Potential socio-economic impact of *Xylella fastidiosa* in the Near East and North Africa (NENA): Risk of introduction and spread, risk perception and socio-economic effects

Gianluigi Cardone*, Michele Digiaro*, Khaled Djelouah*, Hamid El Bilali*, Michel Frem**, Vincenzo Fucilli**, Gaetano Ladisa*, Cosimo Rota*, Thaer Yaseen***

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Abstract

The serious damages of Xylella fastidiosa (Xf) in Euro-Mediterranean countries (e.g. Italy, France, Spain) raise concerns for the Near East and North Africa (NENA). Therefore, a study was performed to a) assess the risk of Xf entry, establishment and spread in target NENA countries (viz. Algeria, Egypt, Jordan, Lebanon, Libya, Morocco, Palestine, Syria, Tunisia); b) analyze risk perception and preparedness level among agri-food chain stakeholders; c) estimate potential socio-economic impacts for olives, grapes and citrus. Pest risk appraisal suggests that Morocco, Lebanon, Palestine and Syria are the most exposed to Xf risk; other target NENA countries, except Algeria, have an intermediate risk. Risk perception analysis shows that governance efficacy and practices application can be improved by involving stakeholders and raising their awareness. Socio-economic impact assessment indicates declining yields, production, profitability, export, employment, and increasing import, with the highest impacts relating to olives, then citrus and grapes. The study suggests that the expected socio-economic impacts are unacceptable and require urgent action against Xf at national and regional levels.

Keywords: *Olive growing, Viticulture, Citrus production, Transboundary plant pests, Pest risk assessment, Profitability, Employment, Trade, Olive quick decline, Risk management.*

1. Introduction

Xylella fastidiosa (*Xf*) is a destructive bacterial pathogen that attacks a wide range of plant species worldwide [about 600, according to EFSA PLH Panel (2020)]. It is a xylem-limited gram-negative bacterium of the family *Xanthomonadaceae* and is considered a serious threat to agriculture, the environment and the economy as a whole. *Xf* causes severe direct damages, as in the case of grapevine Pierce's disease, olive quick decline, citrus variegated chlorosis, phony peach, coffee leaf scorch and other diseases of plum, almond, oak and oleander, and indirect

* International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM-Bari), Valenzano (Bari), Italy.
** Department of Agricultural, Environmental and Territorial Science (DISAAT), University of Bari, Bari, Italy.
*** Regional Office for Near East and North Africa - FAO (FAORNE), Cairo, Egypt.
Corresponding author: cardone@iamb.it

economic impacts on exports. In nature, it is transmitted by xylem-feeding hemipterans (cycadellids, aphrophorids and cercopids) (EFSA PLH Panel, 2015).

Since the detection of *Xf* in Italy, in autumn 2013, and the serious damages induced to the olive trees were officially reported (EFSA PLH Panel, 2015), the interest of the international community in this bacterium has considerably grown, especially because of the risks of its possible spread to the entire Euro-Mediterranean area. Concern to this pathogen was increased by reports of new outbreaks of several *Xf* strains in various countries in Europe (France, Spain, Germany, Portugal and Belgium) and the Middle East (Iran, Israel), suggesting that they were introduced from different countries and on different types of goods (EPPO, 2016; EPPO, 2019a; EPPO, 2019b).

In Apulia (Southern Italy), from 2013 to 2017, *Xf* affected 53,800 hectares of olive groves and about 6.5 million trees (Scholten *et al.*, 2019). Italia Olivicola (2019) quantified the loss of olive oil production over the period 2017-2019 at about 390 million euros, which rose to about one billion euros if one also considers the economic activities downstream (mills, bottling plants, trade and distribution). In the same years, olive oil production decreased by an average of 29,000 tons per year, resulting in a 9.5% decrease in the Italian production. In addition to the economic impact on agriculture, *Xf* also affected centenarian and monumental olive trees, considered inestimable social, historical, landscape and cultural value.

The bacterium also has a severe impact in other world countries. The annual cost of Pierce's disease of grapevine in California was estimated at 104 million US$ (Tumber *et al.*, 2014), while costs due to *Xf* infections on the oleanders on Californian highways were estimated at US$ 125 million (Henry *et al.*, 1997). In New Jersey, bacterial leaf scorch affected 35% of oak trees (Gould *et al.*, 2004), while in Brazil, citrus variegated chlorosis caused the removal of more than 100 million citrus trees since its discovery in 1987, with a current cost for its control of about US$ 120 million per year (IPPC, 2017).

The numerous interceptions of *Xf* on different commodities at various points of entry in Europe have also highlighted the extreme vulnerability of the quarantine system in place, in a world increasingly globalized and characterized by the intense movement of goods and people. At the same time, the epidemiological characteristics of the bacterium (high number of plant hosts, adaptability to different environments and climates, transmission through different vector species) leave little margin for its eradication once introduced and established in a given territory (EFSA PLH Panel, 2019). Therefore, for each country, it is of utmost importance to immediately deal with the problem and implement preventive measures, aiming to prevent the introduction and establishment of this pathogen. The risk of *Xf* entry and spread in the countries of Near East and North Africa (NENA) is high (Yaseen, 2019) and the resulting losses in the main host crops (e.g. olive, grape, *Citrus spp*.) could pose a serious threat for food security and economic growth in the whole region (Impiglia and Lewis, 2019; Scardigno *et al.*, 2017).

In this context, a study was carried out to assess the potential economic and social impacts of a possible introduction and establishment of *Xf* in the NENA countries. Specifically, the study addressed three separate, yet interconnected, research questions: a) What is the potential risk of introducing *Xf* on the main crops in target NENA countries?; b) What is the current risk perception and level of preparedness for *Xf* by policy makers and stakeholders in the agro-food chain in the NENA countries?; and c) What are the potential socio-economic impacts (e.g. productivity, value of production, profitability) of *Xf* for the main crops (i.e. olive, grape, *Citrus spp*.) in NENA region?

In doing so, the paper presents an innovative approach with respect to previous publications as it analyses jointly the issues of risk analysis, risk perception and socio-economic impacts. For this, it develops an ad-hoc methodology (where the results regarding one issue fed in the analysis of the next one) and discusses the cross-implications among the different issues; it goes even further to provide some orientations and recommendations, to be compiled in a regional strategy, to better prepare the NENA region to prevent the introduction/ spread of the bacterium and/or to reduce its potential impacts on the agri-food sector and rural communities. The results of the analysis will also foster and provide a baseline for knowledge exchange and international collaboration among experts in the region.

2. Methods

The study implied implementing a preliminary methodological approach for each activity, as described in the following paragraphs. Data used in the present study were secondary data from the literature (articles, books, reports) and databases as well as primary data collected through ad-hoc surveys. Indeed, the study is based on data retrieved directly from official public sources, whereas in case of lack of data recource was made to interviews (in the form of questionnaires) addressed to different actors of the agri-food system in NENA countries (e.g. producers/farmers, researchers, officers of the national phytosanitary services, etc.). This approach was adopted in order to overcome difficulties relating to the availability of reliable data on *Xf* in NENA countries.

2.1. *Assessment of the risk of X. fastidiosa introduction, establishment and spread in NENA countries*

The study was based on data and information retrieved from official international and/or national public sources. In contrast, when the information was lacking or inexistent, the data were acquired through interviews addressed to policymakers and officers of the national phytosanitary services.

In the first part of the study, the potential risk of introduction, establishment and spread of *Xf* in the NENA countries was assessed, considering the case studies of Algeria, Egypt, Jordan, Lebanon, Libya, Morocco, Palestine, Syria and Tunisia, and focusing the attention on the main host crops that can be infected by this bacterium (viz. olive, grapevine, citrus, stone fruit and ornamental species).

In this context, a questionnaire (see Table 4) was addressed to the selected countries, in order to obtain appropriate information for the assessment of the *Pest Risk Introduction* (PRI) (first 4 questions) and of the *Pest Risk Establishment and Spread* of *Xf* (PRES) (last 6 questions). Data and information for the questions 1, 2, 7, 8 and 9 were retrieved directly from official public sources, whereas for the questions 3, 4, 5, 6 and 10 they were obtained from the answers of plant protection and/or quarantine service officials of the respective countries, as well as by officials of plant protection institutes or extension services.

For each question, three different response options were proposed, corresponding to high, medium or low risk, with assigned scores of 6, 3 and 1, respectively (Rogg *et al.*, 2003).

As the questions had a different relative weight in the determination of the overall potential risk, the score obtained for each question was multiplied by a different partial coefficient ("c") whose value was established by a panel of experts from different scientific institutions. The sum of the partial coefficients for each of the two groups of questions (viz. introduction; establishment and spread) was equal to 1.00.

Therefore, to determine the PRI of the bacterium in each country, the products "score x c" of each of the four initial questions were summed up. Similarly, the PRES of the bacterium was determined by taking into account the last six questions and the same procedure.

Considering that the score for each of the ten questions is variable from 1 to 6, and taking into account the partial coefficients for each question, it follows that the overall risk level for each country may vary from a minimum of 2 to a maximum of 12. Therefore, it was established by a panel of experts that the level of risk should be considered low for values ranging from 2.0 to 4.0, medium from 4.1 to 6.0, high from 6.1 to 12.0.

2.1.1. *Risk assessment of X. fastidiosa introduction*

The answers to four different questions (Q) (Table 4) were considered to assess the risk factors, which are analyzed separately below.

Q 1. In the long-distance spread of *Xf*, the role played by the exchange of infected material between countries is fundamental. Consequently, the PRI of *Xf* in a "free" country is strongly related to the volume of commodities potentially *Xf*-carriers imported from countries where the bacterium is already present.

At present, *Xf* infections have been officially reported in numerous American and some European countries (Italy, France, Spain and Portugal) as well as Iran, Taiwan, and Israel.

For each of the studied countries, the volumes of goods (grouped by significant categories) imported from those countries (except for Israel, which was only more recently identified as an infected country) were considered.

