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JAPIEST: An integral intelligent system for the diagnosis and control of tomatoes diseases and pests in hydroponic greenhouses

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Abstract

Automated Hydroponic Greenhouses represent novel food production systems which include modules for supervising the cultivated soil, packaging plans, as well as prevention, diagnosis and control of pests and diseases. In this setting, we propose the design and implementation of an Integral Intelligent System called JAPIEST, which is focused on the prevention, diagnosis and control of diseases that affect tomatoes (*Licopersicum exculentum*). Plants are farmed inside hydroponic greenhouses, whose particular conditions of temperature, humidity and nutrient consumption rates can influence directly the surge of plagues or diseases. It is relevant to detect and control the occurrence of any given pest or disease because plants are utterly sensitive to variations of environmental conditions and they have a short induced lifecycle. JAPIEST is a novel and valuable tool for farmers to make an early decision of the candidate disease, and then apply a suitable control treatment, based on Integrated Pest Management.

Keywords: Integrated Pest Management; Multi-expert decision; Multi-platform intercommunication system; Multi-level access

1. Introduction

Agricultural production in Mexico has been limited by a series of natural, economical, social, and political factors. Furthermore, about eighty percent of the total productive surface has erratic rain seasons (López-Morales et al., 2006). Besides, the integration of the country in the North-America Free Trade Agreement (NAFTA) makes it compulsory to comply with strict environmental regulations. Both constraints evidence the complexity and difficulties that Mexican farmers currently face. Hence, it is necessary to incorporate technological innovations and improve this productive activity. Two important trends are surging to meet this aim. First, a set of methods based on the well-known Integrated Pest Management (IPM), and on the other hand, the emergence of Automated Hydroponics Greenhouses (AHG). While IPM tackles the right handling of pesticides to comply with environmental restrictions, AHG's are a solution to overcome seasonal farming. Therefore, it is possible to develop superior AHG integrating IPM techniques, which are spread through diverse geographical sites, to further bringing them cooperation and autonomy capabilities. Such AHG's are to share information and knowledge in order to manage adequately crop production cycles, and to reduce the risk of pest or diseases.

Unfortunately, many negative consequences by not fulfilling with the environmental standards for pesticides residues have been reported (Dierksmeier, 1996; Robinson, Henry, & Mansingh, 2002). Consequently, IPM has been widely adopted as a solution to pollution due to pesticides. IPM techniques state that when the so-called infestation levels exceed the economic injury levels, a combination of

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biological, cultural, mechanical and chemical control methods are the best approach to reduce infestation levels. Moreover, IPM pays close attention to the foreseen impact of a particular pesticide in the ecosystem under consideration (cf. Institute, 2007; Greenberg, Sappington, Elzen, Norman, & Sparks, 2004).

However, a complete implementation of IPM requires knowledge of the crop itself, the types of pests that affect the crop, and the biological cycles of the plant. Although the environmental and economical benefits of IPM are well acknowledged, it is required a sheer amount of knowledge on the former topics. Unfortunately, the required knowledge resides typically on a number of different experts, and it is not always available to Hydroponic Greenhouses (HG) owners. Hence, we propose to realize this knowledge available by developing an integral kit, for HG (López-Morales et al., 2006), covering a number of technological innovations.

In this paper, we state the design and implementation of an intelligent pest management system called JAPIEST. The proposed intelligent system integrates the perspectives of different disciplines, such as plant pathology, entomology, horticulture and agricultural meteorology, into a framework that addresses appropriately the type of decision making needed by plant growers (in our case study tomatoes growers). Hence JAPIEST provides a decision support system integrating important IPM features, which are reflected in both, the rule base and the treatment further suggested. The system is inspired in the work presented by Toth, Stinner, Burr, and Kent (2001) and Greenberg et al. (2004). Although such systems are valuable, we intend to facilitate and support the construction of crop profiles and the generation of strategic plans to improve the management of diseases and pests. The usefulness of both, profiles and plans resides on being information sources regarding current pest management practices.

