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# Adoption of Recommended Expert Systems in Agriculture

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**Abstract** – The contemporary agricultural sector heavily depends on expert systems for the identification and eradication of pests. The involvement of human professionals is necessary for the identification and management of these pest-related problems. Obtaining human experts is a challenging task due to their susceptibility to bias in their actions, whether it is deliberate or unintentional. Additionally, human experts tend to exhibit slower processing and retention of extensive data. Furthermore, they possess the ability to avoid accountability for decision-making when they deem it necessary. In contrast to human experts, the computer-based expert system offers the advantage of being accessible at any time and location. An expert system facilitates the integration of human and computer capabilities to effectively tackle a diverse array of problems. Expert systems enhance the probability, frequency, and uniformity of sound decision-making processes. They facilitate immediate, cost-effective expert-level decision-making by individuals lacking expertise in the field. Additionally, they optimize the utilization of all accessible data and allow human experts to allocate their attention towards more advanced and innovative endeavors. Given these factors, expert systems have been developed for various crops such as rice, wheat, tomato, rapeseed, mustard, mango, and others. These systems aim to assist farmers in identifying pests and implementing suitable strategies for pest management.

**Keywords –** Knowledge-Based Systems, Expert Systems, Expert System for Text Animation, Radio Frequency Telemetry, Expert System Language Representation.

## I. INTRODUCTION

Due to the escalating intricacy of the agricultural production system, the acquisition and integration of data from diverse sources have become imperative. In order to enhance decision-making processes and maintain competitiveness, modern farmers frequently seek guidance from agricultural professionals and advisors. Regrettably, the farmer may encounter situations where timely assistance from the agricultural specialist is not readily available. Expert systems have demonstrated their efficacy and potential as a valuable tool in the field of agriculture for addressing this particular issue. Knowledge-based systems (KBS) and Expert Systems (ES) are computational applications that aim to emulate the problem-solving approach of human professionals in a particular field. A specialized expert system could potentially be developed to facilitate decision-making processes and the targeted implementation of technologies in specific contexts.

According to Kalogirou [1], an ES may be illustrated as a computer system that is specifically established to enhance problem-solving capabilities exhibited by a human expert. Another definition of this concept is a system that utilizes the knowledge of humans, which has been stored in a computer, in order to mitigate challenges, which typically necessitate human expertise. In order to tackle challenges that necessitated significant human expertise, a sophisticated computer software utilizing knowledge and inference mechanisms was created. The computer program in question facilitates the resolution of complex problems that would have traditionally demanded substantial cognitive effort from individuals. In order to accomplish this, the system utilizes domain-specific expertise and interfaces to emulate the cognitive processes of human reasoning. Expert systems have the capability to address problems that typically require human intelligence by leveraging human expertise. The expert's knowledge is stored by the computer in the form of data or rules. In the event of challenges or concerns, individuals may refer back to these established guidelines and pertinent pieces of information. Books and manuals encompass a vast amount of information; however, the value of this data is contingent upon its consumption and comprehension by individuals.

The main purpose of ES is to enhance the distribution of specialized knowledge possessed by a singular "expert" to a broader audience. The expert system comprises three primary components, namely the inference engine, the knowledge base, and the user interface. The insights provided by the domain expert are stored within the knowledge base of the system. Rules serve as the established framework for the representation of knowledge. The inference engine is a crucial component of the system, responsible for employing logical reasoning on the data within the knowledge base in order to derive a conclusion or response. The user interface serves as the intermediary component of the system, facilitating the exchange of information between the user and the system. The "explanation facility" that is commonly integrated into various expert systems serves the purpose of elucidating the underlying logic behind a given query or the systematic steps undertaken to reach a particular conclusion or response. Expert systems are widely utilized in various domains such as agriculture, education, the environment, and medicine, due to their significant practical applications. A significant proportion of professionals depend on these four software applications. The forthcoming presentation aims to deliver a thorough and all-encompassing examination of the application of expert systems within the agricultural industry. Expert systems utilized in the field of agriculture share similar components and possess comparable utility to those employed in other domains. The acquisition of human expertise is manifested through the formulation of IF-THEN rules and factual knowledge, which are subsequently employed to address problems by furnishing responses to inquiries inputted into a computer system. These rules and facts are applicable to various scenarios, encompassing pest control (such as inquiries regarding the necessity of spraying, chemical selection, mixing, and application), efficient machinery management practices, recovery from weather-related damages (including freezing, thawing, and drought), and other related areas. The utilization of expert systems in contemporary agriculture has witnessed a notable rise, particularly in the realm of detecting and managing economically significant pests, including plant diseases and insects.

This research has examined the significance of expert systems in the field of agriculture, along with the extensive range of expert systems currently accessible. The initial stage in assessing the necessity of expert systems for knowledge transfer in the field of agriculture involves the identification of the underlying problems. Expert systems offer several advantages over conventional approaches in terms of effectiveness. Rafea and Shaalan [2] have demonstrated that the application of ES in the domain of agriculture has yielded substantial improvements in crop productivity. Nevertheless, a significant proportion of expert systems are exclusively accessible in the English language. This research has been organized as follows: Section II starts with a discussion of the LEY expert system, Section III is about the wheat Pakistani expert system, Section IV focusses on the mango expert system, Section V reviews the rice expert system, Section VI is about the tomato expert system, while Section VII reflects on the Rapeseed-mustard expert system. Lastly, Section VIII draws concluding remarks to the paper.

## II. LEY EXPERT SYSTEMS

This section introduces a system that utilizes computer-controlled radio frequency (RF) telemetry to collect and transmit real-time meteorological data in Washington State. The development of this method can be attributed to the collaborative efforts of the U.S. Bureau of Reclamation, the National Weather Service, the Washington State University, and different private growers' groups. Data is analyzed, collected, and consequently transmitted to the National Weather Service (NWS) on an hourly basis. During the period of spring frost, the National Oceanic and Atmospheric Administration (NOAA) weatherband provides regular updates on prevailing weather conditions on an hourly basis. These updates serve the purpose of assisting fruit farmers in implementing effective measures to protect their crops from frost damage. Up-to-the-minute meteorological data finds application in various domains, including but not limited to crop protection, irrigation scheduling, and pest control.