The risk was considered low for import, in million tons/year, < 1, medium from 1 to 3 and high if > 3.

Q 2. This parameter is also directly related to *Xf*-PRI. Considering that currently, the countries officially infected by *Xf* are physically distant from those analyzed in this study (the only exception is for the very recently discovered outbreak in Israel), only airport and port entry points of goods were taken into consideration, while road entry points were omitted.

The risk was considered low for the number of pathways < 10, medium from 10 to 20, and high if > 20.

Q 3. The presence of competent and technically trained personnel as well as efficient laboratories in terms of number and necessary equipment increases a country's ability to prevent the entry of *Xf*, allowing it to promptly intercept its presence and to apply quick and efficient countermeasures.

Accordingly, the risk was considered low when the level of readiness of the country was assumed to be good, medium when sufficient, high when insufficient.

Q 4. The availability of adequate legislation to prevent the introduction of *Xf* and, more generally, the quarantine of harmful organisms can help to reduce the *Xf*-PRI in a country due to its faster response capacity.

The risk was considered low when the regulatory status of the country (i.e. general legislation on quarantine pests and specific measures for *Xf*) was considered good, medium in the presence of only general legislation on quarantine, high when no legislation was present.

In consideration of the different relative weights in the determination of the overall potential PRI, partial coefficient value c= 0.3 was assigned to Q 1, 3 and 4, and c= 0.1 to Q 2.

2.1.2. *Risk assessment of X. fastidiosa establishment and spread*

Six different parameters (Q5 to Q10 in Table 4) have been considered to assess the risk factors that are analyzed separately below.

Q 5. The availability of a proven surveillance program to combat *Xf* and/or other harmful quarantine organisms reduces the risks of the bacterium establishment and spread in the country due to the faster ability to intervene.

The risk was considered low if the regulatory status was present and implemented, medium if present but not implemented, high if absent.

Q 6. The natural transmission via insect vectors plays an important role in the short distance spread of *Xf*. Considering that many Hemiptera species of sharpshooter leafhoppers (Cicadellidae), spittlebugs (Cercopidae) and cicadas (Cicadidae) are considered as potential vectors of *Xf* strains and that one of the most efficient vector, *Philaenus spumarius*, seems to be present in several Mediterranean countries, it is evident that the easy spread of *Xf* will be highly influenced by the presence of vector species, their transmission efficiency and their spread. Given the low importance assigned in the past to this group of species due to the low direct damage to plants (their importance has been strongly re-evaluated for indirect damage as vectors of pathogens), there is currently little data in the literature on their actual distribution in different countries.

For this parameter, the risk was considered low if the rate of potential vectors was deemed low, medium if vectors were present but not abundant, high if present and abundant.

Q 7. There is a lack of data on the range of temperatures over which the bacterium can thrive, which makes it very difficult to assess the limit to its distribution in the NENA countries. Besides, the climate can also influence the survival of *Xf* vectors, as well as that of its main and alternative hosts.

In general, extreme climatic conditions, such as those typical of arid, semi-arid areas or high altitude areas, can be considered as limiting factors for the spread of the bacterium.

Therefore, the risk was considered low if the "climatically favorable" areas were less than 15% of the country area, medium from 15% to 30%, high if more than 30%.

Q 8. The high *Xf* polyphagia enhances the PRES, and consequently complicates the possibilities of its containment or eradication. To date, about 600 plant species are known to be infected by the different *Xf* subspecies, including cultivated and spontaneous species, herbaceous, shrubby and woody plants, in cultivated fields, gardens, parks, woods and forests. Consequently, the more abundant, in number and distribution, are the host plant species present in a country as an alternative to the cultivated crops, the greater is PRES of *Xf*.

Accordingly, the risk was considered low if the rate of agricultural and forestry land was less than 25% of land area, medium from 25% to 50%, high if more than 50%.

Q 9. The PRES of *Xf* is directly related to the diffusion in the country of the cultivated host species of the bacterial strain introduced. In particular, this risk increases when these crops are significantly present in certain areas, thus facilitating the dissemination by vectors.

For this parameter, the risk was considered low if the rate of area cultivated with the main host crops of *Xf* was less than 5%, medium from 5% to 10%, high if more than 10%.

Q 10. Among the measures to counter the spread of *Xf*, the use of "certified" healthy plants is undoubtedly one of the most effective. It permits to avoid potential outbreaks of infection from which the disease can spread further, and repopulate, with a large margin of safety, areas that have been subject to previous eradication programs.

The risk was considered low when a national certification program was present and implemented, medium when present but not implemented, high when it was absent.

In consideration of the different relative weight in the determination of the overall potential risk, a c= 0.25 was assigned to Q 6 and 7, c= 0.2 to Q 5, and c= 0.1 to Q 8, 9 and 10.

2.2. *Analysis of the perception of the risk and level of preparedness to X. fastidiosa among policymakers and agro-food chain stakeholders in NENA countries*

The main scope of this survey is to establish more effective mechanisms and tools to prevent the spreading of *Xf* and manage the risk of the disease onset, thus mitigating its impact. In particular, the aim is to analyze the organizational setting, attitudes, and degree of understanding of relevant actors and stakeholders at the national and territorial level that may be involved in the disease's management.

In practical terms, the collection of answers to the questionnaire survey will contribute to achieving four main purposes:

1. *Raise the point of view, identify knowledge gaps and assess the perception* of relevant actors and stakeholders about *Xf* disease and containment plans to be addressed;
2. *Understand the network and relationships among stakeholders*, decision-makers, monitoring agencies, farmers and other relevant actors, and then assess the governance system in a given country/territory;
3. *Identify possible communication gaps and weaknesses in the communication strategy* that could hamper the effectiveness of containment measures and ensure good governance;
4. *Collect suggestions from stakeholders* that can help to improve the management of the disease.

To this end, the Structural Equation Modelling (SEM) methodology was adopted to investigate the links between the analyzed domains and between their indices.

2.2.1. *Structure of the questionnaire*

The questionnaire, comprising *44 questions* (multiple-choice, Likert-type scale, matrix table) and provided in English and French, was designed to obtain answers and input for the above purposes. It was structured into *8 different sections,* as follows: a) General data; b) Knowledge (subjective/objective); c) Perception; d) Involvement of the respondent in pest management; e) Pest containment practices (*Xf* control measures); f)

Information; g) Governance of the risk management system for plant diseases. The elaboration of the questionnaire took into consideration the results on pest risk (see Par. 3.1). In fact, there are possible links between the results that emerged from Question 3 "The presence of competent and technically trained personnel as well as efficient laboratorie" and Question 5 "The availability of a proven surveillance program to combat Xf and/or other harmful quarantine organism". The online questionnaire was realized with specific software ©SurveyMonkey. For each country, at least *10 interviews* were foreseen to be collected, to achieve a minimum of *200 questionnaires* necessary to depict a general scenario (not at the country level).

The questions belonging to the specific sections of the questionnaire were grouped by referring to the following specific domains and their indices:

- *Risk* – Such assessment aims to provide insights on what people know about the problem, how they feel about it, what perception they have about the severity and causes of the problem, and what actions they are currently taking (Breukers *et al.*, 2012). Changes in farmers' practices are assumed to be the cumulative result of changes in farmers' knowledge, attitudes and perceptions. The assessment of the risk perception is based on the following three indexes:
    1. *Disease Knowledge Index* (DKI) – it measures the level of knowledge of respondents on various aspects of *Xf* disease, such as knowledge of the pathogen, its spread (vectors), symptoms and host plants.
    2. *Disease Perception Index* (DPI) – it expresses the respondents' evaluation of the susceptibility/probability of an *Xf* outbreak soon and the corresponding expected or actual impacts on production.
    3. *Farm Practices Index* (FPI) – it expresses the strategies and the containment measures deemed most effective for each country.
- *Governance* – This evaluation aims to assess how much the respondents feel involved, how they perceive the effectiveness of disease management and their country's capability in facing the disease, how much they know about who is in charge of managing the epidemic. Three indexes were applied also in this domain:
    1. *Stakeholders' Involvement Index* (SII) – it expresses the level of respondents' involvement in various activities (surveillance, information, extension, response, post-crisis actions, etc.) and the effectiveness of such involvement.
    2. *Country Readiness Index* (CRI) – it expresses the respondents' evaluation of the country's technical/institutional capacity and effectiveness in controlling/ managing the disease.
    3. *Country Information Level* (CIL) – it identifies the main sources of information about the disease and how reliable they are (according to the respondent's appreciation); evaluates the knowledge/ consciousness of the different levels of responsibility (and corresponding authorities) in the disease management.

The answers to each question were compared with a set of rules (e.g. keywords) and related scores. Answers matching with the settled rules were scored +1; answers that do not match the rules were scored -1; and lack of an answer was rated 0. The scores were assigned to every single answer, summed up and standardized in a range from 0 to 1. The average score for each index and the overall value for each domain were calculated.

At the end of this process, were obtained 3 indicators for each domain and an overall index value for each domain (*Risk*, *Governance*). In this way, it is possible to display: i) the average values for indicators, in the two different domains, for each country; ii) the couple of values of the domain indices (*Risk*, *Governance*).

The overall value of the Domain index (*Risk*, *Governance*) represents the area of the triangular radar graph, as follows:

$$\mathrm{RISK} = \frac{1}{2}\sin\frac{360°}{3}(\mathrm{DKI} * \mathrm{DPI} + \mathrm{DPI} * \mathrm{FPI} + \mathrm{FPI} * \mathrm{DKI})$$

$$\mathrm{GOVERNANCE} = \frac{1}{2}\sin\frac{360°}{3}(\mathrm{SII} * \mathrm{CRI} + \mathrm{CRI} * \mathrm{CIL} + \mathrm{CIL} * \mathrm{SII})$$

In order to analyze the results obtained from the survey, a correlation analysis was carried out. The correlation was evaluated for the six indexes and for each domain, as well as in the country context.

The survey was addressed to the following stakeholder *profiles*: plant protection services; extension services; farmers/producers/nurserymen organizations; ministry officials and policymakers (local/national); research organizations (public/private).

