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ORIGINAL ARTICLE

Farmers' knowledge, perceptions, and farm-level management practices of citrus pests and diseases in Morocco

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Abstract
This paper documents pest management practices adopted by citrus farmers in two of the citrus-growing regions in Morocco. The survey data propose possible recommendations to ensure sustainable pest management strategies. By variety, the surface area occupied by the Navel and Maroc-late represented 25% and 23%, respectively. 54% of the citrus farmers used certified sour orange rootstocks. 79% of farmers adopted soil plowing using a plow called *Cover-Crop*. Drip irrigation was widely practiced in the two regions studied. Citrus growers perceived mealybug, medfly, and mites as the most common insects, and Phytophthora rot and dry root rot as the most devastating fungal diseases infecting citrus production. 54% of the respondents used a pre-established treatment schedule. A total of 21 active ingredients of insecticides belonging to 15 different chemical groups were inventoried during the survey. Organophosphates were the most widely used insecticides (28%), followed by pyrethroids (17.9%), and neonicotinoids (16%). For disease control, copper compounds were used by all respondents. The manual–mechanical weed control method was widely practiced. 29% of respondents admitted to having little knowledge about the impact of climate change, 43% reported about a shift in dates of production practices, and 35% experienced pest outbreaks in their orchards. Due to the unregulated management practices, our findings emphasize the necessity of extension services to citrus farmers on the adoption of integrated citrus production. This system will help achieve sustainable citrus production, protect the environment, and optimize citrus yield.

Keywords Citrus farmer · Citrus orchard · Phytoprotection · Gharb · Tadla · Morocco

Introduction

In Morocco, citrus production contributes substantially to the national economy, through the generation of income from diverse activities along its value chain. As a means of livelihood for citrus farmers, the citrus value chain helps create employment at about 25 million working days annually: 18 million at the production level and 7 million in the conditioning and processing industries (Anonymous 2018; Mokrini et al. 2018). In 2016, the total surface area of citrus orchards was more than 126,600 ha, of which 32% is located in Souss-Massa, 20% in Gharb, 16% in Moulouya, and 13% in Tadla. This sector produces an average of 2.6 million tons of fruits per annum (Anonymous 2016). However, the national average yield (20 t/ha) remains low compared to other producing countries such as Brazil, the United States, and China (MAPM 2013).

Concerning the climatic conditions, the Tadla region is characterized by a climate ranging from humid (peaks of the High Atlas range and some peaks of the Middle Atlas) to arid and dominated by a continental type. Conversely, the Mediterranean climate in the Gharb region is characterized by an alternating wet season from October to April and a dry and hot season from May to September (DGCL 2015).

Even though agro-climatic diversity in the two regions favors citrus production, citrus farmers encounter several problems and constraints relating to insect pests and fungal diseases as well as their management methods. Citrus fruits

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are very sensitive to fungal diseases and also to many other pests, which cause damage to the fruit and therefore impact negatively the yield (Khanchouch et al. 2017; Biche 2012; Soumia et al. 2017; Jaouad et al. 2020). The phytosanitary problems faced in the citrus industry lead to low demand for the fruits at both local and international markets. Consequently, the price determination is affected (Montaigne et al. 2015; El Hadad 2001). Agricultural researchers have raised concerns about the Mediterranean fly (*Ceratitis capitata* Wiedmann), citrus leafminer (*Phyllocnistis citrella* Stainton), scale insects, mites, and aphids as the key insect pests hindering citrus production (Tena and Garcia-Marí 2011). However, few studies have been conducted on fungal diseases such as Phytophthora and Fusarium root rot (Allili 2013). These fungal diseases are devastating and their poor management will lead to the total loss of the plantation.

To control these bio-aggressors and reduce their impacts on an economically tolerable level, several control measures need to be employed. But chemical control, in Morocco as elsewhere, remains the most wide method practiced (ONSSA 2015). Ait Houssa II (2020) estimate that the cost of production relating to pesticide use in an orchard in Morocco is US$1000. This is a very exorbitant cost, more especially for small-scale citrus farmers. Researchers recommend the necessity of research for appropriate alternative methods to commercial citrus production (Talibi et al. 2014, 2012). Moreover, pesticide application is detrimental to the farmer's health, income, and environment. These situations could be curbed by enhancing citrus farmers with in-depth knowledge of pests and their environment-friendly management practices.

