RESEARCH PAPER

Integrated management of Bayoud disease on date palm (*Phoenix dactylifera* L.) caused by *Fusarium oxysporum* f. sp. *albedinis* in Algeria

Gestion intégrée de la maladie de Bayoud sur le palmier dattier (Phoenix dactylifera L.) causé par Fusarium oxysporum f. Sp. Albedinis en Algérie

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Abstract

Date palm (*Phoenix dactylifera* L.) is one of the most important fruit trees growing in Algeria, Arabian world and some neighboring countries represents a good crop economy sources for many farmers. Date palm diseases are among the major factors that affecting the products. The agent pathogen F.oxysporum f. sp. Albedinis (Foa) is a soil-borne fungus that cause dangerous disease called Bayoud. To control this tracheomycosis by using chemical methods is uneconomic and inefficient. The practical way for controlling the disease by IPM (Integrated disease management), focused by cultural methods, biological control with antagonistic and mycoparasitic microorganisms, and genetical control by selecting of resistant high quality cultivars, it may will be the best solution against this disease.

Key words : date palm, Bayoud, IPM, antagonistic microorganisms, resistant cultivars.

Résumé

Le palmier dattier (Phoenix dactylifera L.) est l'un des arbres fruitiers les plus importants en Algérie, et dans le monde arabe et dans certains pays voisins comme le Pakistan et l'Indonésie. Les maladies du palmier dattier sont parmi les principaux facteurs qui affectent la production. L'agent pathogène Fusarium oxysporum f. sp. albedinis (Foa) est un champignon du sol qui cause une maladie dangereuse appelée Bayoud. La lutte chimique contre cette trachéomycose est non rentable et inefficace (le parasite se localise au niveau des vaisseaux du bois). La méthode pratique pour lutter contre la maladie est par la lutte intégrée (IPM), axée sur les méthodes culturelles, biologiques avec des microorganismes antagonistes et mycoparasites, et aussi la génétique par la sélection des cultivars résistants de haute qualité, qui sera à l'avenir la meilleure solution contre cette maladie grave.

Mots-clés: *palmier dattier, Bayoud, lute intégrée, microorganisms antagonistes, cultivars résistants.*

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1. Introduction

The vascular fusariosis commonly named Bayoud, caused by *Fusarium oxysporum f. sp. albedinis* (Foa), is the most destructive fungal disease of date palm (*Phoenix dactylifera* L.) (Azouaou-Ait Kettout et al., 2010). The impact of this disease is most severe in North Africa particularlyin Morocco where 2/3 of palm trees were destroyedso far (Fernandez et al., 1995), and 1/3 in Algeria (Fernandez et al., 1995). Since its appearance, the problem has developed as an epidemic disease.In one century the whole area of date palm plantations in Morocco was affected and only a fraction of the initial number of trees is still productive. The spread of this disease in Morocco can be explained by the advancement from one oasis to another along the river valleys, for example, from Morocco, the Bayoud entered in Algeria via oases close to the borders in Moroccan frontiers like Figuig oasis. From there the fungus travelled via the caravan-routes in infested wood and branch to the oases of central Algeria (Benzohra et al., 2015). Actually, the oases of Metlili (1950), Ghardaia (1965) and El-Golea (1978) in Central Algeria are the most distant areas where *F. oxysporurn f. sp. albedinis* (FOA) has been detected (Djerbi, 1987), (Figure 02). There are also other new contaminations in western Algeria's palm groves like Mansoura region at Mzab province in 2013, Moghel and Ouled Khedir regions at Saoura province in 2016 (Benzohra et al., unpulished results).

As for most vascular diseasescaused by soil-borne pathogens, fighting strategies are very limited or quasi-inexistent. Among these strategies, the deploymentof Foa-resistant cultivars appear to be the most suitable andeconomic approach (Djerbi, 1990; Louvet, 1991), but naturalresistant genotypes are scarce with a poor quality of fruits and the date palm breeding system is laborious and offered only asa long-term plan (El Modafar et al., 2010). Alternative controlmeasures such as the use of Foa antagonists are, therefore, necessaryand need to be explored (Bouguedoura et al., 2015).

