BEECARE: A WEB-BASED EXPERT SYSTEM FOR DIAGNOSING HONEY BEE DISEASES

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Abstract
This study emphasizes the application of a web-based expert system in diagnosing honey bee diseases, utilizing the R shiny package. The main objective was to provide accessible and continuous web-based support for beekeepers and agricultural specialists at all times. The proposed expert system diagnoses honey bee diseases based on the user's selection of the observed symptoms. The knowledge base of the BEECARE application contains comprehensive information about the symptoms of nine major diseases affecting honey bees. During the diagnostic process, both images and detailed information related to diseases are displayed to assist the user in confirming the diagnosis. The BEECARE application is accessible to beekeepers in two languages (English and Arabic) and demonstrates precision and reliability in its diagnostic outcomes, achieving 84.4% accuracy in expert validation tests and improving beekeeper diagnostic accuracy by 30% (from 52% to 82%), with a high user satisfaction score of 4.2/5 for ease-of-use. It serves as a practical tool for identifying and managing diseases.

Keywords
Expert system, Bee, Disease, Brood, Worker

Introduction

The concept of "Artificial Intelligence" was first introduced by John McCarthy at the Dartmouth Conference in 1955. He predicted this based on the hypothesis that "it is feasible to construct a machine capable of simulating any facet of learning or any attribute of intelligence that can be accurately described" (Strickland, 2021). Recently, the application of artificial intelligence (AI), a core discipline within computer science, has permeated various sectors, including education, healthcare, banking, industry, and agriculture. This widespread adoption is attributable to its capacity to address challenges that may pose difficulties for humans or necessitate extended processing times (Banerjee et al., 2018). Early notable triumphs in artificial intelligence include IBM Deep Blue's historic win over world chess champion Garry Kasparov in 1997 and AlphaGo's victory over world Go champion Lee Sedol in 2016. These accomplishments underscore the potential of artificial intelligence, particularly deep learning, to exceed human cognitive capability (Chang et al., 2016).
Agriculture is a critical sector for any nation in the present day, and it continues to pose significant challenges. Several factors contribute to this, including the alarming statistic that over 820 million individuals globally are currently grappling with hunger, as reported by the Food and Agriculture Organization of the United Nations. Moreover, projections indicate that the global population will increase to 9.1 billion by 2050, necessitating a 70% increase in food production relative to current levels to meet the increased demand. Additionally, the expanding chasm between the escalating demand for water and the finite resources available suggests that over three billion individuals could be subjected to water stress by 2025. Beyond the conventional and preventive strategies implemented by governments in the agricultural sector, the advent of artificial intelligence in agriculture was first witnessed in 1985. McKinion and Lemmon developed a model, termed GOSSYM, which employed an expert system—a subset of artificial intelligence—to simulate cotton production. The objective of this system is to augment cotton production by considering various factors, such as irrigation, fertilization, weed control, and climatic conditions (Beegum et al., 2023).
An expert system is a concept with several definitions, all of which center around the utilization of human expertise to resolve a specific problem and make this expertise accessible to a broad audience via a computer program with a defined user interface. Pandya (1999) characterized it as "a computer program designed to emulate the problem-solving capability of a human expert." It is also recognized as "a computer system that employs human expertise to resolve problems that typically necessitate human experience." The expert system is based on knowledge and conducts inference procedures to address complex problems that require substantial human expertise. It employs human knowledge and experience as data and rules, which are applied as needed to resolve problems. Studies and reviews from the literature serve as a fundamental source of knowledge, and the program designer is tasked with meticulously reading and interpreting them, subsequently transforming them into logical rules that can be harnessed for problem-solving. The objective of an expert system is to provide an avenue for as many individuals as possible to benefit from prior expertise in resolving a specific problem (Mercy et al., 2011).
The architecture of an expert system is predicated on three essential components: User Interface (UI): The UI encompasses tools, options, and queries that aid the user in initially delineating their problem. Subsequently, it provides a description of the problem, encapsulating the results or solutions. Knowledge Base: This component comprises information and procedural steps derived from experts in the extant literature. It serves as the foundation for the decision-making process

of the system. Inference Engine or Server: This element processes user inputs based on the rules of knowledge to yield final outputs, that is, descriptions of the problem and its resolution (Mercy et al., 2011).