Besides, climate change affects production due to pest outbreaks and causes a decrease in citrus fruit quality, which creates constraints when exporting these products. Consequently, there have been large differences in production between producing and exporting countries depending on their geographical position (Grissa 2010). Crop production in Morocco is prone to drought spells, which impact negatively the national economy. The contribution of agriculture to the country's gross domestic product (GDP) is projected to decrease by three percent (Ouraich and Tyner 2014) if proper climate change adaptation and mitigation practices are not adopted. According to Fares et al. (2017), the availability of water resources to citrus trees is greatly affected by climate change at a global stage. Thus, the choice of irrigation technologies in managing water use sustainably becomes a concern to the public sector.

In most cases, crop losses due to insect pests and diseases can be avoided or reduced by implementing effective protective measures, which depend to a large extent on farmers' knowledge and perception of pest control, as well as the availability and the effectiveness of crop protection methods (Moinina et al. 2018; Oerke 2006; Bond and Grundy 2001; Siddiqui et al. 2019). Approaches employed must have positive impacts not only on citrus grower's income but also on consumer's health and the environment when it comes to pesticide use.

Therefore, it is important to investigate through a survey what farmers know about insect pests and diseases affecting citrus trees, their perception of damage to crop yields, the control methods they choose to apply, and the perceived effectiveness of these methods in short and long terms and if these methods respect the specifications for possible export of the harvest (Moinina et al. 2018; Siddiqui et al. 2019).

The above-mentioned problems and constraints underpin the need to interview farmers and know the realities behind their decisions in terms of the control of key citrus pests and fungal diseases in two main citrus-growing regions. The findings might help to understand the difficulties encountered by farmers during the growing season and how they would overcome the problems and constraints due to their perceptions of insect pests, diseases, and climate change.

In Morocco, there are no detailed reports on pest management practices adopted by citrus farmers. Therefore, this study was carried out to (i) assess farmers' perceptions and practices in managing the main pests and diseases affecting citrus production in the regions of Tadla-Azilal and Gharb; (ii) determine the impact of phytosanitary treatments on yield based on farmers' estimates and factors affecting the current productivity of citrus fruits, and (iii) identify the channels that can be used for effective dissemination of information to assist farmers in best phytosanitary practices.

The results of the study could be used as a critical reference base for the National Agricultural Research and Extension System (ONCA) programs in Morocco by identifying the types of actions that might be necessary for the sustainable management of key citrus pests and diseases. Information is also crucial in the development of integrated and sustainable management strategies for citrus pests.

Materials and methods

Study areas and sampling

This study was conducted in two citrus-producing regions; Tadla and Gharb. The geographical position of the Tadla region gives it a climatic diversity that varies from a humid climate (peaks of the High Atlas Mountains and some peaks of the Middle Atlas) to an arid climate. The dominant climate is continental, with intense cold in winter and very hot summers. Also, there are significant variations in the average annual rainfall. In 2012, the average annual rainfall varied from 291 mm to 460.3 mm while the average annual temperature was from 2 to 40 °C across the provinces in this region. Snow appears from an altitude of 900 m and hot winds are prevalent in summer (DGCL 2015).

Located in the North-West of Morocco, the Gharb region is bordered by the region of Tangier-Tetouan-Al Houceïma in the North, the region of Fez-Meknes in the East, and the Atlantic Ocean in the West. With the Mediterranean climate, the Gharb region is characterized by the alternation of a humid season from October to April and a dry and hot season from May to September. The coldest month of the year is in February when the average temperature dropped to 9.54 °C while the hottest months are July and August with higher temperatures of 27.72 °C (Alaoui amine 2015).