A total of *276 questionnaires* were collected from *13 countries*. Of these, only *220 questionnaires* (slightly less than 80% of the total) were considered complete and valid. In addition to 9 target NENA countries, 4 EU countries where *Xf* was detected were included for comparison.

The 220 valid questionnaires came from:

a) Not Infected Countries: Algeria (24), Egypt (21), Jordan (16), Lebanon (16), Libya (1), Morocco (10), Palestine (11), Tunisia (14), Syria (41).
b) Infected Countries: France (13), Italy (8), Portugal (30), Spain (15).

Two-thirds of respondents (66%) were male; the average age of the respondents was 45. The prevalent activities (or stakes) of respondents were: representatives of research institutions (e.g. universities) (27%); plant protection services/authorities (18%); representatives of the collective organizations (farmers/producers) (9%); representatives of the public administration (9%); advisors/extension agents (8%). The remaining 9% were in prevalence farmers/producers or distributors.

2.3. *Estimation of the potential socio-economic impact of X. fastidiosa on the main crops in NENA countries*

To the best of our knowledge, this is the first study that assesses the socio-economic impacts of *Xf* on the main crops in NENA region. Previous studies were carried out in countries (mainly European ones) where *Xf* is already present. The originality of the work implied a certain difficulty from the methodological point of view and led to the development of a new, innovative methodology. Indeed, an ad-hoc methodology was developed for the assessment of socio-economic impacts and consists of two different steps: (a) customization of the *EFSA Update of the Scientific Opinion on the risks to plant health posed by Xylella fastidiosa in the EU territory* (EFSA PLH Panel, 2019) to the nine target NENA countries taking into account the risk of introduction and spread of *Xf*; (b) assessment of the potential socio-economic impact of *Xf* on each crop (i.e. olive, grapevine and *Citrus spp.*) and in each target NENA country using a set of parameters calculated as proxy for the consequences of the production loss, based on secondary data (see Par. 2.1).

A Panel of experts (EFSA PLH Panel, 2019) estimated, using EFSA's Expert Knowledge Elicitation (EKE) methodology, *yield losses* for the target crops (Table 1), distinguishing for olives, olive groves less than 30 years old (intensive farming) and more than 30 years old (traditional farming), for grapevines, table grape and wine grape vineyards, and considering all *Citrus spp.*

Table 1 - Estimated yield losses with Xylella fastidiosa for the considered crops and uncertainty range.

Crop	*Estimated yield loss (median)*	*90% uncertainty range (confidence interval)*	
		5th percentile	*95th percentile*
Olive trees younger than 30 years	34.6%	14.9%	59.0%
Olive trees older than 30 years	69.1%	36.3%	91.9%
Wine grape in southern EU	2.1%	0.5%	5.6%
Table grape in southern EU	1.0%	0.1%	3.7%
Citrus spp.	10.9%	0.7%	30.2%

Source: EFSA Panel on Plant Health (2019).

Table 2 - Fitting the yield loss (%) with Xylella fastidiosa establishment and spread risk in NENA countries.

Crop	*Perc. - E&S*	*1%*	*2.5%*	*5%*	*10%*	*17%*	*25%*	*33%*	*50%*	*67%*	*75%*	*83%*	*90%*	*95%*	*97.5%*	*99%*
		1.05	*1.13*	*1.25*	*1.50*	*1.85*	*2.25*	*2.65*	*3.50*	*4.35*	*4.75*	*5.15*	*5.50*	*5.75*	*5.88*	*5.95*
Olive	Algeria			1.20												
	Egypt				1.60											
	Libya					1.90										
	Jordan						2.45	2.45								
	Tunisia							3.00								
	Morocco								3.25							
	Palestine								3.45							
	Lebanon								3.75							
	Syria								3.85							
	Yield loss (%) on *olive trees older than 30 years*	24.4	30.6	36.3	43.4	49.8	55.8	60.7	69.1	76.7	80.5	84.6	88.4	91.9	94.3	96.3
	Yield loss (%) on *olive trees younger than 30 years*	9.4	12.1	14.9	18.5	22.0	25.6	28.7	34.6	40.9	44.5	48.9	53.6	59.0	63.5	68.5
Grape	Algeria			1.20												
	Egypt				1.60											
	Libya					1.90										
	Jordan						2.45	2.45								
	Tunisia							3.00								
	Morocco								3.25							
	Palestine								3.45							
	Lebanon								3.75							
	Syria								3.85							
	Yield loss (%) on *wine grape* in southern EU	0.2	0.3	0.5	0.7	0.9	1.2	1.5	2.1	2.8	3.3	3.9	4.7	5.6	6.8	8.1
	Yield loss (%) on *table grape* in southern EU	0.0	0.1	0.1	0.2	0.4	0.5	0.7	1.0	1.5	1.9	2.3	2.9	3.7	4.4	5.4
Citrus spp.	Algeria			1.20												
	Egypt				1.60											
	Libya					1.90										
	Jordan						2.45	2.45								
	Tunisia							3.00								
	Morocco								3.25							
	Palestine								3.45							
	Lebanon								3.75							
	Syria								3.85							
	Yield loss (%) on *Citrus spp.*	0.1	0.3	0.7	1.5	2.8	4.5	6.4	10.9	16.2	19.4	23.1	26.7	30.2	32.5	34.4

Perc.: Percentile; E&S: Establishment & Spread; Yield loss (%): EFSA - Fitted values of the uncertainty distribution on the yield loss (%).
Source: Our elaboration based on EFSA Panel on Plant Health (2019).

The general scenario assumptions common to all three crops are those applied by EFSA Panel on Plant Health (EFSA PLH Panel, 2019). The data and information used by EFSA are mainly derived from the Apulian outbreak study. The similarity with crops and environmental conditions makes it possible to adopt the same values for estimating yield losses in NENA countries. Likewise, data on grapes in Southern Europe were used (cf. Mediterranean climate).

The knowledge of risk in its various forms and with the indicators selected and calculated within the Par. 2.1 “Assessment of the risk of X. fastidiosa introduction, establishment and spread in NENA countries” is preparatory and useful to the elaboration of the Par. 2.3 “Estimation of the potential socio-economic impact of Xf in the main crops in NENA countries”. In fact, the working methodology adopted to customize the establishment and spread risk scores in NENA countries with the assessment of impact for different hosts expressed in terms of yield losses (EFSA PLH Panel, 2019) has similarities with the EKE approach proposed by the *EFSA Guidance on quantitative pest risk assessment* (EFSA PLH Panel, 2018). In particular, in the framework of the European Commission Mandate M-2018-0020 to EFSA about the update of the Scientific Opinion on the risks to plant health posed by *X. fastidiosa* in the EU territory, the EKE was conducted in line with the approach defined by the *EFSA Working Group on EU Priority Pests* to ensure the consistency of results among different projects dealing with the same pest. In the present study, in order to fit the risk of entry and establishment score values (obtained for all investigated countries) on the yield loss (%) on main crops reported by the EFSA scientific opinion, percentiles were calculated according to the adopted scale range (1-6). Later on, the obtained risk score values were associated to the nearest percentile of the EFSA study (Table 2).

Taking into account a set of assumptions, several parameters and indicators were used to estimate the potential socio-economic impacts of *Xf* using secondary data from numerous sources (Table 3).

Productivity refers to yield and production. In order to calculate potential losses in yield (tons per ha) and production (tons) as well as residual production, yield loss coefficients were applied. All estimates are based on average data for a period of 8 years (2010-2017) to offset fluctuations in production.

For olives, the losses were estimated taking into account the share of harvested olive area older and younger than 30 years. Given the lack of data on the orchard age structure, it was assumed that orchards (cf. harvested area) planted after 1987 – i.e. at the latest 30 years ago

Table 3 - Parameters and data sources.

Phenomenon	*Parameter*	*Indicator available*	*Source*
Production	Productivity	Area harvested	FAOSTAT
		Yield	
		Production	
	Value of production	Gross Production Value	FAOSTAT
		Producer Prices	
	Agricultural value-added	Gross Margin	FADN
Social	Employment	Agricultural employment	FADN
Marketing	Trade	Import Quantity	FAOSTAT
		Export Quantity	
	Consumption	Production quantity, Import quantity, Stock variation, Export quantity	

FADN: Farm Accountancy Data Network.

from 2017 – were younger or equal to 30 years. Concerning grapes, data from the International Organisation of Vine and Wine (OIV) were used to distinguish between the table and wine grapes. The expected yield and production losses for table and wine grapes were estimated for each country. For *Citrus spp.*, the following FAOSTAT categories were included: citrus grapefruits (including pomelos), lemons and limes, oranges, tangerines, mandarins, clementines, satsumas.

Value of the Production parameter was elaborated taking into account producer prices and production. Prices are expressed as an average (2010-2017) to take account of their fluctuation. The missing data on producer prices were derived using the average of available prices from other NENA countries. The values of the production loss (US$/ton) were calculated by multiplying the quantity of production lost by price.

To assess profitability, the indicator used was *Agricultural Value Added* at farm level that corresponds to *Gross Margin* (GM), i.e. the difference between gross income and variable costs (input) (Kay *et al.*, 2008). It was determined by referring to the data on revenues and variable costs of the Regione Puglia (2016), as the Italian context is similar, in terms of environment and growing practices, to that of NENA countries. The GM per hectare was calculated for each target crop and in each NENA country in ante-*Xf* and post-*Xf* situations. The reduction of revenues and variable costs was estimated considering input needs (e.g. fertilizers, pesticides, fuel, etc.) for the most relevant field operations (e.g. pruning, fertilization, pest management, irrigation, harvesting) according to the estimated production loss. GM per hectare was used to calculate the loss of GM as a percentage. The loss of GM was recalculated based on the yield loss in each NENA country.