Some related expert systems in agriculture for different products are already reported (Crowe & Mutch, 1994; Rafea, El-Azhari, Ibrahim, Edres, & Mahmoud, 1995; Flamm et al., 1991) and some developments on IPM methods (Saunders et al., 1987; Mansigh, Reichgelt, & Bryson, 2007; El-Sayed, Hesham, & Ahmed, 2000; Prasad, Ranjan, & Sinha, 2006). Nevertheless, they did not provide access through the Internet, or they are based on closed platforms which cannot be updated, exploited (data mining), or hierarchically organized in a network platform. These two drawbacks are tackled since the conception of JAPIEST, which provide these kind of capabilities.

To describe the conception and construction of JAPIEST, the paper is organized as follows. In Section 2, we state the diseases and pests identification to characterize the main harmful species for tomatoes. Section 3 describes the knowledge acquisition process that was followed to establish the rule base. Section 4 illustrates the design of JAPIEST, and then in Section 5 is exemplified. Finally, in Section 6 we delineate the conclusions and propose future work.

2. Diseases and pests identification

Tomatoes is one of the food products most cultivated worldwide. Mexico ranked 9th in the global production, contributing with 2.1 millions of tons (MTn), while China took the first place with 31.6 MTn, and the USA the 2nd with 12.7 MTn.

For a detailed identification of and suitable planification for the treatment of the diseases and pests, it was necessary to classify the main characteristics of harmful species, from every cultivation area or region. Some of these characteristics include morphological (mature form and unripe states) and biological (damage, supervision, and handling) properties. Tables 1 and 2 show an extract of these diseases and pests identification in order to visualize some of the harmful species for tomatoes.

3. Knowledge acquisition methodology

To facilitate the construction of JAPIEST, domain experts were trained to master a technique for representing and acquiring knowledge, called dependency networks. This technique yields easily a graphical representation of the resultant rule base, since knowledge acquisition is a critical step in developing expert system (Gaines, 1987). Once the required knowledge was represented, programmers actually completed the Java codification of the rules. Consequently, domain experts acted as the source of knowledge and the designers of the expert system. The advantage of this technique resides on the high accuracy of the resultant rule base, as has been acknowledged also in PSAOC (2007). Domain experts are entirely aware of the extent of the knowledge they posses, they determine clearly what is the decision process like, and they intuitively fix the relevant variables for such decision making

Table 1
Main pests affecting tomatoes

	Insects	Mites	Nematodes
Suckers	Aphides/White fly/ Trips/...	White acarus	
Masticator	Caterpillar/Worm		
Miners	Leaf miner		Root nematode

Table 2
Main diseases affecting tomatoes

Bacterized	Fungi	Virals
Bacterial cancer	Antractnosis	TMV
Bacterial spot	Stem cancer/Alternariosis	ToMV
Black spot	Cenicilla	TYLCV
Wilted by bacteries	Fusarium/Gray spot on the leave/ Gray mildew/White mildew/ Alternaria Solanis/Alternaria/ Verticilium	TSWV/ CMV PVY/TBSV

process. Therefore, the knowledge flows from the expert as he articulates his inner process, which is then formalized in the rule base.

In addition, domain experts can better communicate their knowledge to other experts; an important consideration where different domains overlap and there must be an agreement among all of them. Domain experts for our case study were selected from academic institutions, which provide the dependency networks to diagnosis and control of pests. Also, we asked experienced farmers dedicated to grow tomatoes in HG's to provide their own rules. These two sources of knowledge complemented each other, resulting in a sound rule base to decide on the best course of action, should a disease be diagnosed. In the following section, we elaborate on the JAPIEST architecture, and give insights of the resultant rule base.

4. Conception of JAPIEST

The driving force behind the conception of JAPIEST is the possibility to disseminate knowledge to a vast number of HG's growers. Therefore, JAPIEST was designed to be accessed on the Internet, so that farmers can consult the expert system and obtain a diagnosis as well as the right treatment. Another design property of JAPIEST consists of providing different access levels according to the type of user. Access is provided to three kind of users: (i) the system administrator, who possesses the rights to modify the complete structure of the database and the rule base; (ii) the expert, who is granted modification of the rules, and (iii) the final user (farmer), who can only query the expert system and submit some questions or hints. In the following, we elaborate on the relevant modules of JAPIEST.