F. oxysporurn f. sp. albedinis (Foa) is an imperfect ascomycete present in the soil which becomes virulent incontact with the roots of date palm. Various studies (Matheron and Benbadis, 1990 ; Rahmania, 2000), suggest that the penetration of the fungus is via the roots. Then, It invades the vascular system of the palms, causing gradual leaf drying andbleaching, hence the name (Bayoud means white). When the terminal bud is reached, the tree dies within a few months or a few years after the beginning of the disease. All attempts at chemical control against this scourge have been unsuccessful (Saaidi, 1979). Various control measureshave been used to counteract the general effects of Bayoud, such as improving culturalpractices, biological and chemical applications, as well as genetic control techniques. Furthermore, genetic control, the use of resistant cultivars, remains the most promising and least toxic to the environment.

The generalized resistance of cultivar Taquerboucht to Bayoud is remarkable in theoases of Tidikelt (In Salah), Saoura (Bechar), Mzab (Ghardaia), Touat (Adrar) and Gourrara (Timmimoun). It is a cultivar that is endemic to the western regions; it requires development and proliferation along with other resistant cultivars or thecreation of new cultivars combining good fruit quality and strong resistance to thedisease. The selecting of resistant cultivars or khalts (date palm trees issued from seeds), is a long term undertaking, which has been going on since 1983 in Algeria. The biological control research using microorganism antagonists has resulted in the characterization and identification of new Saharan species of promise to combat bayoud (Sabaou and Bounaga, 1987).

This work has the objective to present the factors of disease spread, symptoms of bayoud disease, and different methods to control Bayoud disease on date palm in Algeria, by cultural, biological and genetical methods to obtain an integrated disease management against this disease.

2. Symptoms of Bayoud disease

The symptoms are very typical, with initial wilting and discolorationof one or a few leaves. The discoloration starts at the base of one side (Fig. 1, A, B), developing progressively to the top and returning to the other side of leaf. Affected leaves will die in a few days to several weeks. Successively also other leaves show symptoms and the disease progresses to the central leafcluster (Fig. 1, C). When the terminal bud is affected, the tree will die (Fig. 1, D).This process can take from 6 months up to 2 years. At that time, only a part of the roots and the vascular bundles of the stern show a reddish-brown discoloration.

3. Factors for disease propagation and development

For the spread of the disease, we can state some important ways, which can differ according to the situation. A spread between oases occurs mostly by exchange of branchs, originating from infested mo-

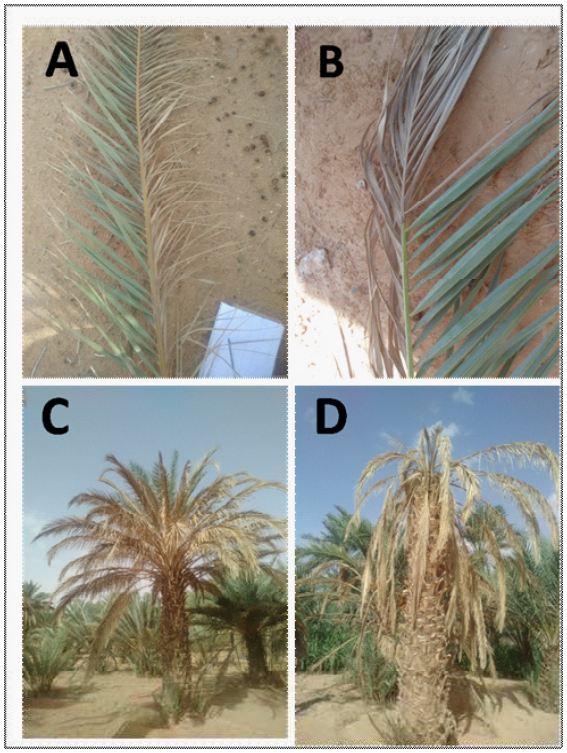

Figure 01. Symptoms of Bayoud disease on different parts of date palm tree, Saoura region. A, B : discoloration on one side of spine ; C : the disease progresses to the central leaf cluster; D: the total mortality of tree.