Regarding *Employment*, considering the production loss expressed in terms of yield losses and the adjustment of yield loss to *Xf* risk, the reduction of work in terms of hours per hectare and the year was estimated taking into account the work needs for the most common field operations (e.g. pruning, harvesting). Italian references (Augusti and Baglini, 1992; Augusti *et al.*, 2018) and database (FADN) were used by authors in the calculation. The loss of work was calculated separately for the olive trees in intensive olive groves (under 30 years of age, with a 5×5 m or 6×6 m layout) and in extensive olive groves (over 30 years of age, with a 7×7 m or 8×8 m layout). The total loss of employment (in working days) per crop and per NENA country was assessed by multiplying the loss of jobs per hectare by the harvested area of each crop.

The potential impact on *Trade* is based on the effect of production loss on crop exports. The average quantity of exports, based on average production, was reduced according to the production loss (in %). The potential impact on trade does not consider any trade bans or restrictions.

Consumption refers to the disaggregation of supply. Data on export, import, stock variation and production were retrieved from FAOSTAT. The lack of data on supply elasticity led to consider the effect on consumption (cf. supply) by holding the quantity imported and the stock variation constant while accounting for production and export decreases. The import increase refers to the quantity to be imported in order to hold consumption constant at pre-*Xf* level, where no substitution effects apply and is calculated by increasing the pre-*Xf* value by the production loss percentage.

3. Results

The results of the assessments, according to the developed methodological approaches, are described for each activity in the following paragraphs.

3.1. *Assessment of the risk of X. fastidiosa introduction, establishment and spread in the NENA countries*

3.1.1. *Risk assessment of X. fastidiosa introduction*

Q 1. According to the official data (elaborated from www.resourcetrade.earth, 2019) about the volume of importation of potential host commodities of *Xf* (live plants, bulbs, roots and cut flowers) from countries where the bacterium is officially reported (average of five years: 2013-2017 in tons/year), Lebanon (10,403,630), Morocco (12,694,870) and Palestine (70[1]*) should be considered countries with a high PRI of *Xf*. Given the low volume of imported goods, Syria (6,220), Egypt (215,680) and Libya (598,140) are less exposed to this risk. Tunisia (1,204,380), Jordan (2,599,590) and Algeria (2,611,650) are in an intermediate position.

Q 2. For their high number of entry points (i.e. international airports and commercial ports) (www.en.wikipedia.org & Ministère de l'agriculture, du développement rural et de la pêche-http://madrp.gov.dz), Egypt (30), Algeria (26) and Morocco (22) should be considered countries with a high PRI. In an intermediate position are Libya (13) and Tunisia (13), whereas Jordan (4) and Syria (7) have the lowest number of entry points and are therefore less exposed. Palestine and Lebanon, for their proximity to Israel, where *Xf* outbreaks have recently been detected and from which many goods are introduced via land to Palestine (truck or rail), should also be considered at high PRI.

Q 3. No country has claimed to have good technical skills to counteract the entry of *Xf* in its territory. Therefore, following the answers obtained directly from the officials interviewed, the level of technical readiness has been considered only sufficient for Algeria, Jordan, Lebanon, Palestine and Tunisia (medium risk), and completely insufficient for all other countries (high risk).

Q 4. All countries, with the only exception of Syria, declared to have appropriate laws in place to prevent the entry of *Xf* (general quarantine law, specific quarantine measures, etc.). Consequently, for all of them the level of risk is low, except for Syria for which it is medium. Sources of information for this parameter were interviews and our elaboration from many references.

3.1.2. *Risk assessment of X. fastidiosa establishment and spread*

Q 5. All countries, except Egypt, Libya and Syria, declared to have appropriate surveillance programs to prevent the PRES of *Xf*. Consequently, for all of them the level of risk is low, except for Egypt, Libya and Syria, for which it is medium.

Q 6. Only a few data are available for this parameter in literature. However, except Jordan, which has reported the abundant presence of potential insect vectors of *Xf* and for which there is consequently a high PRES, for all other countries the risk is considered medium (Algeria, Lebanon, Libya, Morocco, Palestine and Tunisia) or low (Syria and Egypt). Sources of information were interviews and our elaboration from many references.

Q 7. Considering the climatic conditions of each country (elaborated from www.ClimaTemps.com), Lebanon (0% arid and semi-arid areas), Morocco (60.9%), Palestine (61.3%; no data is available, the data here reported refers to Israel) and Syria (66.6%) have been considered countries with a high level of PRES of *Xf*, Tunisia (79.5%) with a medium level of risk, whereas Algeria (93.8%), Egypt (100%), Jordan (93.4%) and Libya (98.8%) with a low level of risk.

Q 8. According to the abundance of alternative hosts, which has been determined indirectly on the basis of the extent of agricultural and forestry land, Lebanon (77.7%), Morocco (81.1%), Syria (78.5%) and Tunisia (71.1%) have been considered countries with a high PRES of *Xf*, Palestine (49.5%) with a medium risk, Algeria (18.2%), Egypt (3.8%), Jordan (13%) and Libya (8.8%) with a low risk. The calculation was based on the analysis of data for five years 2012-2016 from FAOSTAT (http://www.fao.org/statistics/databases).

Q 9. According to the extent of the main crops in agricultural land, Lebanon (15.5%), Palestine (24.2%) and Tunisia (19.7%) have been consid-

[1] For Palestine it was not possible to determine this parameter because all the goods are officially imported from Israel, from which they are then re-exported in Palestine. Anyway, due to its proximity to Israel, where Xf outbreaks were recently detected and from which most goods are imported, the level of risk related to this factor for Palestine was considered "high".

Table 4 - Summary table of the risk assessment of entry and establishment of *Xylella fastidiosa* in NENA countries.

		Questions	*Palestine*	*Syria*	*Egypt*	*Libya*	*Tunisia*	*Jordan*	*Algeria*	*Lebanon*	*Morocco*
Risk of Entry	1	Volume of importation of potential host commodities of *Xf* from countries where the bacterium is officially reported (2013-2017) c= 0.3	1.8	0.3	0.3	0.3	0.9	0.9	0.9	1.8	1.8
	2	Number of entry points (i.e. international airports & ports) c= 0.1	0.6	0.1	0.6	0.3	0.3	0.1	0.6	0.6	0.6
	3	Level of technical readiness to prevent the entry of *Xf* (technical competences of personnel at entry points, number of reference diagnostic lab, etc.) c= 0.3	0.9	1.8	1.8	1.8	0.9	0.9	0.9	0.9	1.8
	4	Existing legislation (phytosanitary requirements/restrictions/prohibitions) to prevent the entry of *Xf* (general quarantine law, specific measures for *Xf*, etc.) c= 0.3	0.3	0.9	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Entry: Partial Risk Score	3.6	3.1	3,0	2.7	2.4	2.2	2.7	3.6	4.5
Risk of Establishment and Spread	5	Existence of surveillance program against the establishment and spread of *Xf* c= 0.2	0.2	0.6	0.6	0.6	0.2	0.2	0.2	0.2	0.2
	6	Presence of potential *Xf* vectors c= 0.25	0.75	0.25	0.25	0.75	0.75	1.5	0.25	0.75	0.75
	7	Suitability of climate to the establishment and spread of *Xf* (% of country area with temperate climate or semi-arid/steppe climate) c= 0.25	1.5	1.5	0.25	0.25	0.75	0.25	0.25	1.5	1.5
	8	Abundance of alternative hosts (% of Agricultural land & Forest land in land area) c= 0.1	0.3	0.6	0.1	0.1	0.6	0.1	0.1	0.6	0.6
	9	Abundance of the main crops (% of olive, grapevine, *Citrus spp.*, stone fruit in agricultural land) c= 0.1	0.6	0.3	0.3	0.1	0.6	0.3	0.1	0.6	0.1
	10	Existence of national programs for the certification of the plant propagation material of olive, grapevine, *Citrus spp.*, and stone fruits c= 0.1	0.1	0.6	0.1	0.1	0.1	0.1	0.3	0.1	0.1
		Establishment & Spread: Partial Risk Score	3.45	3.85	1.6	1.9	3	2.45	1.2	3.75	3.25
		Total Risk	7.05	6.95	4.6	4.6	5.4	4.65	3.9	7.35	7.75

Note: c: coefficient of correction.

ered countries with a high PRES of *Xf*, Egypt (9.4%), Jordan (7.3%) and Syria (6.7%) with a medium level of risk, Algeria (1.7%), Libya (2.3%) and Morocco (4.3%) with a low level of risk. The calculation was based on the analysis of data for five years 2012-2016 (http://www.fao.org/statistics/databases).

Q 10. Except for Syria – which, due to internal political instability, was unable to organise a certification program and should be considered at high PRES of *Xf* – all other countries considered in this study have a more or less advanced certification system for the certification of the plant propagation material of the main crops and are therefore more prepared to contain the spread of the bacterium. Algeria, whose certification system is not yet fully operational, is in an intermediate position. The analysis was based on the results of the interviews.

3.1.3. *Synthesis of pest risk assessment results*

According to the results obtained, all the NENA countries considered in this study show levels of PRI of *Xf* from medium to high (Table 4). Morocco (4.5/6) is particularly vulnerable to this risk, followed by Palestine and Lebanon (3.6), Syria (3.1) and Egypt (3.0), while Libya (2.7), Tunisia (2.4) and Jordan (2.2) seem to be less exposed due to the low volume of imports and the low number of entry points.

The difference in the PRES of *Xf* in different countries is wider. From this point of view, the most vulnerable countries seem to be Syria (3.85/6) and Lebanon (3.75), followed by Palestine (3.45), Morocco (3.25) and Jordan (2.45). Less exposed, mainly due to the less favorable climatic conditions for the development of alternative hosts and insect vectors, but also, in some cases, to the existence of legislation and surveillance programs already in place for *Xf*, seem to be Algeria (1.2), Egypt (1.6) and Libya (1.9) (Table 4).