Survey

Eighty-four citrus farmers' households randomly selected were surveyed in the targeted communities of two regions: 55% of the respondents were in the Gharb region and 45% in the Tadla region. Table 1 shows the agro-ecological zones sampled, the districts, and the sample size. The survey was conducted from March to May 2019. A total of 84 farmers (47 in Gharb and 37 in Tadla) including 14 municipalities were surveyed. The questionnaire was developed to infer information on agricultural and phytosanitary practices of citrus farmers in both regions. Precisely, the farmers were interviewed directly and orally to infer the desired information. Discussions were also developed to better explain the objectives of the questions and understand farmers' perceptions about the information. The interviews were conducted in Arabic or French dialect during face-to-face interaction. The target respondent on a farm was often either the head of the household or the farm manager or any member of the household responsible for making agricultural decisions. Informed consent was requested from respondents before registering their information and the data processed following the general data protection regulations.

Table 1 Number of farmers surveyed by municipality and region

Region	Sample districts	Number of respondents	Surface area (ha)
Tadla	Bni Oukil	2	250
	Ouled Iyad	1	5
	Ouled Ben Hamadi	2	260
	Ouled Yich	4	158.5
	Ouled Said	8	500
	Ouled Youssef	4	109
	Sidi Jaber	16	469.5
Gharb	Boumaiz	22	673
	El Houafat	1	200
	Khnichet	9	715
	Selfat	6	330
	Sidi Abdelaziz	1	11.5
	Zirara	4	581
	Ouled Hssin	4	338.5
	Total	84	4601

The questionnaire covered: (1) basic information about the respondent such as gender, age, level of education; (2) citrus production practices (crop varieties, the yield obtained, external inputs used, main pests and diseases and management practices, and use of chemicals); (3) farmers' knowledge, perceptions and practices regarding pests and diseases; and (4) sources of information for farmers on agriculture and pest control. Citrus production data were based on 2018, covering production activities for the 2017/18 crop year. With regards to citrus farmers' perception of diseases, the study focuses on fungal diseases as these could be easily identified, unlike bacterial and viral diseases infecting citrus crops.

The concept of knowledge, perceptions, and practices was used to analyze farmers' pest management decisions. This concept has been widely used in previous studies (Van Mele 2000; Moinina et al. 2018). In this study, knowledge refers to what citrus farmers know about insect pests and diseases. Respondents were asked about the insects and fungal diseases that devastated their operations. On the other hand, perceptions refer to the problem of pests perceived by farmers, damage to crops, and the effectiveness of control measures. The quantification of crop damage was based on a farmers' estimate of the yield with or without treatment. Quantification of damage by farmers may be less precise, but Van Mele et al. (2002) argue that this provides good information on farmers' perceptions of damage to crops, which in turn conditions their decisions on the course of action. The practices refer to the actual actions that farmers have used to control diseases and insect pests. Farmers listed several options and for those who used pesticides, additional information was obtained on the used pesticides, how they are handled, and the dose at which they are applied.

Statistical analysis

Data analysis on the survey was performed using the statistical software; SPSS 20 and Microsoft Excel 2013. Once the field survey was completed, the latter software was used for inputting data and the final dataset was uploaded to the SPPS software for analysis. A descriptive analysis was performed for calculating frequencies, means, and standard errors. Chi-square tests were used to compare the significance of the categorical variables between farmer categories by age and sex. Analysis of variance (ANOVA) was used for quantitative variables with normal distributions and homogeneous variances. In addition to farmers' perceptions, factors that may be related to current citrus productivity were assessed using a log-linear regression model to understand their effect on citrus yields.

Results

Characteristics of farmers and orchards

The characteristics of the surveyed farmers and their orchards in the regions of Gharb and Tadla are listed in Table 2. The age of farmers varied from 23 to 77 years. Results show that 72% of farmers in the Gharb region and 80% in the Tadla region were over 50 years old. Regarding the level of education, 17% of the surveyed farmers have no formal educational background, 24.5% received primary education, 26.7% secondary education, and 36.7% higher education. It appears that the majority of the surveyed farmers have received academic training. Besides, there was no significant difference in the age of farmers ($P > 0.05$, $V = 0.135$) and level of education between the two regions ($P > 0.05$, $V = 0.242$).

