtain more precise data on the development of herbal medicine ontology.

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