A prototype decision support system has been reviewed by Liu, Pan, Sanchez, Sun, Wang, and Yu [3] with the purpose of assisting managers in the process of designing, installing, and maintaining frost protection structures. The prototype is founded upon four fundamental pillars: frost protection approach, instrumentation, forecasting, and operational management. The purpose of this system is to provide additional support to the existing and forthcoming expert systems designed for commodities management that are currently available in the market or being developed. A unique satellite downlink system is employed by Auburn University to transmit meteorological data to a network of high-performance computers. In order to alert fruit, vegetable, and nursery farmers in Alabama about upcoming freeze events, the relevant data is inputted into a set of computer models. Subsequently, these models provide location-specific forecasts pertaining to temperature, dewpoint, and wet bulb temperature, alongside other relevant attributes.

The ACENET computer network facilitates the transmission of model results to county Extension offices and experts. This network is interconnected with every university through a fiber optic communications system. The uplink station at Auburn University facilitates the immediate dissemination of satellite data to media organizations and individuals with remote satellite dishes, particularly during periods of severe freezing conditions. In order to enhance the system, a trial network of automated weather stations has been established, which incorporates a 10-meter tower specifically designed for monitoring inversions. The capacity of knowledge engineering to tackle unstructured agricultural challenges in the presence of deficiencies in data, information, and expertise has garnered the attention of numerous scholars in this domain. The limited acceptance that has ensued can be attributed to several factors, including a dearth of comprehending regarding the inadequate user engagement, decision-making process, and inaccurate categorization of issues. Developers are currently incorporating the decision-making processes of users into their considerations.

An alternative perspective posits that the majority of television programs serve as a manifestation of scientific pursuits and knowledge. These specifications do not fully satisfy the needs of decision-making users, as these needs are typically expressed in a more colloquial manner and involve the use of symbols and logical reasoning.

## III. WHEAT PAKISTANI EXPERT SYSTEM

Manshood, Salman, Hashem, and Mahmoud [4] have assigned the name Triticum aestivum to the crop commonly known as wheat. Kanak and Gandum are two indigenous appellations associated with the aforementioned subject. The winter season, known as Rabi, is characterized by the harvesting of wheat crops. The utilization of this crop in cotton-wheat and rice-wheat systems can serve as a viable alternative to the cultivation of other crops within these systems. The production of wheat has experienced a significant reduction as a consequence of various diseases. According to the Pakistan Agricultural Research Council (PARC), the estimated annual per capita wheat consumption in Pakistan stands at 120 kg [5]. The cultivation of this crop spans across the entire territory of Pakistan.

Pakistan is positioned within the top 10 nations globally in terms of wheat production. Nevertheless, this statistical observation obscures the underlying challenge faced by the country in adequately nourishing its expanding population. The production of wheat is influenced by various environmental and biotic factors, encompassing weather patterns, insect populations, viral infections, fungal diseases, bacterial pathogens, weed infestations, and other relevant factors. Pakistan exhibits a diverse range of illnesses. Rusts are considered to be the most detrimental. Additionally, it is widely recognized as one of the most prevalent diseases affecting wheat crops. According to Khan, Imtiaz, Munir, Hussain, and Ali [6], wheat leaf rot inflicted significant damage upon all wheat-producing regions in Pakistan in 1978.

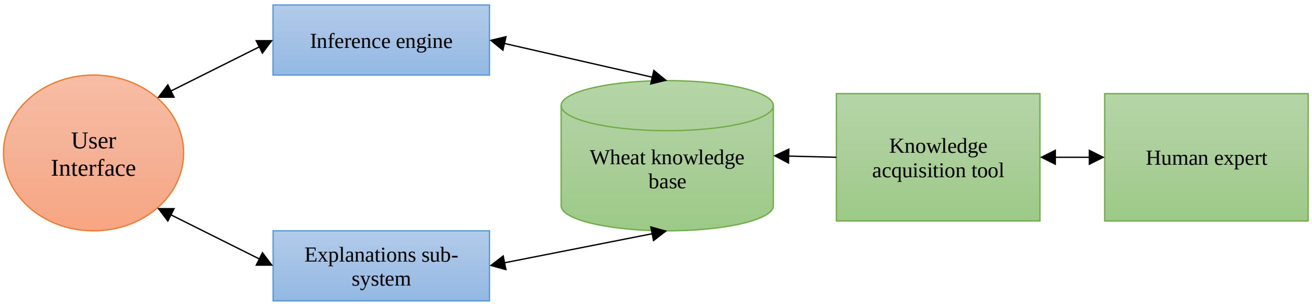


**Fig 1.** Wheat Pakistani ES Architecture

In Pakistan, several notable wheat diseases have been identified, including leaf rust of wheat, black stem rust of wheat, bacterial leaf blight, bunt of wheat, flag smut of wheat, bacterial leaf streak, and root knot. Weeds can potentially impede agricultural productivity, thereby serving as an additional variable that may adversely affect crop yields. Weeds pose a significant concern in various plant-based industries, such as agriculture, horticulture, and forestry, leading to substantial resource wastage. The proliferation of insects and other pests can thrive in an ecosystem characterized by an abundance of weeds. Weeds engage in resource competition with the crop, vying for essential resources such as water, sunlight, and nutrients. The cost of harvesting increases as a result of this. Phalaris minor, Avena fatua, Chenopodium, Cronopus didymus, and Convolvulus are among the commonly observed weed species. Aphids, the Cereal Leaf Beetle, Sawfly, and White Grubs represent a limited selection of the insect pests that feed on wheat plants. Consequently, Wheat may be susceptible to a multitude of disorders. Our line of work focuses on the identification and management of prevalent diseases and pests. Due to the intricate nature of health concerns, a proficient diagnosis is imperative as it requires the expertise of a professional who possesses comprehensive knowledge of the various symptoms associated with a specific medical condition. The bottlenecks in Pakistan's wheat production are examined in [7].