4.1. A modular system

JAPIEST possesses four relevant modules, interacting coordinately. They are a rule base, a database, a graphical support and the module dedicated to advice different kinds and levels of treatments, ranging from cultural practices up to the recommendation of the use on pesticides. The general design of JAPIEST is presented in Fig. 1.

In order to provide a right functionality, the interaction among modules was conceived as depicted in the Use Case diagram in Fig. 2.

To implement JAPIEST, the entire system is based on the Java language. Firstly, the access of the system is possible via Internet. Also, it is feasible to bridge the system with the inference engine, which is called *RULE* (Bigus & Bigus, 2002). At this regard, the intelligent system incorporates only the forward chaining of rules, because the initial values of the plant's symptoms are entered by the farmer directly in the work memory of the expert system, through the web site. Once the expert system gets a valid conclusion, the resultant disease or pest is used to query the treatment database. At the same time, JAPIEST offers a graphical representation of the candidate disease or pest inferred, so that the user could be able to validate the result. Whether the result is validated by the user, then the treatment database is queried. The connection to the

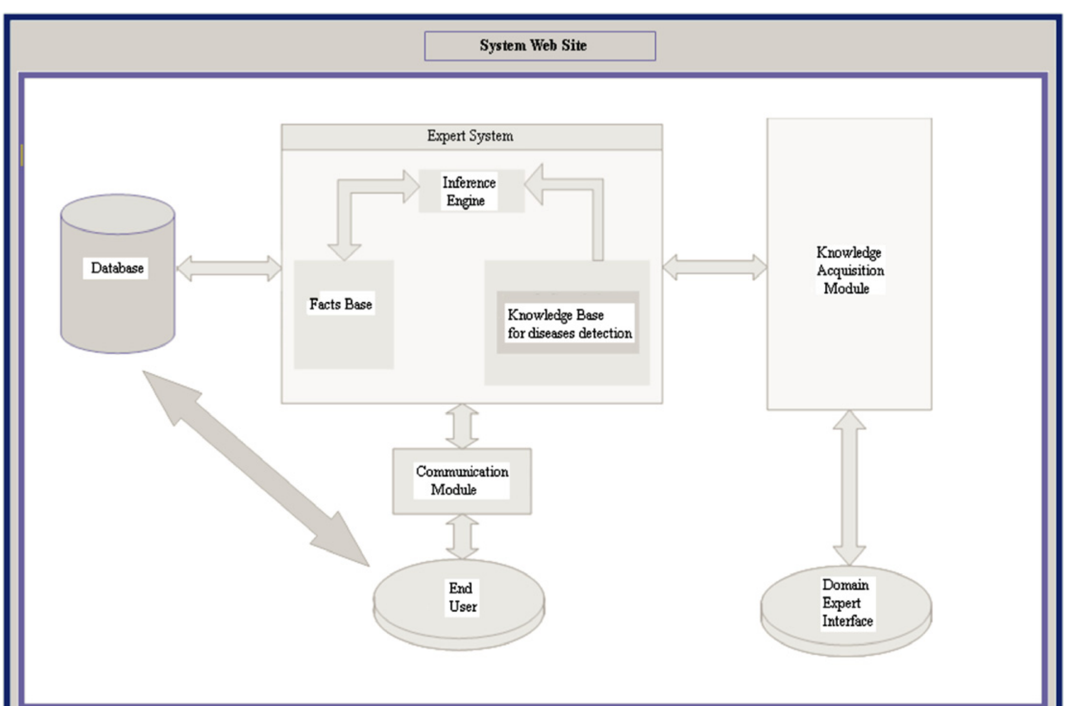

Fig. 1. JAPIEST Main Modules.