Table 2 Characteristics of citrus farmers and orchards in the two regions

Characteristics	Region			
	Gharb	Tadla	Chi-square	V Cramer
Age (years)	Percentage (%)		Sig = 0.817	V = 0.135
Less than 30	6	2.90		
31 to 40	22	17.10		
41 to 50	34	34.30		
51 to 60	24	34.30		
Superior to 60	14	11.40		
Level of education	Percentage (%)		Sig = 0.175	V = 0.242
Illiterate	20	14.30		
Primary	26	22.90		
Secondary	12	31.40		
Superior	42	31.40		
Surface area (ha)	Percentage (%)		Sig = 0.411	V = 0.256
Less than 10	48	37.10		
11 to 20	8	17.10		
21 to 30	2	5.70		
31 to 40	6	11.40		
41 to 50	4	0		
Superior to 50	32	28.60		
Orchad's age (years)	Percentage (%)		Sig = 0.315	V = 0.204
Less than 10	34	40		
11 to 20	34	34.30		
21 to 30	4	11.40		
Superior to 30	28	14.30		

The *t*-test was conducted to determine the variability within the studied population in terms of farmer age, area, agronomic experience, and yield (Table 3). The results show that there was a significant difference between farmers for all these variables (Sig < 0.05). According to Table 2, the most dominant area is less than 10 ha. Large areas (> 60 ha) were also present with a percentage of 26%. Citrus plantations in both regions were mainly young (under 10 years) to moderately young (10 to 20 years), with a percentage of 69% of the total number of the visited orchards. Old plantations, over 30 years old, had a percentage of 20% (Table 2).

Table 2 shows that there was no significant difference in the orchard area ($P > 0.05$, $V = 0.256$) and plantation age ($P > 0.01$, $V = 0.204$) between the two regions. Indeed, the variety profile is much diversified in the regions of Gharb and Tadla and it includes 28 varieties. According to the analysis of the data collected, the total area of the surveyed producers is 4601 ha and mostly occupied by the Navel variety (24% of the total area) followed by Maroc-Late (23%) (Fig. 1).

The choice of rootstock is a very important step in planting citrus trees to avoid soil-borne diseases, such as dry rot and Phytophthora rot. In both the surveyed regions, the most abundant rootstock was sour orange because of its vigor and resistance to Phytophthora root rot (*Phythopthora citropthora*, R.E. Smith and E.H. Smith) (Fig. 2). The choice of this grafting stock is widely adopted in old orchards as it is the oldest grafting stock in Morocco. Volkamer Lemon (*Citrus volkameriana*), Carrizo citrange trifoliate hybrid (*Citrus sinensis* 'Washington' sweet orange X *Poncirus trifoliate*) and C 35 rootstocks are tolerant to viral diseases such as citrus tristeza virus, unlike the Bitter Orange, which has been

Table 3 Descriptive statistics of the studied characters

Characteristics	The studied population			
	Mean	SE	MSE	*t*-test
Age (years)	48.26	9.661	1.048	0.000
Surface area (ha)	54.13	81.746	8.867	0.000
Yield (t/ha)	22.39	13.267	1.439	0.000
Experience (years)	17.15	9.055	0.982	0.000
Gharb				
Age (years)	47.780	10.272	1.453	0.000
Surface area (ha)	62.180	96.481	13.644	0.000
Yield (t/ha)	22.960	13.762	1.946	0.000
Experience (years)	17.600	10.182	1.440	0.000
Tadla				
Age (years)	48.943	8.815	1.490	0.000
Surface area (ha)	42.629	53.503	9.044	0.000
Yield (t/ha)	21.571	12.678	2.143	0.000
Experience (years)	16.514	7.241	1.224	0.000