**Fig. 1** shows a web-oriented ES for the management of the wheat crop in Pakistan. A web-oriented ES for the management of the wheat crop was developed specifically for the agricultural context of Pakistan. Pakistan is a significant contributor to the global production of wheat and other cereal grains. As per Chaudhury [8], it has been estimated that the average wheat consumption per capita in Pakistan amounts to 120 kg annually. Widely cultivated in the regions of Punjab and to a lesser extent in Sindh, it is regarded as the principal cereal crop of Pakistan. The rule-based expert system is utilized to tackle prevalent challenges encountered in wheat cultivation, including diseases and pests. The ES was established based on the application of the e2gLiteTM ES shell that is freely available for download from the internet. The utilization of the JAVA interface enables the processing of input and output sets within the context of this web-based expert system shell. When farmers are in need of prompt access to agricultural specialists, the expert system can be a valuable and potentially extensive tool. This expert system will provide farmers, researchers, and students with a structured and purpose-driven approach to effectively tackle prevalent challenges related to wheat. The expert system consistently generates precise and dependable results.

According to Shaikh, S. Waseem, Ahmed, Swed, and Hasan [9], Pakistan is reported to have a significant prevalence of various illnesses. In Pakistan, several notable diseases affect wheat crops, including leaf rust, black stem rust, bacterial leaf blight, bunt, flag smut, bacterial leaf streak, and root knot. The initial phase in the enhance of an ES integrates problem identification. The identification of diseases and pests affecting wheat crops is a diagnostic challenge in order to determine the underlying issues. These recurring issues have significant implications on the financial earnings of farmers. The demand for aid is rapidly increasing. Despite the presence of experts, their accessibility is often limited, especially in remote areas. Consequently, the demand for expert systems in rural areas, where farmers face limited availability of professional support, is evident. Diagnosis, commonly referred to as diagnostic issue resolution, is the systematic process of identifying the underlying cause of a problem. The process of resolving diagnostic issues is heavily dependent on the collection and interpretation of information, with the aim of identifying the root cause of the problem. The knowledge base is where the intellectual capacity of each expert system is located. The process of acquiring knowledge serves as the foundational step in the development of a knowledge base.

The knowledge base alludes to intellectual ability of every ES to be housed. The repository integrates the domain expert knowledge. The major purpose of knowledge engineers is to collectively establish the knowledge base in collaboration to domain experts. The process of obtaining knowledge acts as the first phase of creating solid knowledge base. One of the critical phases in the creation of ES involves the collection of pertinent data. To achieve a high level of decision-making proficiency, a system must initially obtain knowledge from a subject matter expert. The process of acquiring novel information can present difficulties for a knowledge engineer, especially when they are in the early stages of their career within the discipline. The acquisition of knowledge can be facilitated through various means, such as interviews, observations, case studies involving experts, and the utilization of machine rule induction. Knowledge acquisition is frequently perceived as a significant obstacle by expert system developers due to its crucial role in determining the general system performance. The primary cause of this delay can be attributed to the lack of communication and understanding between the knowledge expert and the subject matter expert. In the present scenario, a comprehensive investigation was conducted, wherein numerous farmers were interviewed, with the aim of gaining a deeper understanding and identifying the prevailing challenges. Human experts were also consulted. Additionally, we consulted various authoritative texts and scholarly articles within the discipline. The utilization of expert interviews proved to be highly valuable in gauging the extent of information required to effectively tackle the identified issues.

The acquisition of knowledge is considered a critical step in the expert system development life cycle, as emphasized by Putri and Sidiq [10]. To attain a high level of decision-making proficiency, a system must initially acquire knowledge from a domain expert. Interviews, expert observation, case studies, and automated rule induction are commonly employed techniques for the acquisition of knowledge. The process of knowledge representation is subsequent to the acquisition of knowledge. The e2glite ES shell knowledge base integrates of a set of straightforward if-then rules. The activation of rules in an inference engine is typically initiated by the underlying logic. The predominant methods of reasoning employed by rule-based expert systems encompass forward chaining and backward chaining.

## IV. MANGO EXPERT SYSTEM

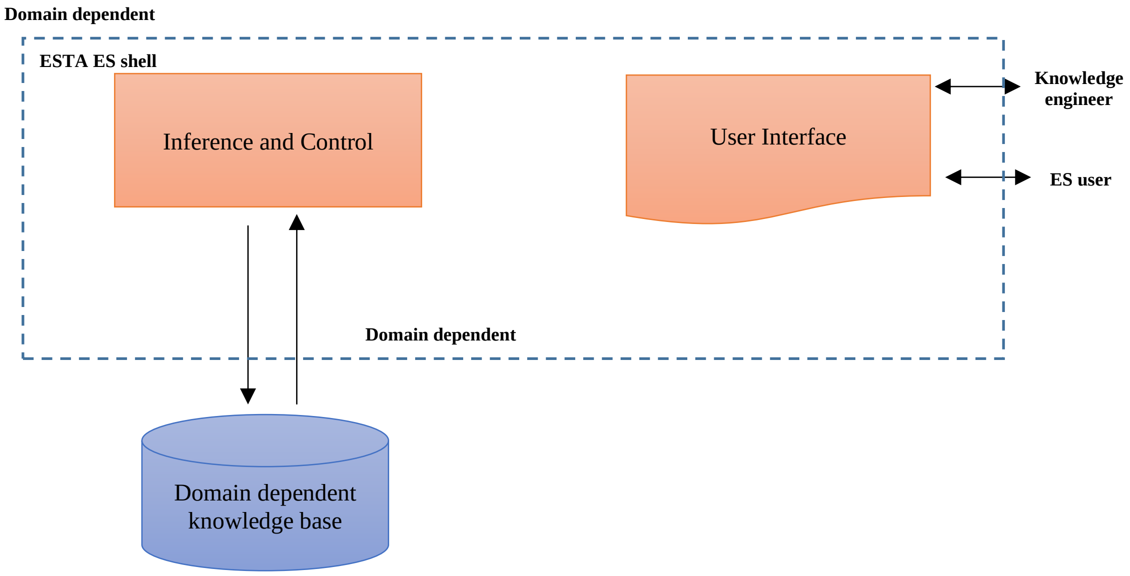


**Fig 2.** Mango ES Architecture

The majority of the Indian population depends on agriculture as their major source of livelihood, and it is indisputable that this sector plays a pivotal role in driving the nation's economy. Fruit cultivation maintains a significant position within the Indian economy alongside various other crops of commercial importance. Annually, the global fruit production amounts to approximately 370 million metric tons (MT). India's annual fruit production, which amounts to approximately 32 million metric tons (MT), constitutes approximately 8% of the total global fruit production. Approximately 180 families of fruits are cultivated in various regions across the world. India's fruit crop is primarily cultivated across various agroclimatic regions within the country.