Aggregating the results, by summing the two different risk values (PRI and PRES), it appears that the countries most exposed to the risk of effective entry and establishment of *Xf* are Morocco, Lebanon, Palestine and Syria (Figure 1). For them, the values vary between 6.95 and 7.75, which are well above the value of 6.0 set as a high-risk threshold. All the other countries considered in this study fall into an intermediate risk class, although with risk levels ranging from 4.6 (Egypt and Libya) to 5.4 (Tunisia). Just below the risk threshold (4.0) there is only Algeria, with a risk level of 3.9, mainly conditioned by the low PRI of the pathogen.

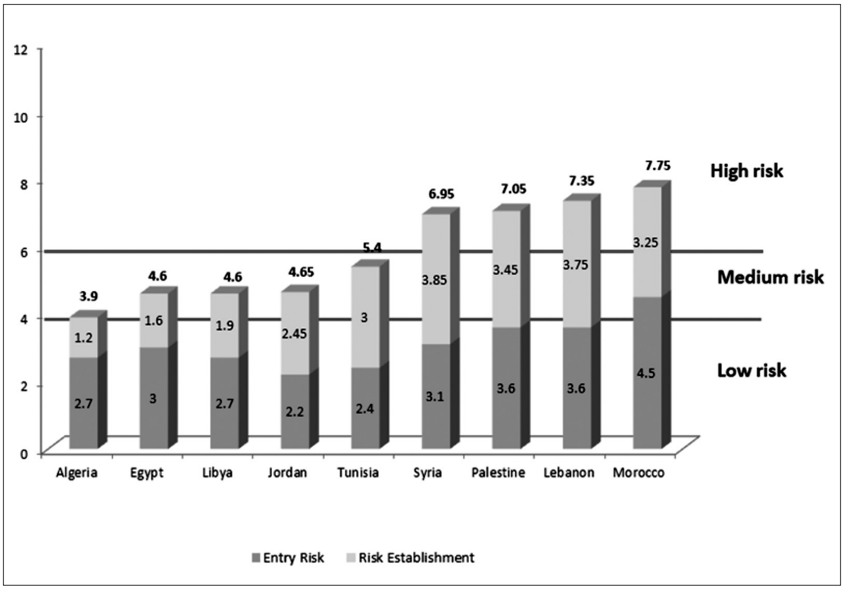


Figure 1 - Graphic representation of the risk assessment of entry and establishment of *Xylella fastidiosa* in NENA countries.

3.2. *Perception of the risk and level of preparedness to X. fastidiosa among policymakers and agro-food chain stakeholders in NENA countries*

At the end of the scoring process, were obtained 3 indicators for each domain and an overall index value for each domain (*Risk*, *Governance*).

In general, *Governance* influences *Risk* for all countries (R^2 = 0.271, ß = 0.520, at 0.001 sig. level) as well as for NENA countries (Not Infected, R^2 = 0.327, ß = 0.572, at 0.001 sig. level) and EU countries (Infected, R^2 = 0.103, ß = 0.322, at 0.01 sig. level).

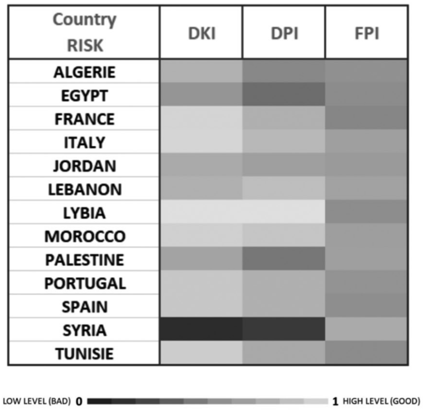
In Figure 2, for the two main domains, the value of each indicator is displayed, together with the overall value for the Domain index (indicated as "Plot Area"). A paler color means a good level for the indicator (closer to 1) instead a darker color means a lower value of the indicator (closer to 0).

The pairs of values were plotted in a diagram with the average values of the *Risk* (x-axis) *vs. Governance* (y-axis) domain's indices (Figure 3). By superimposing on the graph, a semiotic square, built according to the Greimas' rules (Greimas, 1966), one can more easily identify the categories of respondents' behavior (or country's attitude) (Ladisa, 2018).

Figure 2 - Values of indicators for the Risk (A) and Governance (B) domains, for each country.

(A)

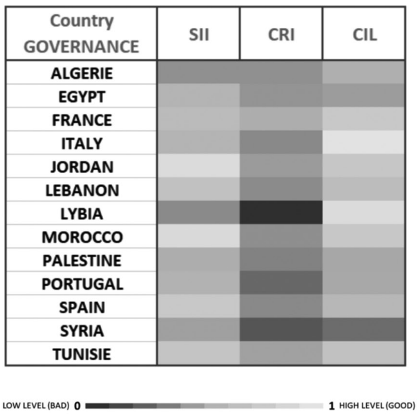
Country RISK	DKI	DPI	FPI	Plot Area
ALGERIE	0.89	0.76	0.79	0.85
EGYPT	0.80	0.65	0.77	0.71
FRANCE	0.97	0.88	0.75	0.98
ITALY	0.98	0.91	0.84	1.07
JORDAN	0.87	0.84	0.82	0.92
LEBANON	0.89	0.92	0.85	1.01
LYBIA	1.00	1.00	0.78	1.10
MOROCCO	0.97	0.94	0.83	1.08
PALESTINE	0.85	0.69	0.84	0.81
PORTUGAL	0.94	0.88	0.80	0.99
SPAIN	0.94	0.88	0.78	0.98
SYRIA	0.35	0.43	0.87	0.36
TUNISIE	0.96	0.87	0.77	0.97



DKI - Disease Knowledge Index
DPI - Disease Perception Index
FPI - Farm Practices Index

(B)

Country GOVERNANCE	SII	CRI	CIL	Plot Area
ALGERIE	0.56	0.56	0.66	0.46
EGYPT	0.67	0.58	0.60	0.50
FRANCE	0.70	0.65	0.75	0.63
ITALY	0.68	0.54	0.83	0.60
JORDAN	0.81	0.60	0.74	0.66
LEBANON	0.72	0.55	0.71	0.56
LYBIA	0.55	0.20	0.81	0.31
MOROCCO	0.81	0.56	0.74	0.64
PALESTINE	0.65	0.52	0.63	0.47
PORTUGAL	0.67	0.43	0.64	0.43
SPAIN	0.75	0.54	0.69	0.56
SYRIA	0.61	0.36	0.44	0.28
TUNISIE	0.73	0.62	0.72	0.62



SII - Stakeholders Involvement Index
CRI - Country Readiness Index
CIL - Country Information Level

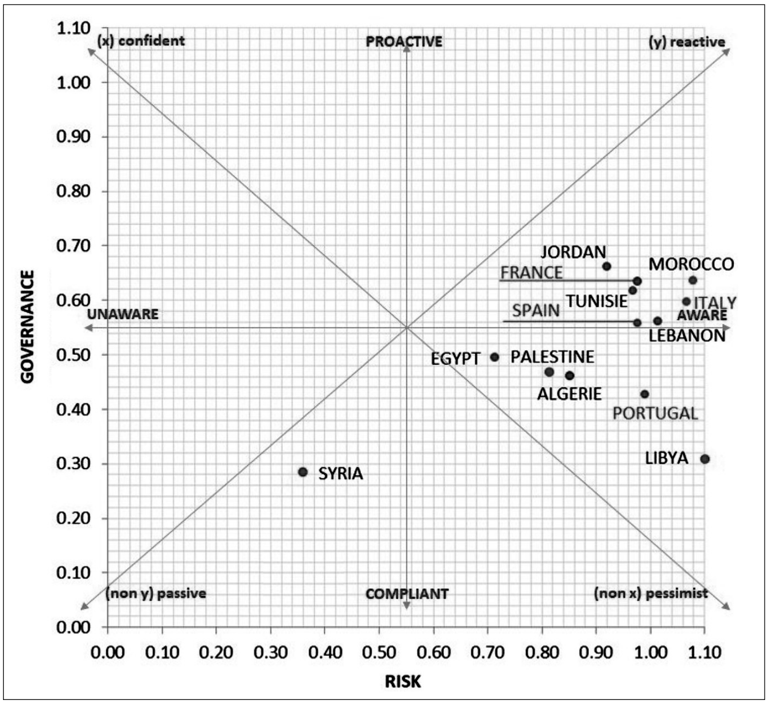


Figure 3 - Graph representing a couple of Risk vs. Governance index for each country. In red the countries were *Xylella fastidiosa* has already been detected.

3.2.1. *Attitude of countries*

Most of the countries surveyed, where *Xf* has not yet been detected, show quite a high level of awareness of the disease: they have high knowledge of the pathogen and its vectors as well as of the symptoms; less evident is in these countries the perception of risk and the availability to adopt specific farming practices to manage the disease. The overall value of the *Risk* index is closer to 1.00 (high). In this view, their approach to Risk is quite similar to that of the EU countries where *Xf* has already been detected (Italy, France, Spain, Portugal).

Looking at *Governance*, it is possible to distinguish two main behaviors:

i) On one side, the countries that show a more proactive/reactive attitude, more confidence in the level of information, in the capability to involve stakeholders and, finally, in the readiness (in terms of disease prevention and control capacity, availability of human/technical/financial resources). In these countries (NENA countries: Jordan, Morocco, Tunisia and Lebanon; EU countries: France, Italy, Spain), the value of the Governance index is above the average.

ii) On the other side, the countries that show a more compliant/pessimistic attitude. In these countries (NENA countries: Egypt, Palestine, Algeria, Libya; EU countries: Portugal) the value of the Governance index is below average. In general, Readiness is estimated to be low in these countries.

3.2.2. *Causation between domains and indicators*

To investigate the links between the domains of *Governance* and *Risk* (perception and management) and between their indices, the SEM (Structural Equation Modelling) technique (Schumacker and Lomax, 2004) was adopted. SEM allows multivariate statistical analyses which makes it possible to analyze the linear relationships between variables from the analysis of the covariance between variables.