SE Standard error, *MSE* Mean Standard error

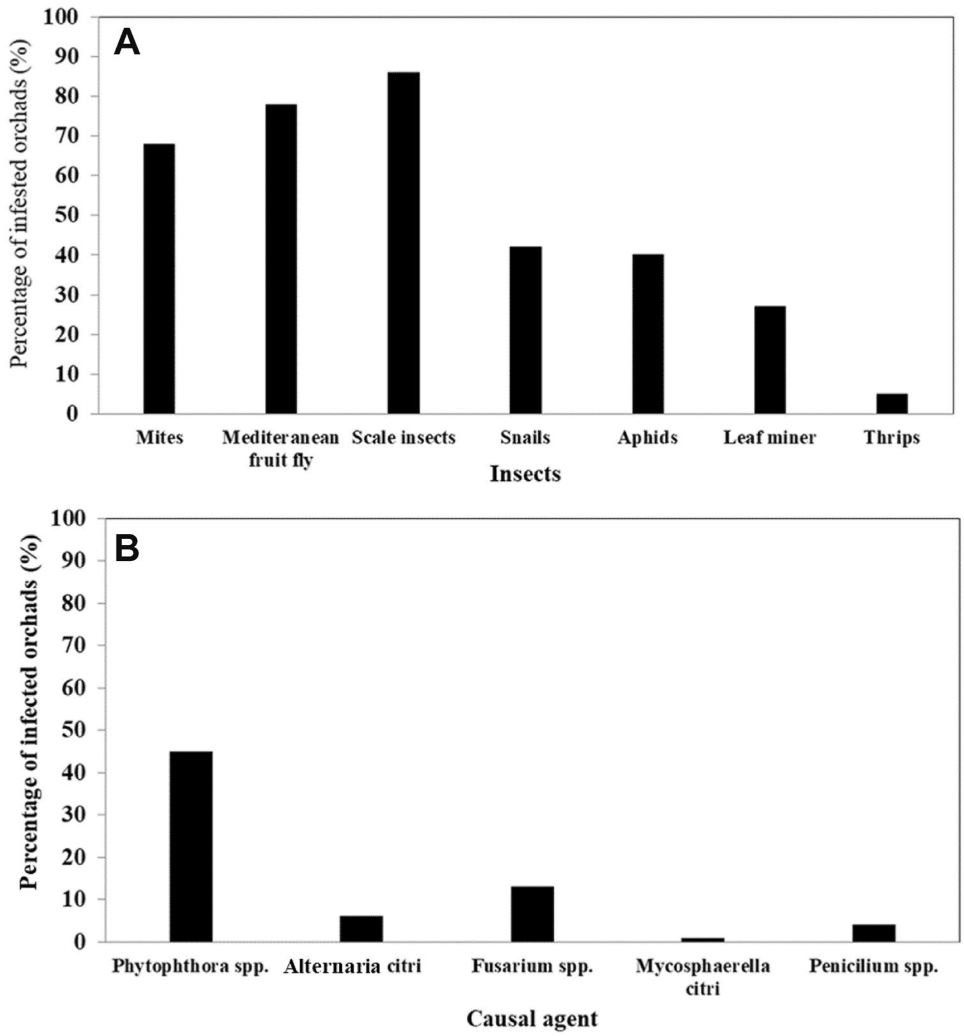

Fig. 1 Infestation rate of orchards by pests **(a)** and diseases **(b)** in the surveyed growing citrus regions