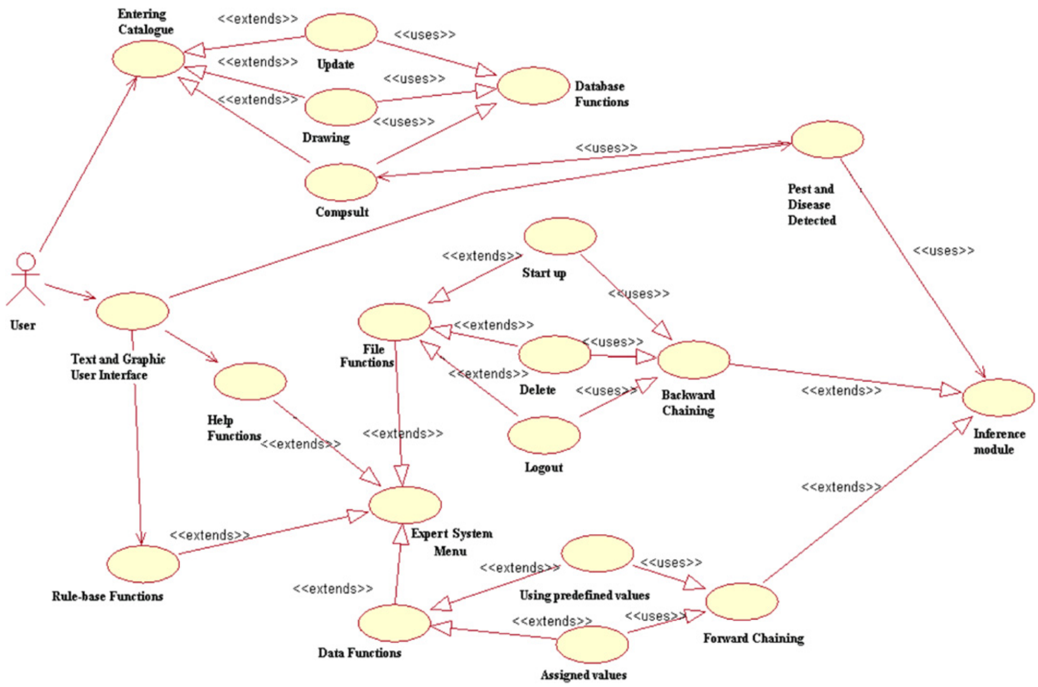

Fig. 2. JAPIEST Model with Use Case Diagram.

Data Base Management System (MySql) is transparent, because Java already possesses the appropriate drivers. As a conclusion, with the Use Cases design and the Java technology, we constructed an integral intelligent system, whose modules work coordinately to provide added value to HG's owners.

4.2. The rule base for the expert system

The extracted knowledge is condensed in a rule base, useful to determine the plague or disease that might be affecting the plants production. An excerpt of the rule base is given in the following, along with the Java codification of the rule.

```
IF Pest-cause = fungi
    AND percentage-humidity-range=90–100
    AND percentage-temperature-range=28–
30
    AND symptom-placement1=stem
    AND symptom-placement2=leaves
    AND symptom-placement3=Fruits
    AND especific-charateristic1=start-
on-inferior-leaves(olders)
    AND especific-charateristic2=Inju-
ries-collapse-on-stems-n-Fruits
    AND especific-charateristic3=rotted-
with-concentric-rings
    AND especific-charateristic4=yellow-
aureole-surrounding-the-rings
    THEN pest-type=Alternaria solani
(Tizon-Temprano)
```

The codification of the former rule can be obtained by

```
Rule Alternaria-Solani=new Rule(rb,
"Alternaria Solani",new Clause[ ]
{
    new Clause(CE, Equal, "Fungi"),
    new Clause(Rank-Humidity, Equal, "90–
100"),
    new Clause(Rank-Temperature, Equal,
"28–30"),
    new Clause(LocSint1, Equal, "Stem"),
    new Clause(LocSint2, Equal, "Leaves"),
    new Clause(LocSint3, Equal, "Fruits"),
    new Clause(CaractEsp1,Equal, "Start-
on-inferior-leaves(olders)"),
    new Clause(CaractEsp2, Equal, "Inju-
ries-collapse-on-stems-n-Fruits"),
    new Clause(CaractEsp3, Equal, "rotted-
with-concentric-rings"),
    new Clause(CaractEsp4, Equal, "yellow-
aureole-surrounding-the-rings")},
new Clause(TipoEnf, Equal, "Alternaria
Solani (Tizon-Temprano)"));
```

The conclusion obtained by the expert system is passed to the treatment database. The general design of the treatment database follows.