SEM methods, in comparison with classical approaches such as linear regression, allow to simultaneously analyze several types of interrelationships between variables in an experiment. Variables can be directly observable (as in this case) or indirectly observable (latent), that is,

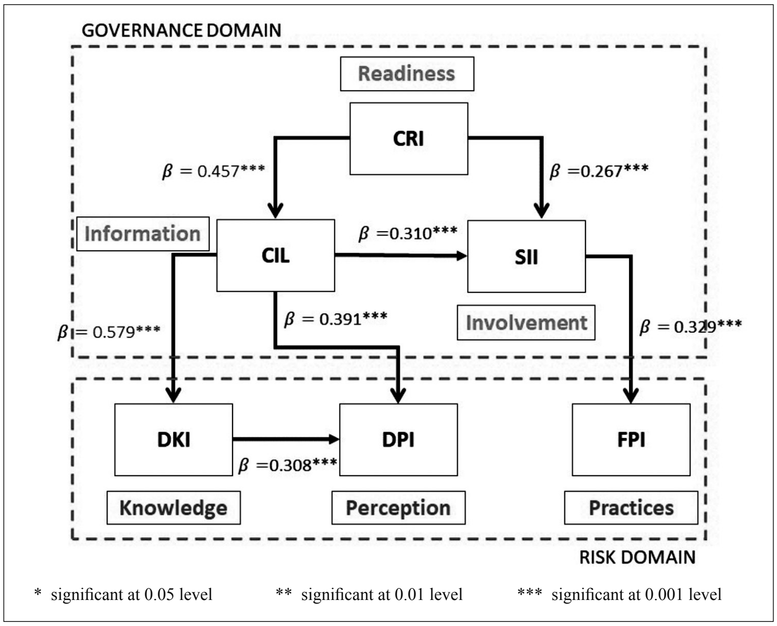


Figure 4 - SEM model among indices and domains: the whole sample (220 questionnaires).

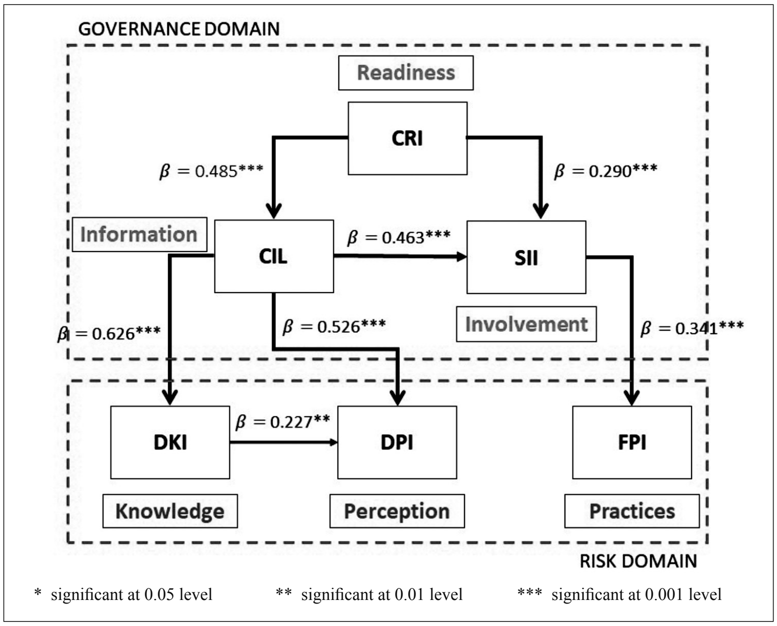


Figure 5 - SEM model among indices and domains: not-infected countries (154 questionnaires).

variables that are inferred from multiple indicators. In particular:

- Variables may be directly or indirectly related. For example, the effect of A on C may be direct, (A→C), or it may be indirect or mediated by B, (A→B→C). SEM can distinguish direct from indirect relations.
- A relation between variables may be recursive. That is, the effect of A on B, (A→B), may be different from the effect of B on A, (B→A).
- Any variable in a SEM model may simultaneously act as an independent and a dependent variable, i.e. each indicator can both in-

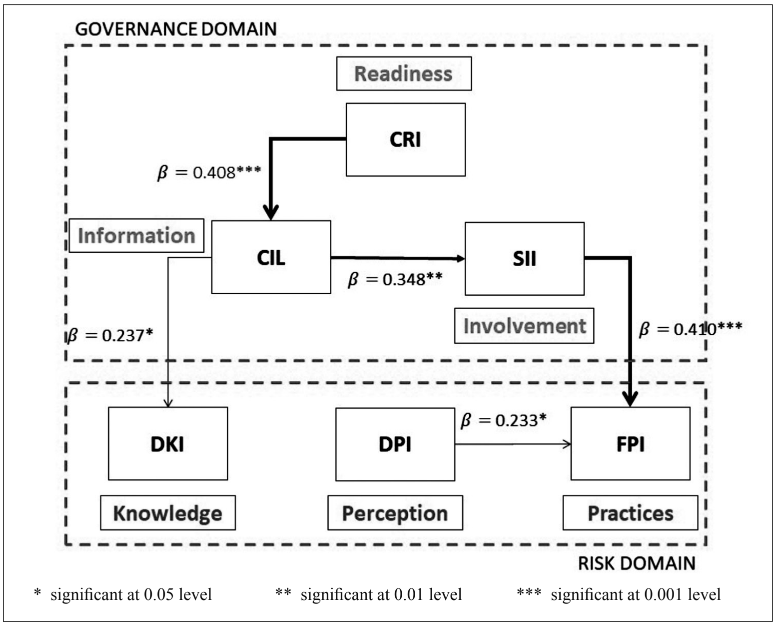


Figure 6 - SEM model among indices and domains: infected countries (66 questionnaires).

fluences, and be affected by, other indicators in the model.

The nature of the relationship between variables is given by the regression coefficient (β); it describes how much the dependent variable changes when an independent variable changes by one unit. SEM directly integrates the errors of measurement into a statistical model; by doing so, the estimates of regression coefficients are more precise than they are with classical methods such as multiple regression, factorial analysis, analysis of variance or discriminant analysis.

As reported in Figures 4, 5 and 6, the arrows direction indicates the hypothesized and tested relations between the involved indicators; the more the line thickness is, the lowest is the tested level of significance (* significant at 0.05 level; ** highly significant at 0.01 level; *** very highly significant at 0.001 level).

Causation analysis shows that:

- There are linkages between the domains of Governance and Risk (perception and management) as well as between some of their indices (Figure 4).
- Country readiness influences the practices implementation with a strong mediation effect through the information level and stakeholder involvement.
- The availability to implement farm practices (FPI) is only influenced by the level of stakeholder involvement (SII) without any mediation effect through risk perception (DPI).
- The country's level of information (CIL) influences the knowledge of the disease (DKI) more than its perception (DPI); in turn DKI influences DPI.
- According to the two statements above, supporting the implementation of the practices is more advisable to improve the level of information in the country, thus increasing the level of stakeholder involvement.

The above statements are confirmed both for the whole sample (Figure 4), as well as for non-infected countries; the intensity of correlations is higher in non-infected areas (Figure 5).

Moreover, in infected countries:

- The Country Information Level (CIL), through the mediating effect of the Stakeholder Involvement (SII), could support the implementation of practices (FPI) more than the disease perception level (DPI) (Figure 6).
- It is confirmed that, in the implementation of practices (FPI), disease perception (DPI) plays a more relevant role than of objective knowledge of the disease (DKI).

- Finally, the capability to react to the disease through the implementation of practices (FPI) could be achieved by improving risk perception (DPI) or using information (CIL) through stakeholder involvement (SII) and rule-setting (CRI).

3.3. *Potential socio-economic impacts of X. fastidiosa in target NENA countries*

According to FAOSTAT, the average *olive* production in the target NENA countries was about 4.8 million tons in the period 2010-2017. Morocco is the largest producer with 1,324,064 tons (27.5% of olive production in target NENA countries) followed by Tunisia with 896,351 tons (18.6%). The average olive yield in the same period was 2.34 tons/ha (ranging from 9.62 tons/ha in Egypt to 0.52 tons/ha in Tunisia). Meanwhile, the share of the harvested area of olive trees under 30 years of age ranged in 2017 from 88.1% in Egypt to 32.1% in Jordan.

The *Yield* loss depends on the olive grove age; it varies from 1.13 tons/ha in Palestine to 0.13 tons/ha in Libya for olive groves over 30 years old, and from 1.57 tons/ha in Egypt to 0.03 tons/ha in Tunisia for olive groves under 30 years old (Table 5).

Olive *production* loss ranges from 498,319.09 tons in Morocco to 24,534.42 tons in Lebanon (Figure 7).

The *value of olive production* losses in the nine NENA countries is estimated at around US$ 1 billion; it ranges from US$ 25,316,822 in Lebanon (2% of the total value of the production loss) to US$ 247,260,950 in Morocco (23% of the production value loss) (Figure 8).

Table 5 - Estimation of potential olive yield losses (tons/ha) due to *Xylella fastidiosa* outbreak in NENA countries.