Honey bees (*Apis mellifera* L.) are confronted with a diverse array of pests, including diseases, insects, mites, birds, and mammals. The BEECARE application primarily focuses on the diseases and pests that affect both brood and worker bees. Generally, nations, and specifically beekeepers, endeavor to curtail losses instigated by pests to augment honey production and enhance its quality. This effort also extends to other bee-derived products, such as beeswax, pollen, and propolis. An imprecise diagnosis of pests not only inflicts damage on the affected colonies but can also propagate to neighboring colonies, thereby escalating the associated treatment costs. Over the past several decades, there has been a surge in interest in beekeeping and its associated products in Syria (Barhoum et al., 2017). According to statistical data, the number of honey bee colonies increased from 54,431 in 1961 to 631,526 in 2011. However, this number declined to 535,538 in 2022, marking a 15.2% decrease. This decline was concomitant with a 14.16% reduction in honey production.

General strategies are effective in managing and mitigating various honey bee pests. These strategies include replacing weak queen bees with smaller, well-bred counterparts, providing balanced nutrition to bees during periods of food scarcity, and regularly sanitizing and disinfecting beekeeping equipment. Nevertheless, accurate pest diagnosis is of paramount importance. This serves as a foundational step that enables beekeepers to implement appropriate strategies, thereby circumventing ineffective or misguided approaches. The agricultural sector in Syria has been significantly impacted by the prevailing economic and health conditions, including the repercussions of the COVID-19 pandemic. This impact is manifested through escalating transportation costs, labor expenditures, and rising prices of agricultural medicines and supplies. In particular, beekeepers have been substantially affected. As technological advancements accelerate and the dissemination of information improves, expert systems have emerged as effective tools for guiding farmers and beekeepers. These systems assist in resolving various challenges and keeping abreast of developments in their respective fields (Abu, 2020). In light of these circumstances, the proposition of developing an expert system for diagnosing certain honey bee diseases and pests has emerged as an optimal strategy to assist beekeepers in accurately identifying and managing these issues.

The expert system application is envisaged to function as a potent and efficacious instrument to aid beekeepers, particularly when immediate assistance is not easily accessible.

Materials and Methods

Framework of BEECARE application

This study delineates the development of an expert system deployed on a web-based platform aimed at diagnosing a range of pests and diseases afflicting honey bees. The system was constructed using R language (version 4.4.0) and is underpinned by the Shiny package for its programming needs.

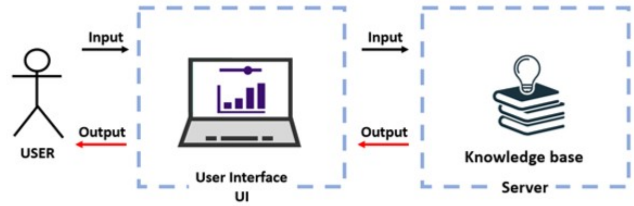


Figure 1. General structure of the rule-based expert system using Shiny

The Shiny package provides a robust environment for creating intricate web applications, circumventing the need for proficiency in other programming languages such as HTML, CSS, or JavaScript. Furthermore, Shiny offers an extensive array of user interface components that can be readily customized and employed with a considerable degree of flexibility. Its interactive server facilitates the formulation of any variety of logical rules and processes that the application seeks to implement.

Elements of Honey Bee Diseases Diagnosis

In this paper, the primary focus is directed towards diseases affecting the brood: American foulbrood (AFB), European foulbrood (EFB), Chalkbrood, Stonebrood, and Sacbrood virus, and affecting the worker bees: Nosema, Bee paralysis (Viral diseases), *Varroa destructor*, and Tracheal mite.