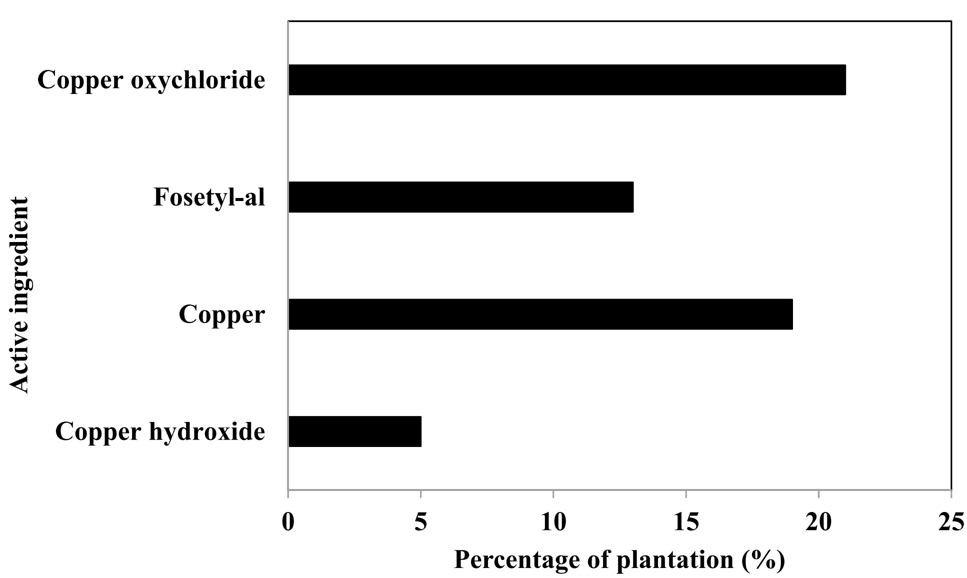

Fig. 2 Active ingredients used against fungal diseases in citrus plantations of two surveyed regions Ghareb and Tadla in Morocco

reported to be susceptible to this disease. Furthermore, the distribution of soil types showed no significant difference in soil type between the two regions ($P > 0.05$, $V = 0.110$) (Table 1).

Cultural practices adopted by farmers

In this study, the types of irrigation and the origin of the plant material adopted by farmers in the two regions were evaluated (Table 1). The survey conducted reflects the awareness of citrus growers on the importance of certified seedlings, showing that the majority of the surveyed farmers (52% in Gharb and 54% in Tadla) opted for the choice of certified plant material. Furthermore, there was no significant difference in the origin of the plant material between the two regions ($P > 0.05$, $V = 0.073$).

Drip irrigation was the most wide irrigation method used in the two studied regions (85.7% in the Tadla region and 52% in the Gharb region); farmers in the Tadla region adopted the drip system more than farmers in the Gharb. Results underline a significant difference in the irrigation system between the two regions ($P = 0.01$, $V = 0.350$) (Table 1). Concerning soil tillage, 79% of the farmer's used a plough called *Cover-Crop*, which was generally used for aeration and weeding. However, 7% of farmers did not till their soil but they mounded their trees. Farmers who tilled their soil adopted two to three passages of a harrower per year during the period following pruning.

Main pests, diseases, and weeds problems

The main pest species recorded in the studied areas and the percentage of orchards infested by each pest are summarized in Fig. 1a. The most common pest found in the studied citrus orchards was the mealybug (86%) followed by medfly, *C. capitata* (78%), and mites (68%) (*Panonychus citri* McGregor and *Tetranychus urticae* Koch) (Fig. 1a). Figure 1b illustrates the causal agents of the diseases identified in the surveyed orchards and the percentage of the infected orchards. Accordingly, the most common disease found in citrus orchards was Phytophthora root rot (45%), followed by dry root rot (13%), and the rest were other fungal diseases including *Alternaria* spp. and *Penicillium* spp. Besides, our results indicate that 55% of the visited orchards showed the presence of weeds. According to Table 4, there is no significant difference in the number of pests ($P > 0.05$, $V = 0.150$) and diseases encountered in the orchard ($P > 0.05$, $V = 0.405$) between the two regions. As for the occurrence of Phytophthora disease (*Phytophthora. citropthora*, R.E. Smith and E.H. Smith), there was a significant difference between the two regions ($P < 0.05$, $V = 0.339$). Phytophthora root rot was more common in the Gharb region at a percentage of 60% compared to Tadla, where it has a percentage of 25.7%. There was no significant difference in the occurrence of dry root rot between the two regions ($P > 0.05$; $V = 0.065$).

Table 4 Distribution of pests and diseases by region

	Region			
	Gharb	Tadla	Chi-square	Cramer's V
Number of pests (%)			Sig = 0 .860	V = 0.150
1	4.00	0.00		
2	14.00	14.30		
3	44.00	40.00		
4	22.00	25.70		
5	10.00	14.30		
6	6.00	5.70		
Number of diseases (%)			Si0 = 0.008	V = 0.405
0	38.00	65.70		
1	50.00	22.90		
2	10.00	0.00		
3	2.00	8.60		
4	0.00	2.90		
Occurrence of Phytophtora spp. (%)			Sig* = 0.002	V = 0.339
Absence	40.00	74.30		
Presence	60.00	25.70		
Occurrence of Fusarium spp. (%)			Sig = 0.396	V = 0.065
Absence	84.00	88.60		
Presence	16.00	11.40		