Country	*Orchards age structure (%)*	*Yield loss coefficient (%)*	*Average area 2010-2017 (ha)*	*Production 2010-2017 (tons)*	*Yield 2010-2017 (tons/ha)*	*Yield loss (tons/ha)*
Algeria	> 30 years: 37.3	36.3	136,621,32	205,713.60	0.56	0.20
	< 30 years: 62.7	14.9	229,655,68	345,797.40	0.94	0.14
Egypt	> 30 years: 11.9	43.4	7,625,52	74,707.96	1.14	0.50
	< 30 years: 88.1	18.5	56,454,48	553,090.04	8.48	1.57
Jordan	> 30 years: 67.9	58.3	41,992,76	102,264.87	1.66	0.97
	< 30 years: 2.1	27.15	19,852,25	48,346.13	0.78	0.21
Lebanon	> 30 years: 65.5	69.1	37,438,49	76,141.13	1.34	0.92
	< 30 years: 34.5	34.6	19,719,51	40,104.87	0.70	0.24
Libya	> 30 years: 19.8	49.8	51,576,03	36,786.42	0.14	0.07
	< 30 years: 80.2	22	208,908,97	149,003.58	0.58	0.13
Morocco	> 30 years: 26.9	69.1	255,678,58	356,173.22	0.38	0.26
	< 30 years: 73.1	34.6	694,799,42	967,890.78	1.03	0.36
Palestine*	> 30 years: 100	69.1	57,586,00	92,613.00	1.63	1.13
	< 30 years: 0	34.6	-	-	-	-
Syria	> 30 years: 43.4	69.1	304,876,32	377,007.12	0.54	0.37
	< 30 years: 56.6	34.6	397,603,68	491,672.88	0.70	0.24
Tunisia	> 30 years: 78.6	60.7	1,346,539,04	704,531.89	0.41	0.25
	< 30 years: 21.4	28.7	366,614,96	191,819.11	0.11	0.03

Source: Our elaboration based on FAOSTAT data.
**Area decreased in Palestine, so it is assumed that there are no young olive groves.*

Figure 7 - Estimation of potential olive production losses (thousand tons) due to *Xylella fastidiosa* outbreak.

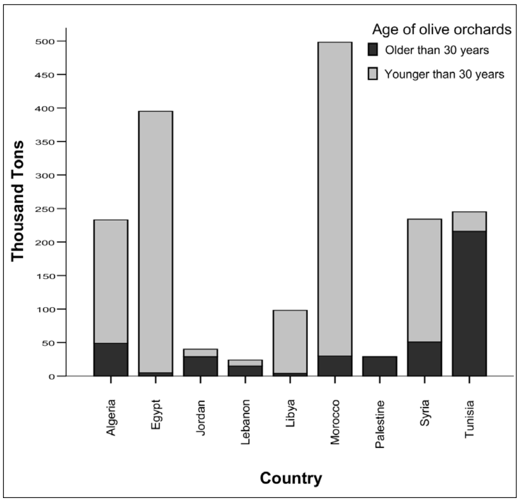
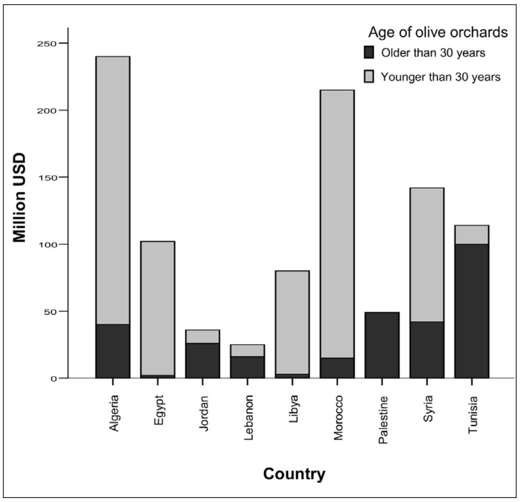


Figure 8 - Potential olive production losses (million US$) due to *Xylella fastidiosa* outbreak.

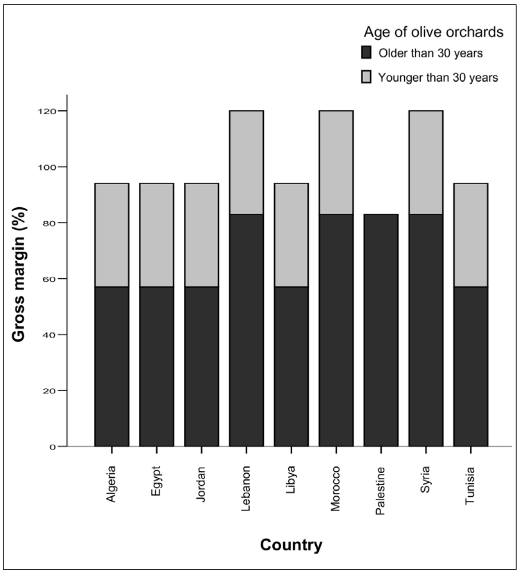


Considering the relative loss of production, the loss of *agricultural value-added* at farm level (cf. gross margin) was 37% in the olive-growing area under 30, while the highest gross margin loss in olive groves over 30 (83%) was predicted for Lebanon, Morocco, Palestine and Syria (Figure 9).

The employment loss depends on the harvested olive-growing area. The total loss of *employment* has been calculated for each NENA country, distinguishing the olive-growing area below 30 (intensive olive grove: 5×5 m or 6×6 m) and above 30 (extensive olive groves: 7×7m or 8×8m); it ranges from 774,247 workdays in Egypt to 16,171,090 workdays in Syria, 17,175,137 workdays in Morocco and 40,695,973 workdays in Tunisia.

The average annual *exportation* of olives and preserved olives is estimated at 154,162 tons in the nine targets NENA countries and is expected to decrease to 84,129 tons (55% of the overall average export of olives) in case of *Xf* outbreak. Export reductions following potential *Xf* outbreaks decrease from Lebanon (79%), Jordan, Syria and Tunisia (73%), Palestine (69%), Morocco (62%), Algeria (58%), Libya (47%) to Egypt (37%). Taking into account the estimated export losses and holding consumption and stock variation constant, an increase in *imports* of olives is also expected; it ranges from 19,336 tons in Palestine, 25,017 tons in Lebanon, 34,391 tons in Libya, 65,497 tons in Jordan, 70,516 tons in Egypt, 78,509 tons in Algeria, to 201,918 tons in Tunisia, 216,487 tons in Syria and 286,967 tons in Morocco.

Figure 9 - Loss of gross margin in olive area (in %) due to *Xylella fastidiosa* outbreak.



FAOSTAT data shows that the average yearly production of *grapes* in the nine targets NENA countries is estimated at around 3 million tons

Table 6 - Estimation of table grape production losses (tons & %) due to *Xylella fastidiosa* outbreak in NENA countries.

Country	*Average production 2010-2017 (tons)*	*Production losses (tons)*	*Residual production (tons)*	*Production losses (%)*
Algeria	440,335	440	439,895	0.10
Egypt	1,424,124	2,848	1,421,275	0.20
Jordan	41,598	250	41,349	0.60
Lebanon	52,830	528	52,302	1.00
Libya	31,440	126	31,314	0.40
Morocco	299,229	2,992	296,236	1.00
Palestine	32,986	330	32,656	1.00
Syria	236,536	2,365	234,171	1.00
Tunisia	90,453	633	89,820	0.70
Total	2,649,531	10,513	2,639,018	0.40

Source: Our calculation based on data from FAOSTAT.

in the period 2010-2017. The harvested area of grapes is 279,018 ha in NENA countries (of which 25.4% in Egypt and 25.1% in Algeria). The average yield is 9 tons/ha (from 21.5 Tons/ha in Egypt to 4 tons/ha in Libya). Libya has the maximum share of table grapes (95.5%) while the maximum share of wine grapes is in Tunisia (35.9%).

The overall average amount of table grape *production* losses due to *Xf* outbreak is estimated at 10,513 tons, which represents 0.4% of the overall average table grape production in NENA countries over the period 2010-2017. *Xf* is expected to induce a slight decrease in table grape production in different proportions in NENA countries (Table 6). The overall average amount of wine grape production losses due to *Xf* is estimated at 5,036 tons (i.e. 1.27% of the overall average production).

The average *yield* decrease of table grapes due to the *Xf* outbreak in NENA countries varies from 0.01 tons/ha in Algeria to 0.09 tons/ha in Lebanon, while that of wine grapes varies from 0.04 tons/ha in Algeria and Libya to 0.18 Tons/ha in Lebanon (Figure 10). Therefore, yield damage seems to be relatively very low for grapes compared to olives and citrus fruits.

The total value of grape *production* losses in the nine NENA countries is estimated at around 10 million US$ (of which 65% for table grapes and 35% for wine grapes). In the proportion of this value, Syria is estimated to have the highest loss (27.4 %) followed by Morocco (23.6%), Egypt (16.1%) and Algeria (13%). Lebanon and Tunisia suffer a loss of 7.8% and 7.5%, respectively, while the lowest losses are expected in Jordan (2.2%), Palestine (1.3%), and Libya (1.1%).

Considering the harvested area and relative loss of production, the *gross margin* loss is 10% for table grapes (i.e. 2,338,178 US$; from 35,832 US$ in Jordan to 662,887 US$ in Egypt) and 9% (343,071 US$; from 1,809 US$ in Jordan to 114,237 US$ in Algeria) for wine grapes.

The total loss of *employment* – calculated considering the important practices (e.g. pruning, harvesting) and the production loss – is higher in Algeria (272,122 workdays) and Egypt (247,591 workdays), mainly due to the larger area of grapes harvested, and lower in Jordan (13,091 workdays) and Palestine (17,126 workdays).

Average total *export* losses due to *Xf* outbreak are estimated at 545 tons, representing 0.45% of total average exports of grapes (i.e. 120,421 tons) from NENA countries in the period 2010-2017. Holding consumption and stock variation constant, Morocco (3,450.39 tons), Syria (3,196.51 tons) and Egypt (2,587.57 tons) are expected to undergo a sharp increase in *import* quantities.

Figure 10 - Potential grapes production losses (in tons) due to *Xylella fastidiosa* outbreak.