Information and data pertinent to the symptoms used in diagnosing honey bee diseases were gleaned from various references and scholarly literature (Owen et al., 2023; Ritter and Akratanakul, 2011). A systematic review of these references was conducted to extract all relevant symptoms for each disease, ensuring comprehensive coverage of both common and rare diagnostic indicators of the disease. This information was subsequently represented as if-else rules. Figure 1 provides a visual representation of the structure of the rule-based expert system utilized in the BEECARE application, developed using the Shiny package.

Design and setup of the expert system

Typically, an expert system is adept at managing a specific, well-defined domain. The quality of an expert system is intrinsically tied to the comprehensiveness and accuracy of its knowledge base.

To establish an effective expert system, it is imperative to begin with a clear definition of the problem. In the context of the BEECARE application, the problem is diagnostic in nature, with the objective of identifying the disease afflicting either the brood or worker bees. This identification is based on a specific set of symptoms observed by beekeepers in the event of infection. Any inaccuracies in problem identification can lead to substantial financial implications for beekeepers, particularly for those who are novices in the field. Consequently, the collection and interpretation of data pertinent to the problem of disease identification are of paramount impor-

Table 1. Questions and symptoms for brood and worker bees

No.	Questions	Symptoms
For brood:		
1	Brood shape?	– Empty-spotted brood – Recessed-spotted brood – Spotted – Dead larvae between closed brood
2	Brood color?	– Black – Greenish grey/yellow – Dark brown – Light brown – Bluish grey – Versicolor – Brittle (white powder)
3	The shape of the infected larva when removed?	– Rope – Do not rope – Pointed head is easy to remove – Cannot be removed – Liquid glue
4	The smell of the infected larva?	– Foul (yeast) – No smell
For worker:		
1	Symptoms appearing on abdomen?	– Swelling – Involuntary movement
2	Symptoms appearing on wings?	– Apart- Floppy- K shape – Irregular shape
3	Symptoms appearing on brood or pupa?	– Red spots – Distorted – irregular – Dead in- and out- side the cell – Feces inside the cell
4	Symptoms appearing on adult insect?	– Climb the legs of the hive – Crawl in front of the hive – Weak – Inability to fly – Dwarfism - Deformed - Inability to fly – Nervousness – Shiny black greasy color – Isolated above the frame

tance in resolving the diagnostic problem.

In general, the resolution of a diagnostic problem can be viewed as the process of constructing a hypothesis (the disease) that adequately accounts for a given set of observations (the symptoms) (Donner-Banzhoff, 2018). Within the framework of the BEECARE application, causal knowledge was harnessed by identifying the symptoms that precipitate a specific disease. This was achieved by formulating standard logical rules that emulate the process of human diagnosis.

Following the definition of the problem, the preparation of the knowledge base is necessary. The knowledge base serves as the cornerstone of any expert system, and its development requires expert input. The objective of the knowledge base is to amass the requisite skills to tackle the problem at hand, aspiring to reach a level of expertise comparable to that of humans (Beheshti, 2022). The knowledge base is critical to the success of any expert system (Janjanam et al., 2021). In the context of the BEECARE application, a knowledge base was developed using a compendium of books and reviews specific to honey bee diseases.

A multi-step process was followed to construct the knowledge base. First, an exhaustive list of symptoms for each of the nine targeted diseases was compiled from the literature. Symptoms were categorized based on the affected stage (brood or worker bees). Second, each symptom was encoded as a distinct variable, and the relationships between symptoms and diseases were mapped using a decision matrix. This matrix served as the foundation for translating expert knowledge into formal logical rules (Figures 5 and 6). Third, the rules were formulated using an "if-else" structure, where each rule combined symptom observations to infer a specific disease. For instance, the simultaneous presence of brood "Empty, spotted brood," "Black," "Rope," and "Liquid glue" triggers the rule for American Foulbrood (AFB).