ther plants, but also by the tradein woody materials, made from infested wood. It is confirmed by the history of the epidemic that propagation from one oasis to another is mostly correlated to caravan-routes of nomads, who take infected palms with them. In case, there is a river connection between oases (as is the case of Draa valley in Morocco and Saoura valley in Algeria), spread can happen via the river water too. The spread between plantations in the same oasis can be occurred in the same way, the irrigation water is here very important. Another important factor is the wind which can transport infested soil and spores all around the oasis, as well as the transportation of infested wood by man (e.g. to an incineration place), Spread within the plantation is mostly seen starting by one of a few infested trees and progressing to many foci. This is due to transport infested soil and irrigation water. Development of the individual foci is mostly circular, as a result of the root contact between diseased and healthy trees.

Development of disease symptoms after infection of a tree is strongly dependent on the cultural practices (Freeman and Maymon, 2000). Intensive irrigation-results in a better development of trees and a higher production of quality dates, but accelerated also the development of Bayoud. Cropping of other plants in the shade of date palmsincreases the biological activity of the soil and can also increasethe saprophytic growth of Foa. Especially, when crops aregrown which can act as symptomless carriers, such as lucerne (Medicago sativa L.) or henna (Lowsonia inermis L.), Foa growth will be influenced significantly.

4. Integrated disease management of Bayoud

Because the date palm is one of major important trees in the Sahara communities and the ecosystem, control of the disease will reduce desertification and increase food supply and income ofthe local inhabitants (Benzohra et al., 2015). Coming to a better understanding and development of controlmethods for Bayoud disease; Main research topics are:

a) Fundamental studies on disease epidemiology, pathogen detection and rapid identification;

b) Cultural and biological control methods;

c) Selection and breeding for resistance and high quality;

d) in vitro propagation;

e) Eradication of infested foci.

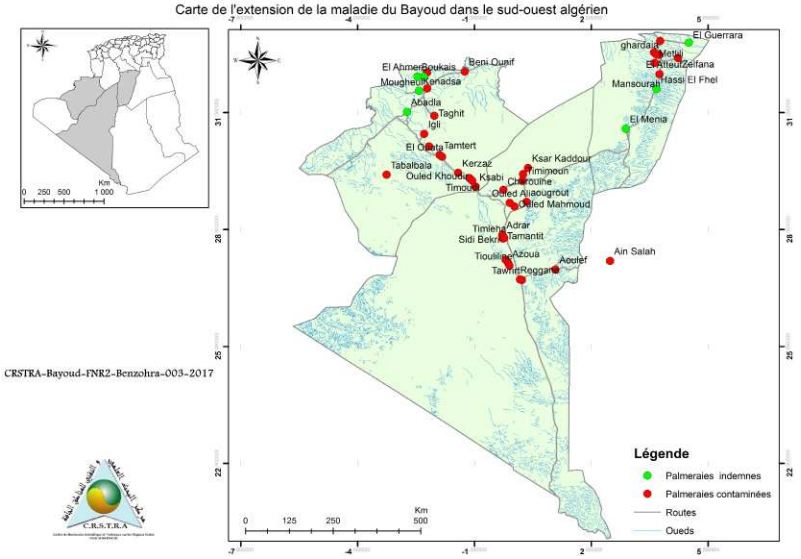

Fig. 02: Map of Algeria indicating the different areas with date palms; those in red colour are infested groves by Bayoud, those in green are healthy groves (CRSTRA-FNR-Bayoud-2017-03).

4.1. Cultural control

In cultural control, the measures to protect healthy areas are being implemented in the palmary. The European and Mediterranean Plant Protection Organisation (EPPO), Paris, France) recommended in 1990 that the phytosanitary countries should prohibit the importation of material from infected countries.