The mango, scientifically known as Mangifera indica, is an indigenous tropical fruit originating from India. This particular fruit is classified within the Anacardiaceae family and is highly regarded as the preeminent member of this botanical group. In India, approximately 1.23 million hectares, which accounts for 70% of its fruit-growing area, is allocated for the cultivation of this particular fruit. As a result, the annual yield amounts to 10.99 million metric tons, representing 57.18% of the global output. Over the course of numerous centuries of deliberate breeding, agriculturalists in India have successfully generated more than 500 distinct cultivars of mango through selective processes, originating from the original wild specimens. China, Pakistan, Thailand, Australia, and the Philippines are prominent stakeholders in the worldwide production of this particular fruit. India significantly surpasses its competitors in the export of processed mangoes.

India is widely recognized as the largest producer of mangoes globally. However, the nation faces a substantial challenge in terms of crop loss due to spoilage occurring at various stages after harvesting. Estimates indicate that this loss ranges from 20% to 22%. The primary factors contributing to this phenomenon are evident in the dataset. Conventional agricultural management practices, which are frequently characterized by inefficiency, continue to be widely employed. The scientific maintenance of the orchard is infrequently practiced. Typically, orchardists solely traverse the orchard during the period when fruit is available. This can be attributed to their lack of knowledge and education. The current level of knowledge and expertise transfer from laboratory settings to the realm of commercial fruit farming is inadequate. One additional obstacle hindering the adoption and utilization of cutting-edge technology among orchardists pertains to their limited knowledge base and limited access to training resources. Nevertheless, the agricultural and horticultural production in developed nations has evolved into a highly advanced and intricate industry. The process of making judgments involves the accumulation and synthesis of information and expertise derived from diverse sources, such as [11]. The aforementioned development has led to the emergence of precision agriculture and computerized farm management.

Consequently, the agricultural practices in developed nations have adopted state-of-the-art technology. In contemporary agricultural systems, the cultivation of crops necessitates the careful consideration of various factors, encompassing environmental elements, scientific investigations, and technological progressions, both prior to and throughout the cultivation process. The process of making decisions involves a dynamic interplay between information and expertise. The appropriate utilization of knowledge in relation to data unveils the trajectory towards efficacious action. The corpus of agricultural knowledge is vast, posing a formidable challenge for even the most well-informed expert in the field to fully comprehend the importance of all pertinent factors. In addition, the expert should possess ample knowledge and aptitude in problem-solving to effectively navigate and address the extensive volume of information at hand. As a result, computerized farm management and precision agriculture have emerged as methods to facilitate the efficient dissemination of information from researchers to farmers and to ensure the optimal implementation of this information. The scope of computerized farm management, specifically expert systems, is highly promising in terms of effectively organizing and coordinating knowledge across various sub-areas of agriculture, leading to optimal output.

The development of computer systems integrating regression models, database management, simulation prototypes, and a rule foundation is aimed at offering farmers a diverse range of recommendations. The justification for the implementation and utilization of a knowledge-based (KB) system in the field of agriculture arises from the sector's inherent lack of comprehensive knowledge and the prevalence of diverse methodologies to address its various challenges. Ensuring regular and diligent care of a fruit tree both prior to and during its fruiting seasons is imperative for the optimal growth and development of high-quality fruit. In the event of a tree's illness, it is imperative to conduct a diagnosis in order to determine the appropriate course of treatment.

Orchard owners are required to possess expertise in the field or have access to other knowledgeable individuals or reputable agricultural institutions for assistance in this domain. In the Indian agricultural sector, farmers and orchardists are currently encountering a range of challenges and are actively addressing them. To commence, it is evident that the farmers possess a limited level of education and comprehension pertaining to these matters. Furthermore, it presents a challenge for even the most proficient farmer to consider all pertinent factors. One additional challenge faced by farmers pertains to the arduous task of identifying and recruiting specialized professionals in the field. Another issue that arises is the significant interdependence of choices made in agricultural practices.

It is atypical for a singular component to serve as the determinative factor in making a decision. Consequently, the development of an expert system that enables direct user access (including educators, novices, farmers, scientists, and researchers) has become feasible. This system serves the purpose of providing guidance, augmenting knowledge, and addressing inquiries. In the context of this discourse, the term "ailment" will be employed to denote various conditions, encompassing illnesses, disorders, and pests, with the understanding that these terms are interchangeable. Certain damages to mango orchards may be readily apparent to experienced producers, while others may require the expertise of a trained individual for accurate diagnosis. This is due to the fact that most farmers are not familiar with the distinctive indicators associated with each mango disease. An analytic ES may be industrialized to perform tasks equivalent to those of a human expert, thereby circumventing the aforementioned challenges. This study aims to collect data on diseases affecting Indian mango trees through consultations with experts, plant pathologists, and analysis of published literature. The acquired information will be organized in a suitable format to facilitate the development of an expert system within the Prolog-oriented ES shell identified as ESTA (Expert System for Text Animation) in **Fig. 2**.

Prasad, Ranjan, and Sinha [12] developed an expert system named AMRAPALIKA to discern a total of 14 discrete pests, comprising 8 diseases and 6 insects, within the Indian mango cultivar. An expert system has been developed to address various diseases and pests, including black spot, powdery mildew, anthracnose, die back, red rust, bacterial spot, malformation, and sooty mold. According to Sharma [13], India holds a significant share of 57.18 percent in global output, producing an annual yield of 10.99 million tonnes. This output is derived from an area of 1.23 million hectares, which represents approximately 70 percent of the total fruit-growing area. According to Agro Food Processing Technology [14], a significant proportion of the total fruit output, estimated to be more than 20-22%, is lost as a result of spoilage during different post-harvest phases. This is a noteworthy concern, particularly considering that India holds the distinctions of being the greatest international producer of mangoes.

Ayus and Panigrahi [15] described the development of a rule-oriented ES using ESTA to effectively diagnose the prevalent diseases and insect pests that commonly afflict Indian mango crops. The mango expert system offers diagnostic capabilities by utilizing user input to respond to inquiries regarding particular symptoms of illnesses or pests. The system is designed to store comprehensive data pertaining to the symptoms and treatments associated with 14 distinct pests affecting the Indian mango tree. This encompasses pests that manifest during the fruiting season as well as those that do not. The system retrieves relevant images from its image database that are associated with the symptoms being searched for, and presents them alongside the user's query.