Upon completion of the knowledge base, the processing phase commences on the server side. Various methodologies have been employed for processing, including rule-based systems, logical expressions, and semantic networks. In the context of the BEECARE application, a combination of rule-based systems and logical expressions has been utilized, leading to accurate disease diagnosis. Figure 2 shows a schematic representation of the system architecture of the BEECARE application.

User interface (UI) and input processing (Server)

An intuitive, interactive user interface has been engineered, enabling users to engage with the system seamlessly, irrespective of their pre-existing knowledge of the disease. This

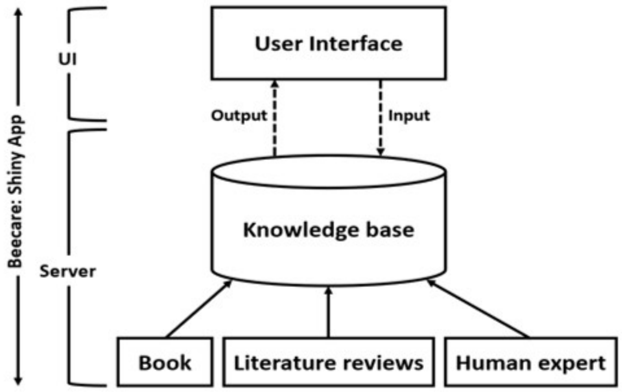


Figure 2. System architecture of the BEECARE application

Figure 3. The overall user interface of the BEECARE application

design approach enhances the accessibility and usability of the system, thereby promoting a user-friendly experience. The user interface dynamically adapts based on the queries used to diagnose the disease, contingent upon the selected location of symptom observation (either brood or workers). The shiny::radioButtons function is employed to select the location for symptom observation. For querying symptoms, the shiny::selectInput function is utilized. Following a comprehensive review of the relevant literature, four pertinent questions associated with brood and worker symptoms were identified (Table 1). The questions and corresponding symptom options were designed to be mutually exclusive and collectively exhaustive, covering all possible variations described in the literature. This ensures that users can accurately describe their observations without any ambiguity. The overall user interface of the BEECARE application is shown in Figure 3.

Evaluation of the BEECARE Expert System

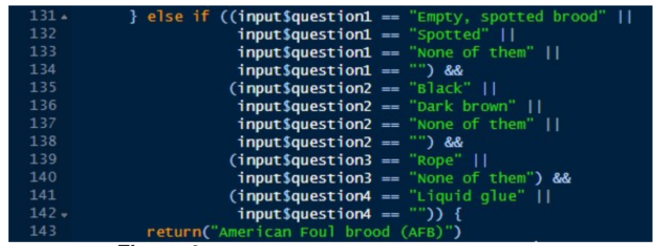
The BEECARE system was evaluated through a two-stage process. First, diagnostic accuracy was assessed by three beekeeping experts who used the system to diagnose 45 cases (15 each). Their results were compared to the experts' own diagnoses. Second, usability and diagnostic impact were tested with 10 local beekeepers. They diagnosed three infected specimens independently and then using BEECARE; both sets of diagnoses were compared to an expert consensus. Finally, user satisfaction with the interface was measured via a 5-point Likert scale questionnaire, where responses were scored as follows: 1 = Very Dissatisfied, 2 = Dissatisfied, 3 = Neutral, 4 = Satisfied, and 5 = Very Satisfied.

Results and Discussion

Results

Expert System Mechanism

The expert system is designed to process inputs by leveraging a knowledge base. This system operates on a set of "if-else" rules, utilizing a backward chaining technique. This technique is initiated from the established rules and progresses systematically to achieve the desired goal. This method ensures a logical and efficient approach to problem solving within the system. An instance of the disease is American Foulbrood (AFB) (Figure 4). Figures 5 and 6 present a flowchart delineating the symptoms associated with each disease, which have been systematically translated into a series of if-else rules for efficient diagnosis.



```
    } else if ((input$question1 == "Empty, spotted brood" ||
               input$question1 == "Spotted" ||
               input$question1 == "None of them" ||
               input$question1 == "") &&
              (input$question2 == "Black" ||
               input$question2 == "Dark brown" ||
               input$question2 == "None of them" ||
               input$question2 == "") &&
              (input$question3 == "Rope" ||
               input$question3 == "None of them") &&
              (input$question4 == "Liquid glue" ||
               input$question4 == "")) {
      return("American Foul brood (AFB)")
```