Algeria and Morocco have set up internal phytosanitary controls that prevent the transport of discharges from contaminated areas. In the case of early detection of a new Bayoud outbreak in a healthy area, eradication is the means of control used. After the delimitation of the fireplace with a sufficient margin of safety, the trees are turn off and incinerated on site; the soil is subsequently sterilized with chloropicrin. This technique has been improved by the use of a mixture of methyl bromide and chloropicrin. In recent years the use of chloropicrin was completely forbidden due to its dangerous and its low effectiveness. Indeed, methyl bromide possesses a strong capacity for penetration into the soil and ensures good sterilization (Frederix and Den Brader, 1989). The area thus treated is fenced and forbidden to cultivate for a long period. But this method is very expensive, polluting and its effectiveness is not guaranteed. Despite these disadvantages, it remains the only method applied, especially in Algeria.

4.2. Biological control

4.2.1. Mycorrization

Mycorhization of date palm is an important axis, as it concerns both the physiological aspect of the plant (growth and production), and the phytopathological aspect (contribution to fight against Bayoud). In fact, mycorrhization is the biological element used by plants, in symbiosis with fungi, to strengthen resistance to soil pathogens (Barttschi et al., 1981), and to water and saline stresses (Tinker, 1975 ; Duddridge et al., 1980).

The effect of endomycorhization by Glomusintraradices on the growth of the date palm and its resistance to attacks by *Fusarium oxysporum f. sp. albedinis* on different substrates was studied). Mycorrhization improved seedling growth by approximately 26%. The presence of the pathogen caused a biomass decline of 82.5% with a mortality rate of 100% whereas the presence of mycorrhiza reduced this mortality rate to 55% (Souna et al., 2010).

Mycorrhization has improved the growth of date palm plants by improving water supply and mineral nutrition. This improvement is due to a large surface area of absorption resulting from the development of the external mycelium to the endophyte, thus allowing the exploitation of water and minerals beyond the root depletion zone (Tinker, 1975; Owusu and Wild, 1979). It is very marked at the level of the aerial part and not in the root part. It can therefore be said that

mycorrhization improves the growth of the aerial part by increasing the surface area of photosynthesis (number of leaves, length, and green biomass) and consequently more nutrients than the mycorrhizal fungus can use.

Mycorrhization also showed a protective effect against Foa attacks. Oihabi (1991) observed a reaction in the mycorrhizal date palm infected with the same pathogenic agent by the development of microfibrils enveloping the pathogenic hyphae causing their degeneration. This has already been shown by Dehne (1982) indicating that the influence of mycorrhizae on vesicles and arbuscules remains limited to the sites of their location in the root. Mycorrhizal fungi never colonize the meristematic zone or the central cylinder. They progress to the apex of the root by colonizing tissues newly formed by the radicular meristem. It is at the level of the bark that the only possible encounter between Foa and the mycorrhizal fungus occurs where it inhibits the activity of the pathogen (Oihibi, 1991). However, the progression of the latter at the level of the central cylinder prevents the total protective effect of the mycorrhizae.

Examination of soils in many cases has shown that even if the density of inoculum was high and the conditions for disease settlement were favorable, disease severity and incidence has remained low on susceptible plants. Varieties of microorganisms, such as non-pathogenic *Fusarium spp. and fluorescent Pseudomonas,* have been shown to be involved in this soil suppressive ability of Fusariosis (Sneh, 1998).

4.2.2. Biological agents

In the case of date palm, several studies have reported the non-receptivity of certain soils to the development of Bayoud (Sedra and Maslouhy, 1995). This non-receptivity has been related, later, to the phenomena of competition between the causal agent Foa and other non-pathogenic *Fusarium* species predominant in these soils, and to the antagonism of several bacteria, actinomycete and fungi (Maslouhy, 1989).

The use of biological agents to enhance the plant defense mechanisms against pathogens represents an ecologically friendly alternative to pesticides repeatedly used to control plant diseases (Dehne, 1982). This strategy has more significance against soil-borne pathogens such as Bayoud on date palm, for which fighting strategies are very restricted or quasi-unavailable. The deployment of such strategies should have a great impact taking into account the perennial aspect of the crop, the socio-economical and ecological issues to use chemicals within date palm groves and the long-term solution that represent the breeding program.