The formal inclusion of deduction, abduction, and induction in problem-solving cycle diagnostic has been observed in the context of hypothetical reasoning. The utilization of logical problem-solving techniques, including deductive diagnosis, abductive diagnosis, consistency-oriented diagnosis, can be traced back to ancient times. The categorization rules of this expert system are formulated using ESTA syntax, and they are derived from logical models that represent visual symptoms and diseases. The rule-oriented approach has been effective in different other diagnostic ES, as evidenced by studies conducted by Safarchi, Fatima, Ayati, and Vafaee [16]. Once again, the decision has been made to utilize the backward-chaining rule-based strategy for knowledge representation. The decision to employ backward chaining was motivated by its goal-oriented characteristics and its similarity to the diagnostic reasoning process. The subsequent phase involves the incorporation of a module addressing nutritional deficits within this body of knowledge.

In the context of developing nations, where a significant number of farmers lack proficiency in the English language, it is imperative to develop expert systems in local languages and ensure their accessibility to rural communities through local administrative bodies or councils. Nevertheless, the implementation of a hypermedia-based expert system that possesses the capability to communicate via text, images, and sound holds significant potential for utility and positive reception. The potential for enhanced benefits among farmers residing in remote regions could be realized through the incorporation of a voice interface within the system. The voice interface of the expert system enables accessibility for farmers with limited literacy skills. Nevertheless, the current state of speech recognition technology is relatively nascent, thereby limiting its ability to offer these interfaces at present.

## V. RICE EXPERT SYSTEM

The utilization of information technology to enhance agricultural productivity has attracted significant interest from both academic and industrial sectors. The transfer of knowledge holds significant importance across various aspects of sustainable agriculture due to the critical role it plays in facilitating communication, sharing of information, and transactions. Rice plants, being the third most cultivated crop following maize and wheat, are a focal point in endeavors aimed at ensuring food security. Nevertheless, rice serves as the principal source of carbohydrates for the majority of individuals worldwide. Factors such as soil composition, climatic conditions, and the ability of rice plants to withstand pests and diseases are merely the initial aspects to be taken into account in order to achieve efficient management of rice cultivation.

The subsequent phase involves pest control, which can be accomplished through the utilization of chemical pesticides, implementation of biological pest management strategies, and utilization of pest-resistant seed varieties. The extended utilization of incorrect fertilizer dosages has the potential to increase soil acidity and deteriorate soil physical properties. Additionally, the appropriate selection and application of fertilizers, along with their optimal quantities, are crucial factors in enhancing crop yields. To effectively oversee the cultivation of rice plants, farmers must possess access to pertinent data and information. An expert system refers to an information technology tool that has the potential to assist farmers in fulfilling their data requirements. Artificial intelligence techniques enable the emulation of human cognitive processes and reasoning within specific domains, resulting in the development of "expert systems".

Numerous enterprises have adopted this technology in order to enhance productivity and profitability through the implementation of well-informed business decisions. Expert systems are a specialized branch within the field of artificial intelligence that originated from the pursuit of developing computer programs possessing intelligence comparable to that of humans. The development of expert systems is heavily dependent on the establishment of the problem's scope and the acquisition of data from domain experts in the pertinent disciplines. The reliability of the expert system is contingent upon the caliber of the information incorporated within the knowledge base. The limited availability of agricultural experts during critical periods poses challenges for ordinary farmers seeking tailored advice from professionals based on their unique circumstances.

The dissemination of information regarding effective planting methods continues to rely on conventional approaches, while the absence of communication facilities between researchers and farmers hinders the timely provision of solutions to the challenges encountered by farmers. The suboptimal rice yields can be attributed to the limited access of farmers to resources and knowledge regarding the adoption and application of optimal agricultural practices. The efficacy and utility of the expert system in addressing this agricultural issue have been demonstrated, indicating significant potential in this domain.

In India, Balleda, Satyanvesh, Sampath, Varma, and Baruah [17] developed an expert system in **Fig. 3** with the aim of enhancing the detection and management of diseases affecting rice crops. The authors provided a comprehensive account of the development and design process of rule-oriented ES, employing the ESTA shell. Additionally, they design an architectural model for ES specifically tailored to the agricultural domain. The methodology is focused on the identification of common diseases affecting rice plants. The rice expert system comprises three major elements, such as user interface, inference engine, and knowledge base. The inclusion of decision support modules in expert systems, which feature interactive user interfaces, enables the diagnosis of specific illnesses by eliciting user responses to inquiries regarding symptoms.

Logic programming serves as the fundamental basis for the code developed by ESTA. The system integrates a comprehensive database of organized knowledge encompassing data pertaining to diseases affecting rice plants, their corresponding symptoms, and the proven efficacious treatments. Additionally, the system integrates an image library to offer visual resources that can assist in the decision-making process. The image database is responsible for storing images that are linked to symptoms of illnesses. The intelligent system module utilizes a rule-based decision-making interface to generate prompts based on these images. The system has been evaluated using domain datasets, and the accuracy of its output has been verified by domain experts.

The establishment of a comprehensive knowledge base serves as the fundamental framework for any expert system. The effectiveness of expert systems is contingent upon the quality and comprehensiveness of their knowledge bases. The knowledge base of this expert system is constructed using the ESTA methodology, which involves the collaboration of a domain-specific expert. The enhancement of ES using the ESTA methodology encompasses a sequence of steps that collectively contribute to the accumulation of specialized knowledge within a specific domain. The construction of the knowledge base for this system occurs through a three-stage process: initial identification of input issues, acquisition of knowledge, and subsequent representation of acquired knowledge. The development of an expert system in this study incorporates the utilization of diagnosing common rice disorders as a means to gain further knowledge about these diseases.