Figure 4. if-else rule for AFB. &&: AND, ||: OR

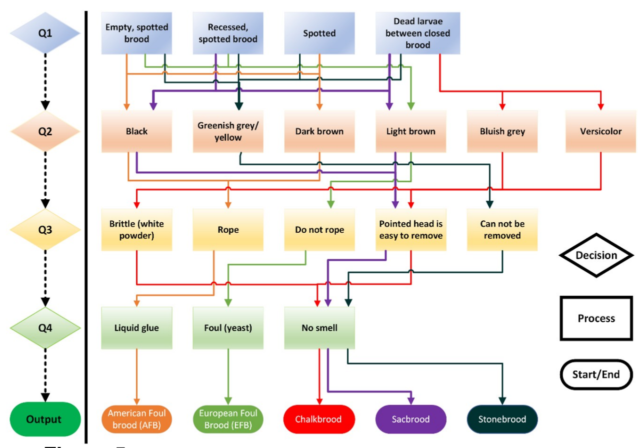


Figure 5. Flowchart of symptoms associated with brood disease

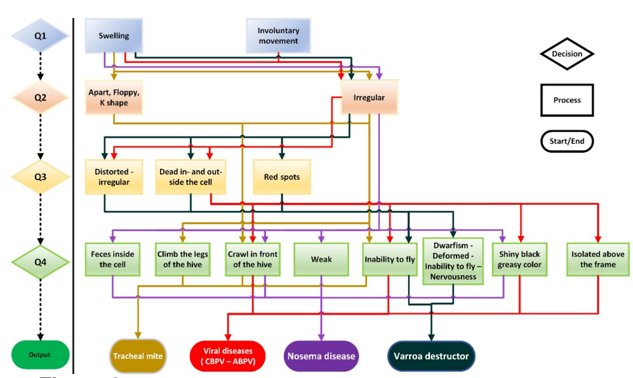


Figure 6. Flowchart of symptoms associated with worker disease

Displaying Diagnostic Results

Upon accurate diagnosis, the user is presented with pertinent information and representative images of the disease. Additionally, the system provides references to useful websites that offer guidance on treatment strategies and preventive measures.

Figure 7 presents characteristic information and visuals associated with the American Foulbrood (AFB) disease. Figure 8 displays all the selected knowledge bases that facilitate the precise diagnosis of AFB. The BEECARE expert system is openly accessible via two web-based interfaces to accommodate users in both English and Arabic. The English version of the application can be accessed at the following link: `https://expsysbee.shinyapps.io/bees/`. For Arabic users, the application is available at: `https://expsysbee.shinyapps.io/beesar/`.

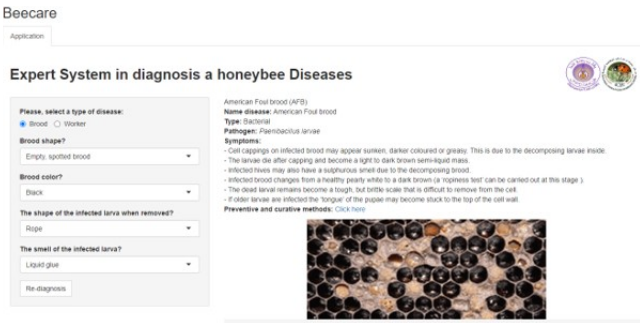


Figure 7. Screen shot showing characteristic information and visuals for AFB disease by user interface