4.3. The database

Once the plague or the disease has been diagnosed, the system searches a recommended treatment, giving options

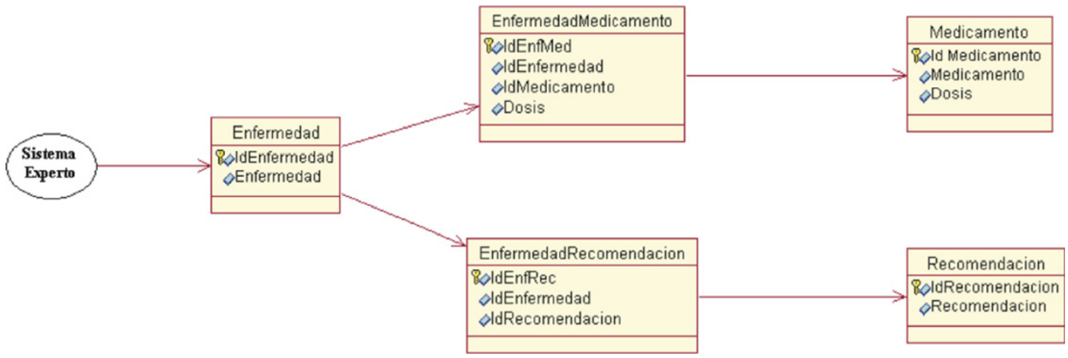

Fig. 3. Design of the treatment database.

to the user on what pesticides to use, and the right dose. These guidelines are set based on IPM best practices. The design of the database is given in Fig. 3.

5. JAPIEST illustrated

In the following, the information and actions taken by the modules are further explained. For the sake of giving more details, we describe briefly the tasks of the main modules and their corresponding goals.

5.1. Entering the information from user module

By a series of questions supported step by step by a graphical example, this module asks the user for general information about the general plants conditions (stem, leaves, fruits in case of a bearing stage of fruit set (see Fig. 4), roots, etc.) as well as the environmental conditions as Humidity, sun radiation, canopy air temperature, air temperature, etc., found in the HG. Former information is useful in HG to compute several variables, such as the Vapour Pressure Deficit (VPD).

5.2. Computing the Vapour Pressure Deficit

An important parameter in greenhouses plant production is the VPD, which is the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated. When the air becomes saturated, water will condense out to form clouds, dew or films of water over leaves. It is this last instance that makes VPD important for greenhouse regulation. If a film of water forms on a plant leaf it becomes far more susceptible to rot. On the other hand, as the VPD increases, the plant needs to draw more water from its roots (and if it is a cutting, dry out and die). For this reason the ideal range for VPD in a greenhouse is from 0.45 kPa to 1.25 kPa, ideally sitting at around 0.85 kPa. As a general rule, most plants grow well at VPDs of between 0.8 and 0.95 kPa (cf. Prenger & Ling, 2001).

To compute the VPD we need the ambient (greenhouse) air temperature, the relative humidity and if possible, the canopy air temperature. We must then compute the saturation pressure directly from the ambient temperature in °C as