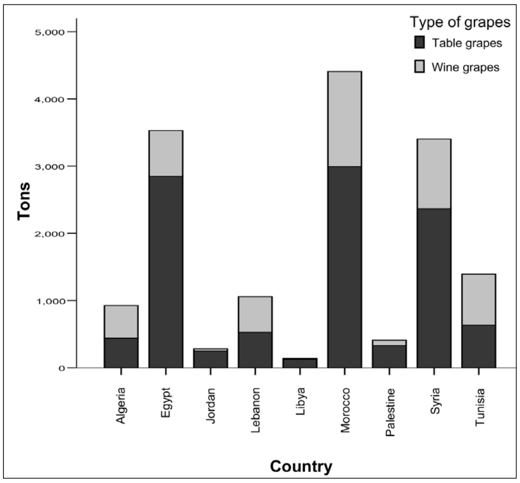
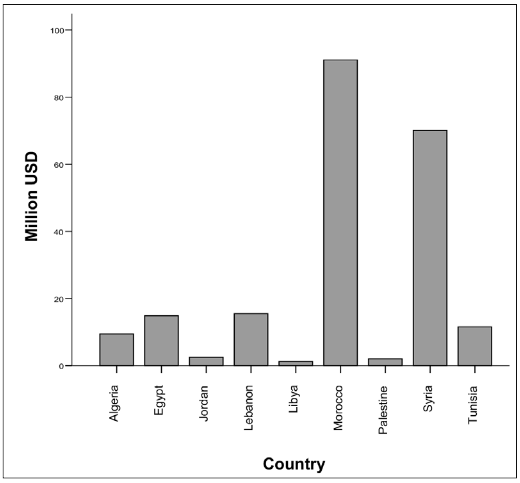


Figure 11 - Potential citrus production losses (in million US$) due to *Xylella fastidiosa* outbreak.



FAOSTAT data indicate that *Citrus spp.* production in the target NENA countries was about 9.3 million tons/year from 2010 to 2017 (of which, 44.5% in Egypt and 20% in Morocco). The average total harvested area of *Citrus spp.* is 419,264 ha (of which 42% in Egypt and 27% in Morocco). The average citrus yield was 23.14 tons/ha (from 59.5 tons/ha in Algeria to 10.5 tons/ha in Libya). Citrus *production* losses due to *Xf* outbreak are estimated at 472,068 tons/year, representing about 5% of the overall average production (Table 7). Production losses, therefore, seem to be relatively low to moderate for citrus fruits, ranging from 2.89 tons/ha in Syria to 0.28 tons/ha in Libya.

The total value of citrus production losses in the nine NENA countries is estimated at 218,351,994 US$ (of which, 41.7% in Morocco and 32.1% in Syria). The *production value* loss varies from 5.3% in Tunisia and 4.3% in Algeria to 0.57% in Libya (Figure 11**)**.

The highest *gross margin* loss (35%) was estimated in Morocco, Lebanon, Palestine and Syria; while the gross margin is expected to

Table 7 - Estimated citrus production losses (tons & %).

Country	*Average production 2010-2017 (tons)*	*Production losses (tons)*	*Residual production (tons)*	*Production losses (%)*
Algeria	1,169,046	8,183	1,160,862	0.7
Egypt	4,144,019	62,160	4,081,858	1.5
Jordan	110,596	6,027	104,568	5.5
Lebanon	289,597	31,566	258,031	10.9
Libya	79,491	2,226	77,265	2.8
Morocco	1,865,136	203,300	1,661,836	10.9
Palestine	25,060	2,732	22,329	10.9
Syria	1,159,125	126,345	1,032,781	10.9
Tunisia	461,388	29,529	431,859	6.4
Total	9,303,457	472,068	8,831,389	5.07

Source: Our calculation from FAOSTAT.

decrease by only 9% in Algeria, Egypt, Jordan, Libya and Tunisia.

The overall loss of *employment* is estimated at 2,738,800 workdays. Morocco (965,558 workdays) and Egypt (911,337 workdays) are the countries where the greatest job losses are expected, mainly due to the high citrus-growing area, with respect to Palestine (11,003 workdays), Jordan (33,749 workdays) and Libya (40,274 workdays).

The average overall quantity citrus *export* loss due to *Xf* outbreak is estimated at 85,363 tons, which represents 5.4% of the current overall average (i.e. 1.6 million tons). Export losses are the highest in Morocco (58,803.18 tons) and Egypt (13,528.56 tons). The increase in *imports* to meet the constant citrus consumption is expected to range from 2191.6 tons in Libya to 109,746.11 tons in Syria and 116,338.72 tons in Morocco.

4. Discussion

Pest risk appraisal suggests that Morocco, Lebanon, Palestine and Syria are the most exposed to the risk of *Xylella fastidiosa entry* and *establishment*. All the other target NENA countries, except Algeria, fall into an intermediate risk class. For each country, it is important to deal with the problem immediately and to implement measures aiming to prevent the pathogen introduction and establishment. In this context, guidelines and procedures should be developed to strengthen quarantine inspections at borders and plant protection services within the country.

Risk perception analysis shows that both Governance and Risk domains highlight a relationship between the readiness (CRI), stakeholders' involvement (SII), and adoption of practices (FPI). Thus, it is possible to activate positive feedback about governance efficacy and practices application by directly involving stakeholders. Since practices application in the infected areas is influenced more by risk perception than by the actual knowledge, it is important to raise the information level to avoid that subjective knowledge leads to a distorted perception of the real situation.

Socio-economic impact assessment indicates declining yields, production, profitability, trade (cf. export), employment, and increasing import to keep the same consumption levels. The highest impacts were recorded on olives, followed by citrus and grapes. In particular, the loss of production is estimated at about 2.3 million tons (of which 78.6% olives, 20.7% citrus and 0.7% grapes), production value at about 1.3 billion US$ (82.4% olives) and employment at about 92.3 million workdays (97% olives). In the olive sector, Morocco shows values among the highest in terms of production losses in terms of weight and value, income and employment. Concerning the grape sector, Egypt, Morocco and Syria overall show greater economic impacts, while for the social ones Algeria is added to the previous countries. In the citrus sector, Morocco and Syria show greater losses in production and income, while in terms of job losses Egypt must be added to the preceding countries. The exploratory analysis strongly suggests that the expected socio-economic impacts are unacceptable and makes the case for a region-wide analysis that considers all NENA countries.

The analysis highlights different linkages between the different components of the study. Some examples are analyzed in detail hereafter.

The first consideration regards the relationship between pest risk analysis and risk perception. By comparing the perception of Risk (as a result of the DKI, DPI, FPI indices) and the Risk index (cf. PRI and PRES), it can be noticed that there are countries (Egypt, Morocco) in which the perceived risk is equivalent to the real risk (realistic attitude). However, there is also a greater number of countries where the perceived risk is higher than the real risk (Jordan, Tunisia, Libya, and Algeria) (pessimistic attitude). Finally, more worrying is the condition of those countries (Lebanon, Palestine, and Syria) in which the perception of risk is lower than the real risk. This unrealistically confident attitude is probably due to low knowledge of the disease or low perception of the probability of its entry, or both (as in the case of Syria, which has the lowest DKI and DPI values among the analyzed NENA countries).

Regarding the relation between the knowledge of the real risk, awareness and actions to address the pathogen, it emerges from the results that greater effectiveness in the application of mitigation measures through the adoption of targeted farming practices can be achieved by increasing both the knowledge of the disease and the perception of risk (which is connected to the latter). There is a need for a governance model that is capable of increasing the level of information in the country, while at the same time favoring the involvement of all institutional and technical actors, which can raise the level of attention and awareness and better direct control actions both in non-infected areas and (although to a lesser extent) in those already infected. This also underlines that a preventive action (that is, acting in areas not yet affected by the pathogen) can exert its effects in a greater way.

As for the relation between the knowledge of the risk and the mitigation of the potential socio-economic impacts, the ad-hoc methodologies developed, respectively, for i) the assessment of socio-economic impacts of *Xf* in the main crops and for ii) the risk assessment of *X. fastidiosa* establishment and spread provide a valid and reliable basis for future applications in similar settings. Moreover, for further investigation on relationships between the variables examined within both analytical frameworks (e.g. the contribution of risk-knowledge to minimize the potential economic impacts) an extended multivariate statistical analysis could be performed. In particular, within a single SEM analysis two distinct but interconnected models can be approached: a measurement model aimed to measure and evaluate latent constructs (e.g. variables referring to risk and governance domain), which are often not manifest or readily observable and multiple item scales, or a set of manifest observations, are generally used; and a structural model, aimed to simultaneously test all the causal relationships among variables referring to the socio-economic and risk assessment domains.

5. Conclusion

This is the first study that evaluates the potential impacts of *Xf* in NENA region. The originality of the study stems from the combination of secondary and primary data as well as the integration of three components – pest risk analysis/assessment, pest risk perception and socio-economic impacts – that are generally addressed separately. This combination allows having a more comprehensive understanding about issues at stake as well as measures to address the problem of *Xf* by adopting a multidimensional, integrated approach with the involvement of all concerned stakeholders. Doing so, the paper provides a valuable contribution to the efforts for the preventive management of *Xf* in the target NENA countries (*viz*. Algeria, Egypt, Jordan, Lebanon, Libya, Morocco, Palestine, Syria, Tunisia) and the Mediterranean region at large.

The study points out that there is a high risk of entry and spread of *Xf* in NENA region, which would have devastating and far-reaching socio-economic impacts. The analysis also shows that the higher pest risk translates in higher potential damages. However, the high risk of *Xf* introduction, establishment and spread in the target NENA countries does not always correspond to a high-risk perception. This is a serious issue that should be addressed in order to increase the preparedness of the agri-food system actors and rural communities to the bacterium.

Action is, indeed, needed both at national and regional levels. For an effective intervention, each country should promptly implement measures of different types, i.e. legislative (adequate regulations on quarantine pathogens), financial, technical (facilities and personnel), scientific (laboratories). Meanwhile, to ensure an effective, efficient and sustainable region-wide management of *Xf* risk, the main orientations and recommendations drafted during the International Pre-Conference "Transboundary plant pests and diseases in NENA countries" organized by FAO and CIHEAM-Bari in January 2020 include: i) establishing a *Regional Committee for Sustainable Management of Transboundary Plant Pests and Diseases*; ii) developing studies for the *assessment of risks* from invasive pests and diseases from technical and socio-economic points of view; iii) drafting a *Regional strategic plan* for managing the risk of transboundary plant pests and diseases; iv) implementing an overarching *communication strategy* to raise information level; v) supporting international collaboration and expert/personnel exchange; vi) creating a

Regional transboundary trust fund for pests and diseases to finance activities to avoid mainly economic, migration and social crises.

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