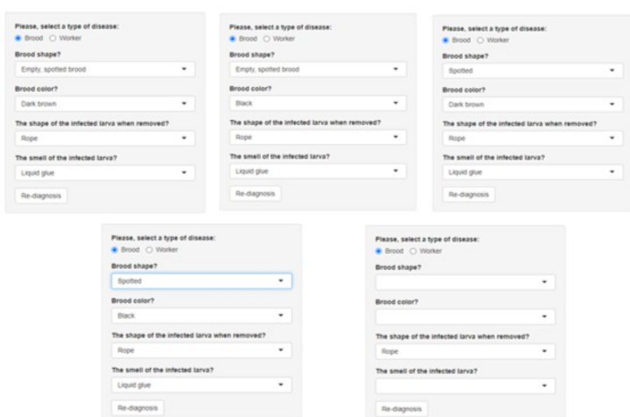


Figure 8. Screenshot showing characteristic information and visuals for AFB disease by user interface

Evaluation of the BEECARE Expert System

A two-stage validation process was conducted to evaluate the reliability and usability of the BEECARE expert system.

In the first stage, the system was tested by three beekeeping experts, each of whom selected the observed symptoms 15 times. These were then entered into the BEECARE application according to the symptom options defined in the user interface of the application. The system's diagnostic results were compared with those of experts, achieving an overall accuracy of 84.4% (38 out of 45 cases) and correctly identifying most cases across all disease categories. Additionally, the experts suggested several improvements, such as incorporating machine learning to enhance the system's ability to predict multiple diseases with varying probabilities.

In the second stage, usability and reliability tests were conducted with 10 local beekeepers who had no prior experience with expert systems. Three infected specimens were presented as images, and the beekeepers were asked to diagnose them first without assistance and then using the BEECARE application. Their diagnoses were then compared with the expert consensus. The results showed that 82% of diagnoses made with the BEECARE system matched the experts' diagnoses, compared to only 52% without it, representing a 30% increase in diagnostic accuracy.

Furthermore, the beekeepers expressed complete satisfaction with the user interface and clarity of the information displayed, with an average ease-of-use score of 4.2 out of 5 on the Likert scale.

Discussion

Expert systems hinge on reasoning about problems by processing knowledge rules using an "if-else" model. Harrison (1991) observed that expert systems are domain-specific and not equipped to tackle problems with multiple causative factors.

Within the realm of agriculture, expert systems can be employed to facilitate a series of decisions pertaining to the selection, interpretation, prediction, and diagnosis of specific agricultural issues (Singh and Hussain, 2018). Expert systems have found applications across a diverse range of areas, encompassing pest management, disease management, field management, crop management, production management, weed management (Eli-Chukwu, 2019), and the diagnosis of diseases in animals (Gu et al., 2012), including those affecting honey bees (McClure et al., 1993).

The task of evaluating the performance and validating the accuracy of expert systems is complex, particularly given that the evaluation process entails a comparison of the system's outputs with those of a human expert, a process that can occasionally be imprecise (Harrison, 1991). Therefore, the evaluation of expert systems is a continuous process. Numerous studies have formulated criteria for this evaluation, which are applicable to both general expert systems and those tailored specifically for the agricultural sector (Crassweller et al., 1993; O'Keefe and O'Leary, 1993).

Conclusions

This study introduces the application of web-based expert systems for diagnosing certain honey bee diseases. The rapid advancement of Internet technology has made these systems accessible to a broad spectrum of beekeepers and farmers, thereby simplifying access to expert systems via the Internet. However, the utility of such expert systems remains some-

what constrained for beekeepers owing to several dominant factors. These include the prevalence of illiteracy, a lack of proficiency in utilizing the Internet and applications, the requirement for an expert system to support multiple languages, and the need for continuous updates to incorporate new diseases and contemporary prevention methods. Other factors include the availability and location of pastures and optimal feeding times based on the beekeeper's region.
In essence, the primary objective of an expert system is to disseminate specialized knowledge to non-experts. The incorporation of Internet technology has significantly amplified the advantages of these systems. Nevertheless, the evolution of web-based expert systems introduces new challenges, underscoring the need for further research and the availability of ample data and information.

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