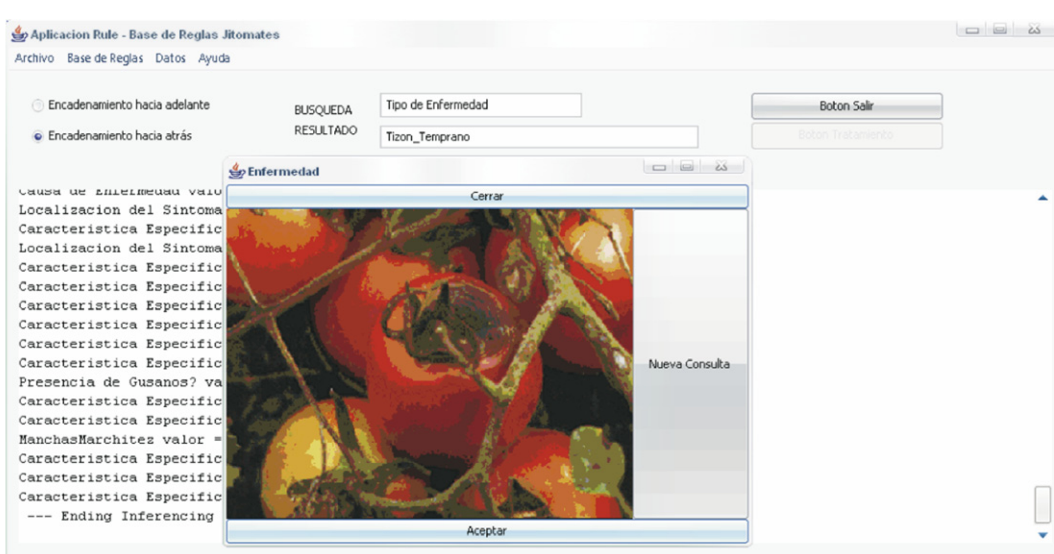

Fig. 4. Asking for the fruit condition with a graphical illustration.

$$vp_{sat} = 6.8947 \cdot e^{(A/T+B+CT+DT^2+ET^3+F\ln(T))} \tag{1}$$

Then,

$$vp_{air} = vp_{sat} \cdot RH/100, \tag{2}$$

Finally VPD is obtained as follows:

$$VPD = vp_{sat} - vp_{air} \tag{3}$$

where T_c is the temperature in °C, $T = 1.8 \cdot T_c + 491.67$ is the temperature of the air in K, $A = -1.04 \times 10^4$, $B = -11.29465$, $C = -0.027022355$, $D = 1.289036 \times 10^{-5}$, $E = -2.4780681 \times 10^{-9}$, $F = 6.5459673$, and RH is the Relative Humidity.

By computing the current VPD, JAPIEST can actually know whether the plant production is susceptible to develop diseases by some unbalanced environmental conditions or being amenable by a kind of pest.

5.3. Diagnosis and control module

Based on the first stage of the information provided by the user, different modules will be called in order to make a multi-expert diagnosis. JAPIEST then tries to determine the kind of pest and the level of infestation, to suggest a precise treatment which will be sorted by urgency level and available methods in the particular greenhouse (biological, mechanical, chemical, pesticides). Whether infestation, pest and/or disease is not severe, it is recommended to change some cultural practices. If a biological method can be applied and the net is active, then a link is established to

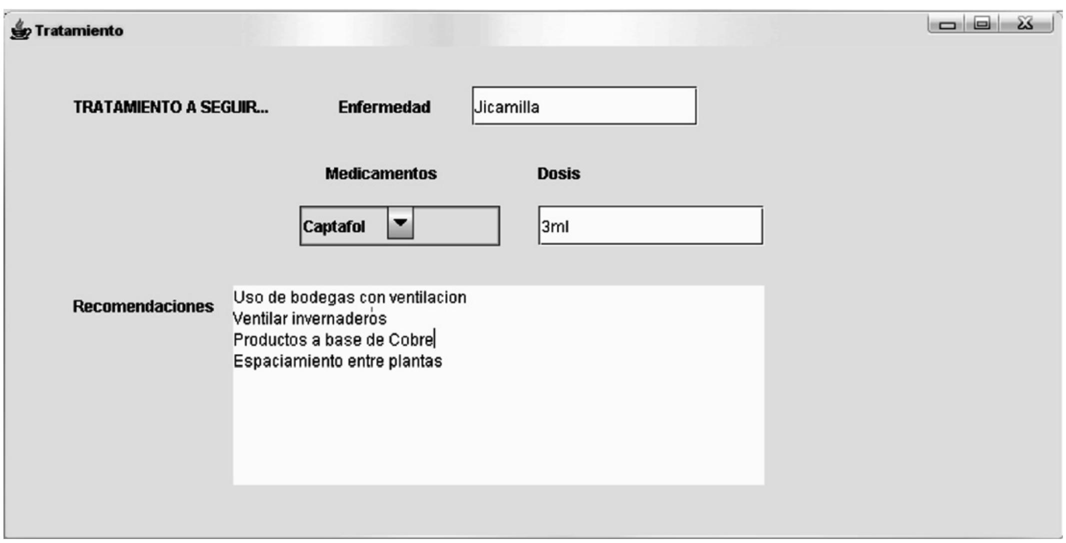

Fig. 5. Chemical treatment, application method and commercial name.