The success of biological control agent in turning-on plant defense mechanisms against pathogens depends of their ability to establish metabolically active populations that could mediate host protection and/or compete directly or indirectly with the pathogens for nutrient resources. Against soil-borne pathogens, several studies have reported the use of endophytic and plant growth-promoting bacteria, including Bacillus spp. and Pseudomonas spp. (El-Hassni et al., 2007).

4.3. Genetical control

The use of resistant date cultivars remains the only effective method for controlling vascular fusariosis (Djerbi and Sedra, 1986 ; El Modafar et al., 2010 ; Saleh et al., 2015). In 1972, Among 32 Moroccan varieties tested in the experimental stations of INRA in Errachidia and Zagora, only six varieties showed total resistance to Foa. These varieties are Black Bousthami, White Bousthami, Iklane, Tadment, Sayre Layalet and Bouffaggous or Moussa. Another resistant variety (Boukhanni) was found 20 years later (Sedra, 1993). Unfortunately, all these varieties have a low date quality, which is a handicap to their large-scale transplant (Sedra, 2000). Other studies have been carried out on resistant clones of good quality obtained from natural seedlings or controlled crosses such as Ennajda (INRA-3014), Al-Amal (INRA-1443), Al-Fayda (INRA-1447), Bourihane (INRA-1414) and Mabrouk (INRA-1394) were selected. The Ennajda clone (INRA-3014), cultivated on a large scale for the reconstruction of the Moroccan palm grove, produces good quality fruits accepted by phoeniculturists (Sedra, 2003 ; 2005 ; 2011). In Algeria, a lot of prospections of resistance sources in our oases, were showed a very limited number of resistant cultivars like Taquerboucht, Tamedjouhert and Figuig (Table 01).

5. Conclusion

In conclusion, this study has investigated a search of different methods to control Bayoud disease using cultural, biological and genetical control.

The cultural method is important to protect the healthy oases, by stopping spread of Bayoud disease. It is necessary to destroy the inoculum in infested foci as efficiently as possible, before any other measure can be taken into account. For that, a carefulclearing-up of infested foci, with incineration of all woody mate-

Table 01: Resistant and susceptible date palm cultivars to Bayoud disease, from Saoura, Touat, Gourrara and Mzab regions.

Regions	Resistant cultivars	Tolerant cultivars	Susceptible cultivars
Touat	Taquerboucht	Agharres, Taguezza.	H'mira, Tinnaceur, Tenquor, Ghemmou, Madjhoul. Taquerbucht ×551009 (F1).
Gourrara	Resistant cultivars	Tolerant cultivars	Susceptible cultivars
	Taquerboucht, Tamedjouhert, Tilemsou (Hmira).	Agharres, Afilal, Adem Bara, AdemBoula, Minchar.	Tinnaceur, Tenquor, CheikhM'hamed, Adem Bara, Abdessalem, Mahdi, Aicha, DeglaGhlida, Timliha.
Saoura	Resistant cultivars	Tolerant cultivars	Susceptible cultivars
	Taquerboucht, Figuig, Tenghagh.	Hartan, Hmira et Charka.	Feggous, Mahdjouba, Tinnaceur, Boudjeloude, Madjehoul, Bouskri, Reteibiya.
Mzab	Resistant cultivars	Tolerant cultivars	Susceptible cultivars
	Taquerboucht.	-	H'mira, Tinnaceur, Deglet-Nour, Ghars.

rialon the spot, is absolutely necessary. In connection with this, the elimination of inoculums, resting in the soil, is also necessary.

The biological control seams by the mycorrizical microorganisms and in vitro selected Foa antagonists, some isolates of Bacillus spp., Pseudomonas spp., and Rahnella aquatilis, were having also the ability to induce defense reactions of date palm without causing any seedlings mortality. Further studies are conducted in order to highlight the in planta effect of these antagonists on the endophytic development of Foa, and to set up the ecological conditions required for their settlement within the date palm rhizosphere.

The genetical control is by selection and in vitro micro-propagation of new resistant cultivars like Taquerboucht, Tenghaghand Tamdjouhert.

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