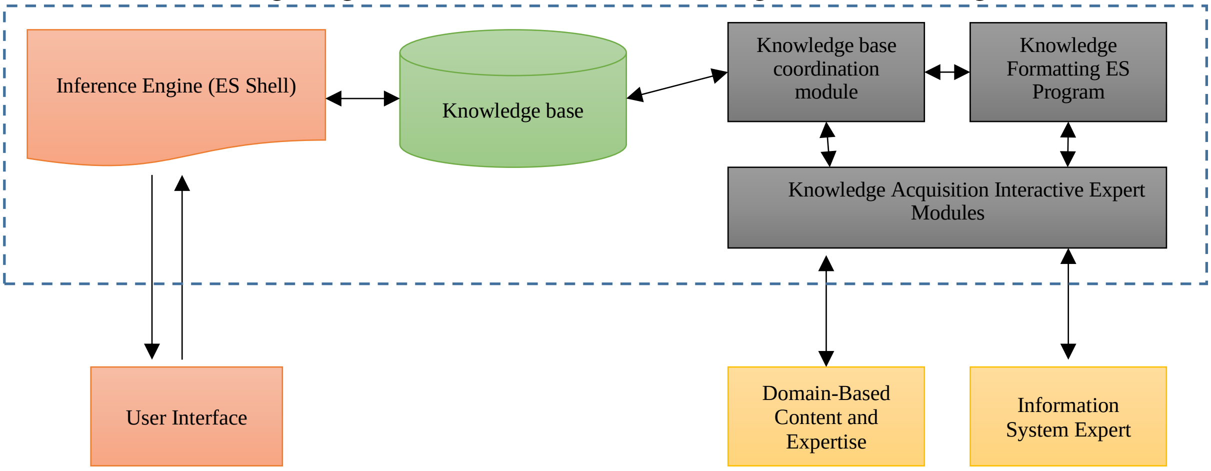


**Fig 3.** Rice ES Architecture

## VI. TOMATO EXPERT SYSTEM

Tomatoes exhibit optimal growth in temperate conditions, particularly in soil that is meticulously maintained. The application of organic materials, such as manure, has the potential to significantly enhance success rates and yield improvements in agricultural practices. Furthermore, the utilization of these materials can serve as a means of mitigating potential hazards and challenges that could otherwise pose risks to crop production. Certain types of vegetables, such as tomatoes, cucumbers, peppers, cabbage, and onions, exhibit limited suitability for consecutive cultivation on a given plot of land, with a maximum frequency of two to three plantings per annum. A preceding crop for tomatoes should consist of herbaceous plants that can effectively improve the soil structure, such as the molokhia crop. It is crucial to maintain a diverse cultivation system to ensure soil health.

Consequently, planting tomatoes on a rotational basis is not recommended due to the potential soil damage and increased susceptibility to diseases associated with this practice. By avoiding diseases originating from the soil, the overall health and productivity of the tomato crop can be safeguarded. The cultivation of tomatoes holds significant importance, thereby necessitating the utilization of exclusively certified seedlings within one's garden. **Table 1** shows the CLIPS ES language representation of diseases.

**Table 1: CLIPS expert system language representations of 10 distinct diseases**

| | |
|---|---|
| **Damping Off** | Tomato seedlings exhibit vulnerability to damping off, a condition caused by the presence of the fungal pathogens Pythium and Rhizoctonia. The occurrence of seedling non-emergence in the greenhouse or the premature mortality of young seedlings following transplantation is a frequently encountered issue. The plant stems that have successfully endured have been hydrated in close proximity to the soil. |
| **Septoria leaf spot** | Septoria Lycopersicon, a fungal pathogen, induces a highly destructive ailment in tomato plants, primarily impacting the foliage, petioles, and stems while sparing the fruit. Once plants enter the fruit production stage, it is common for the lower leaves situated closer to the ground to become susceptible to infection. The leaves of the elder plant exhibit the presence of numerous minuscule circular dots, encircled by black borders and featuring a central region of beige coloration. |

| | |
|---|---|
| **Bacterial stem and fruit canker** | The microorganism formerly identified as Pseudomonas solanacearum has been reclassified as Ralstonia solanacearum and is responsible for the highly destructive ailment commonly referred to as bacterial wilt or Southern bacterial blight. The persistence of this bacteria in the soil for extended durations is facilitated through various mechanisms, including transplantation, cultivation, insect feeding damage, and natural wounds that promote the formation of additional roots, thereby enabling the bacteria to gain entry into the plant's root system. |
| **Early blight** | The etiology of this disease can be attributed to the fungi Alternaria linariae, previously identified as A. solani. Initial manifestations of the disease are characterized by the appearance of diminutive, brown lesions primarily on the mature foliage of the affected plants. The affected region may exhibit an expansion of spots, accompanied by the appearance of concentric rings arranged in a bull's-eye configuration at the core of the afflicted area. |
| **Bacterial leaf spot** | This disease is attributed to various strains of the bacterium Xanthomonas, with Xanthomonas perforans being the predominant causative agent. It specifically targets green tomatoes, while red tomatoes remain unaffected. Peppers are susceptible to infection as well. The prevalence of the disease is higher during periods of increased precipitation. |
| **Bacterial wilt** | Southern bacterial blight, or the bacterial wilt, is a highly consequential ailment induced by the pathogenic microorganism Ralstonia solanacearum (previously identified as Pseudomonas solanacearum). The aforementioned bacterium exhibits the ability to endure in the soil for prolonged durations and gains entry into the roots via various means, including wounds resulting from transplanting, insect feeding damage, cultivation, and natural wounds occurring at the emergence sites of secondary roots. |
| **Leaf curl** | The transmission of Tomato yellow leaf curl virus (TYLCV) is not associated with seed-borne mechanisms, but rather occurs through the vectorization of whiteflies. The aforementioned disease poses a significant threat to the productivity of tomato and pepper crops. Whiteflies have the potential to introduce disease into the garden by means of infected weeds in close proximity, including various nightshades and jimsonweed. Following infection, tomato plants have the potential to remain asymptomatic for a duration of approximately 2 to 3 weeks. |
| **Mosaic** | Various viruses elicit distinct symptoms on tomato plants. The manifestation of virus infection can be observed through the occurrence of dark and light green leaves mottling. The Tobacco mosaic virus (TMV) induces a characteristic pattern of discoloration on mature leaves and has the potential to induce leaflet deformities, resulting in a shoestring-like appearance. |
| **Tomato spotted wilt disease** | The fungal pathogen Septoria lycopersici is responsible for the occurrence of this detrimental ailment affecting the leaves, petioles, and stems of tomato plants, while the fruit remains unaffected. Typically, infection tends to manifest on the lower foliage in close proximity to the soil, subsequent to the commencement of fruit development in plants. |
| **Fusarium** | The fungus Fusarium oxysporum causes this illness during the warmer months. Infected plants show their presence by their lowest leaves drooping and becoming yellow before finally withering and dying. Leaves often become golden yellow on one side of the stem before the other. |

Hatou, Sakamoto, Fukuyama, Nonami, and Hashimoto [18] developed a web-oriented expert data system for the farming of tomato crops in India (see **Fig. 4**). A highly skilled team comprising computer engineers, programmers, and designers is currently engaged in the development of a tomato crop expert advice system. The primary objective of this endeavor is to establish a collaborative partnership with renowned agriculture scientists and industry professionals specializing in tomato cultivation. The expert system consists of two primary components, namely the tomato crop ES and the tomato data system. The former resource offers users an extensive collection of static data encompassing various aspects such as tomato species, diseases, pests, and chemical controls.