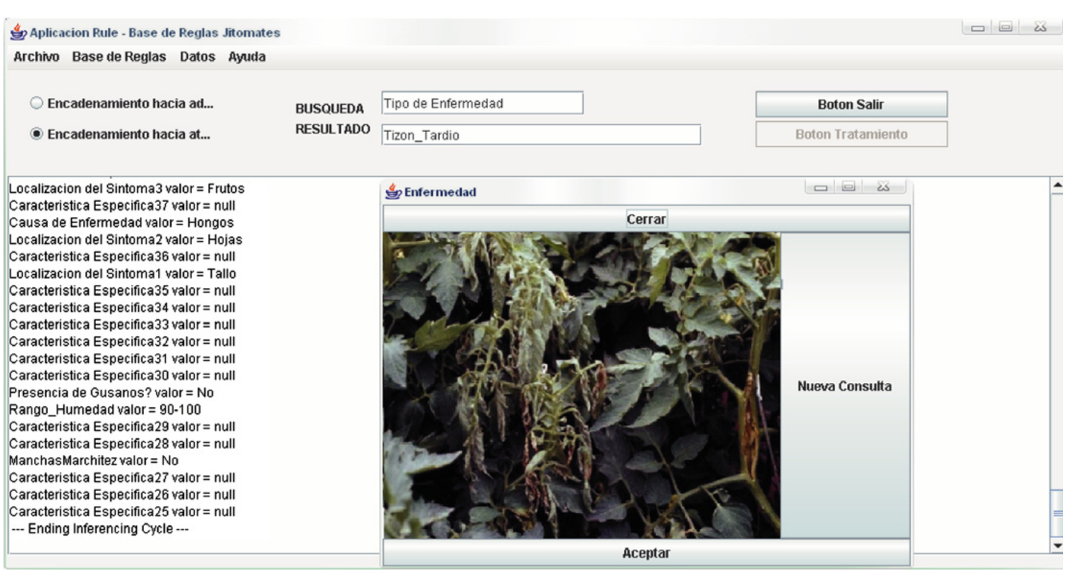

Fig. 6. Graphical support of JAPIEST results.

show the different biological treatments for a precisely plague presented (University, 2007). Finally, some chemical methods and their corresponding ingredient active or their commercial name are suggested (v.gr. Fig. 5) together with a dosage and some recommendations for the application.

In order to confirm that the pest and/or disease drawn by the system, holds as the most likely infestation, a graphical support is provided (v.gr. Fig. 6).

6. Concluding remarks and research perspectives

Based on an integrated development environment involving, Java, MySQL, RULE and some interconnecting modules, an expert system is presented to help growers with some helpful advices from experts in different domains. Since the decision to tackle the pest and diseases based exclusively on chemicals has shown a serious drawback, a new agriculture scheme requires to preserve plants production in an artificial regulated environment such as greenhouses, along with an Integrated Pest Management. JAPIEST provides correct answers to the integration of these different domain experts and growers by interfacing different terminologies, skills levels, and different levels of tackling the pest and disease based on the infestation level, taking into account biological and cultural practices, pesticides usage, and the chemical methods, involved in IPM.

Based on JAPIEST, it could be possible to provide AHG's with cooperation and autonomy capabilities in order to share information and knowledge for the maintenance of healthy crop production cycles. Some extensions can be targeted to the on-line supervision and management of: (i) main production, (ii) recollection (iii) packaging, and (iv) delivering. Moreover, the integral project on course also considers to feed nutrients automatically, and to control the environmental variables of the Automated Hydroponic Greenhouses.

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