The user actively participates in an online dialogue with the expert system within an advising system. The responsibility for providing responses to the inquiries of the expert system lies with the user. The expert system is capable of accurately identifying specific illnesses or pests and providing corresponding management measures based on the input provided by the user. The expert system also encompasses the identification of common diseases and pests affecting tomato crops, along with the various diverse varieties of tomatoes. The rule-based expert system employs the ID3 Algorithm and various optimization techniques to validate the symptoms exhibited by the tomato crop. The present system is an expert system that has been advanced using Java Server Pages (JSP) and MySQL technologies for online implementation.

The objective of the Tomato Crop Expert Advisory System is to facilitate collaboration between esteemed specialists in the domain of tomato cultivation and agriculture, alongside a proficient group of software developers and designers. The curriculum consists of two primary components. 1) The provision of Data Processing Systematic Guidance (2) enables information system users to avail comprehensive databases encompassing various facets of tomato plant and fruit biology, encompassing species classification, symptomatology, chemical interventions, as well as pest and viral afflictions. The user actively participates in an online dialogue with the expert system within the context of an Advisory System. The Expert System will present inquiries, and it is the responsibility of the user to furnish answers. The expert system utilizes user input to identify the illness and subsequently provides a disease control approach.

The expected functionalities of this web application are as follows: This website provides users with up-to-date information on tomatoes, including details on diseases, viruses, and methods for managing them, all of which contribute to achieving optimal crop yields. The website is organized into four primary sections, namely tomato crop information, tomato advisory model, other web application services, and agriculture-related connections. The utilization of the website's online directory articles, service, and forum service will enhance the level of engagement among members within the tomato community, thereby fostering advancements in research and development within the tomato industry as a whole.

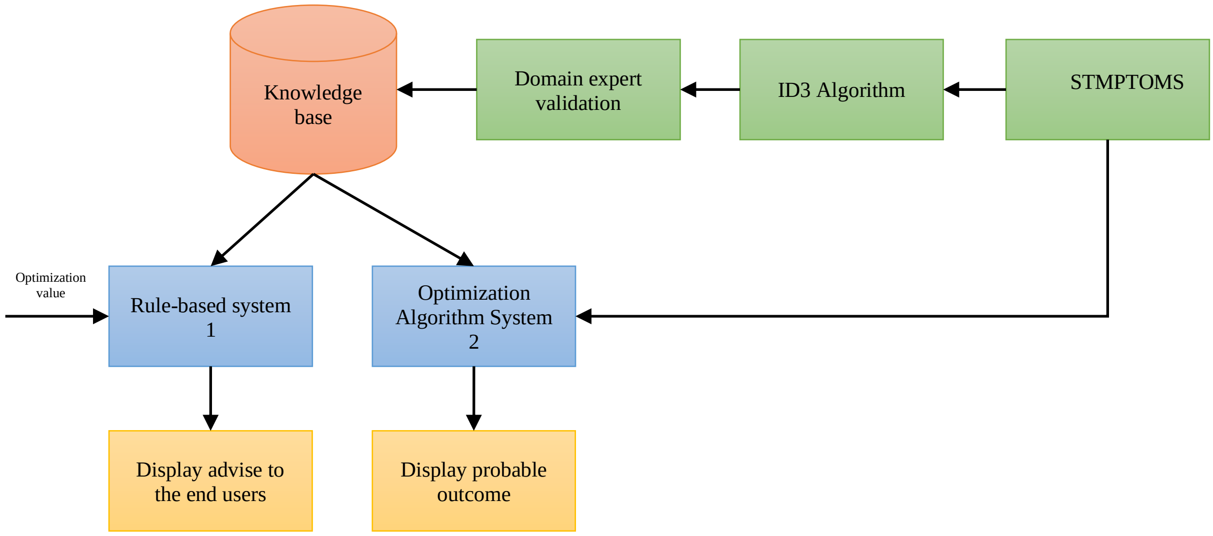


**Fig 4.** Tomato ES Architecture

## VII. RAPESEED-MUSTARD EXPERT SYSTEM

India holds the third position worldwide in terms of oilseed production. In the Indian agricultural landscape, an estimated area of approximately 27 million hectares is allocated for the cultivation of oilseeds. It is noteworthy that a significant proportion, approximately 72%, of this land is utilized under rain-fed conditions. Glycine max (L.) Merill (Soybean), Brassica species (rapeseed-mustard), Arachis hypogaea L (groundnut), and Helienthus annus L (sunflower) collectively constitute over 85% of the cultivated land dedicated to oilseed production in India. It is worth noting that India cultivates a total of nine oilseed crops. According to Singh [19], approximately one-fourth of the overall cultivated land for oilseed production is allocated to rapeseed-mustard, positioning it as the second most prominent oilseed crop in terms of both output and domestic utilization. In India, the cultivation of rapeseed and mustard is carried out in a region that has been geographically categorized into 5 discrete agro-ecological zones, according to present climatic conditions in each respective area.

According to Udmale, Ichikawa, Manandhar, Ishidaira, and Kiem [20], approximately 55 percent of India's cultivated land is dependent on rainfall as the primary source of irrigation. Approximately 27% of the global rapeseed-mustard crop is cultivated in rainfed environments, rendering them highly susceptible to various risks and challenges. Rapeseed-mustard, being a commercially important oilseed crop, has been the focus of continuous efforts to develop cultivars that are resource-efficient and adaptable to various agroecological conditions. For an extended period, indigenous farmers in America have heavily depended on rapeseed and mustard as fundamental agricultural crops. Rapeseed exhibits considerable diversity in terms of its native varieties, including but not limited to: B. napus ssp. oleifera DC var. annua (Gobhi Sarson), Brassica campestris syn. B. rapa var. Brown Sarson (Brown Sarson), vesicaria Mill/ Eruca sativa (taramira), and (B. campestris syn. B. rapa var. Indian mustard (Toria), Brassica juncea Cosson & Czernj), Brassica nigra (black mustard), and Ethiopian mustard (Brassica carinata (A. Braun)) are all taxa belonging to the Brassicaceae family.

To date, researchers involved in the All India Coordinated Research Project on Rapeseed-Mustard (AICRP-RM) have successfully created and officially communicated to the Indian government and State governments a total of over 160 enhanced varieties of these particular species, specifically tailored to various geographical regions. While the majority of these variations possess documentation, it is distributed and presented in diverse formats. The task of rendering this scattered data into a usable and easily discoverable format presents considerable obstacles. The availability of this data can be advantageous for various stakeholders such as farmers, extension workers, students, and researchers. It can assist them in making informed decisions regarding the selection of crop varieties that align with their specific requirements. The selection of variety by the farmer is the most pivotal factor for any given harvest. Farmers and extension workers necessitate a profound understanding of agricultural specialization and technical knowledge in order to effectively aid farmers in making optimal choices regarding crop varieties.

Farmers may encounter challenges in accessing current scientific and technical knowledge due to the unreliability, high costs, or limited availability of conventional methods of dissemination. Consequently, this lack of access hinders their ability to make informed decisions in a timely manner. The potential of expert systems in agriculture to address the issue at hand has been acknowledged by Zlobin, Torgachev, Morozova, Semenikhina, and Fedyushin [21]. The utilization of the World Wide Web (WWW) has played a significant role in facilitating tools development that enhance individuals' ability to make informed decisions in the contemporary era of digital technology. A web-based expert system is accessible to aid farmers and extension workers in selecting the most suitable rapeseed-mustard varieties for their respective regions. Expert systems are advanced computer programs that employ inference-based and knowledge-based methodologies to address problems that would typically necessitate human involvement.

Zhang, Ding, Cui, Li, Ullah, and He [22] developed a visual-based ES for the identification and diagnosis of illnesses affecting rapeseed and mustard crops in India (see **Fig. 5**). By utilizing this specialized system, we successfully diagnosed and applied management strategies for economically consequential diseases, including white rust, white rot, white rot of rapeseed-mustard, alternaria blight, powdery mildew, and downy mildew complex. According to Das Jyoti, Sultana, Hassan, and Hasan Khan Robin [23], the incidence of Alternaria blight has been found to result in an average reduction in harvest seed yield of up to 47%. White rust in B. juncea has been linked to yield losses of up to 47%. The increased prevalence of disease, specifically rot of mustard, has emerged as a significant concern both in India and globally. This has led to substantial reductions in output, with losses reaching up to 40 percent, consequently discouraging mustard farmers.

According to Mehta [24], the compilation of information regarding the impact of diseases affecting rapeseed-mustard plants on different plant components, as well as strategies for their management, was conducted through the collaboration of an expert panel and the utilization of secondary sources, including scholarly articles. The symptoms associated with plant diseases were classified into six distinct categories, encompassing the plant's flowers, stems, leaves, pods, roots, and overall plant health. The video and still photos of illness symptoms were captured using digital and video cameras of superior quality. According to Chohan et al. [25], electronic devices have the capability to capture visual indicators of pests and plant diseases, enabling prompt and efficient diagnosis. The structure of a system typically encompasses essential components such as a database, user interface (UI), inference engine, and knowledge base (KB). The conventional stages in system development encompass problem identification, data collection, data modeling, code creation, testing, and assessment.

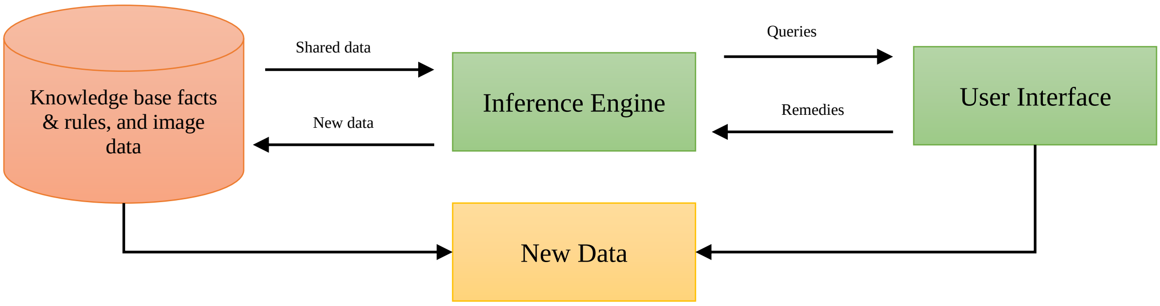


**Fig 5.** Rapeseed-Mustard ES Architecture

## VIII. CONCLUSION

This research has investigated the significance of ES in the domain of agriculture, along with the extensive range of expert systems currently accessible. The initial stage in assessing the necessity of expert systems for knowledge transfer in the field of agriculture is problem identification. Expert systems offer several advantages over conventional approaches, thereby enhancing their effectiveness. Expert systems have been shown to increase agricultural yields by a significant amount, according to studies conducted in this area. However, a large percentage of expert systems are only available in English. Developing an agricultural expert system in the farmer's native language facilitates the provision of essential information, thereby enhancing agricultural productivity. Farmers frequently seek guidance from agricultural experts and consultants to address the issue of pest and disease control on their farms. Nevertheless, the decision-making process is likely to be prolonged due to the insufficient availability of agricultural experts and extension workers. The potential consequences of the delay will be exacerbated by any resulting damages. Utilizing an expert system is a highly effective approach for expediting decision-making processes and optimizing time management. The utilization of expert systems in the field of agriculture has proven to be highly advantageous in terms of optimizing crop production and minimizing yield losses. It is crucial to provide farmers with access to established expert systems that have demonstrated their utility.

### CRediT Author Statement
The author reviewed the results and approved the final version of the manuscript.

### Data Availability
The datasets generated during the current study are available from the corresponding author upon reasonable request.

### Conflicts of Interests
The authors declare that they have no conflicts of interest regarding the publication of this paper.

### Funding
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### Competing Interests
The authors declare no competing interests.

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