Pest and disease management

a. ***Processing decision and compliance with the pre-harvest deadline***
Table 5 shows that 54% of the surveyed farmers established a phytosanitary calendar to initiate chemical treatments. This schedule is based on the date of appearance of the pest and the date when the treatment will be effective in targeting the susceptible stage. Treatments based on monitoring opted for daily or weekly observation of symptoms and a count of pests present on the traps, the decision to treat takes place when the harmful level is reached. According to Table 7, there was no significant difference in pre-harvest compliance ($P > 0.05$, $V = 0.238$) and treatment decision ($P > 0.05$, $V = 0.870$) between the two studied regions.

b. ***Active ingredients and targets***

Table 6 illustrates the insecticides used for each of the identified targets and their percentage of use. A total of 15 pesticides consisting of 21 active ingredients have been listed. The most common chemical family applied was organophosphates (28%), followed by pyrethroids (17.9%), neonicotinoids (16%), and metaldehyde (12.7%). To control mites, 10 active ingredients were used, while 5 and 8 active ingredients were used for Mediterranean fruit fly and aphids, respectively. However, snails were only controlled by one active ingredient called metaldehyde. Furthermore, results show that for abamectin, there is a significant difference between the two regions ($P < 0.05$, $V = 0.277$) with a percentage of use of 32% in the Gharb region and 9% in the Tadla region (Table 7). Lambda-cyhalothrin was widely used in Tadla (63%) and Gharb (30%) regions, a significant difference between the two regions was observed ($P < 0.05$, $V = 0.326$). There was a significant difference in the use of malathion between the two regions ($P < 0.05$, $V = 0.231$), as it is used at 18% in Gharb and 3% in Tadla. There was also a significant difference in the use of bifenthrin ($P < 0.05$; $V = 0.288$), as it is used in the Tadla region with a percentage of 23%, and in the Gharb region with a percentage of 4%. This is explained by the fact that farmers from the Tadla region use this active ingredient for mite control more than the Gharb region.

For disease control, the most commonly used active ingredient was copper (13%), followed by fosetyl-aluminum (19%) and copper oxychloride (13%) (Fig. 2). Copper, copper oxychloride, and copper hydroxide were used for the preventive control of Phytophthora and other fungal diseases such as *Alternaria* spp. and grey leaf spots disease. Fosetyl-aluminium is mainly used for the control of *Phytophthora* spp. curatively. Regarding the weed control in citrus orchards, the most commonly used weeding method was manual–mechanical, followed by mechanical-chemical weeding, and the surveyed farmers couple several weeding methods to deal with the high presence of weeds; it is no longer sufficient to use a single weeding method.

Table 5 Adherence to pre-harvest interval and treatment decision by region

	Region			
	Gharb	Tadla	Chi-square	Cramer's V
PHI respect (%)			Sig = 0.175	V = 0.238
Yes	76.50	64.70		
No	23.50	35.30		
Treatment's decision (%)			Sig = 0.281	V = 0.870
Treatment schedule	52.90	61.80		
Monitoring	47.10	38.20		

Choice of pesticides products

The choice of plant protection products is of major importance for pest and disease control. Different criteria were assessed during this survey (Table 8). To understand the farmers' decision-making for the choice of the phytosanitary products, the chi-square test was conducted and the results indicated a significant difference in the choice of the product between the two regions ($P < 0.05$, $V = 0.408$). The majority of farmers in the Gharb region (36%) chose plant protection products based on their efficiency, while farmers in the Tadla region (41%) relied on agricultural advisors. Concerning rinse water, the majority of farmers reuse it in their plots (68% in the Gharb region and 74% in Tadla).

Regression Model

A regression analysis was done to estimate the effects of various socioeconomic and production factors on citrus productivity (Table 9). The dependent variable was citrus yield (tons/ha) for the 2017–2018 cropping season. Results show that the number of treatments and orchard's age was positively and significantly associated with citrus yield. This implies that farmers who applied more treatments were likely to have a better yield than those who did not. These results partly explain the farmers' positive perception of the effectiveness of pesticide sprays on citrus yield. Soil plowing and the age of the farmer showed a significant negative effect on citrus yield. This implies that younger farmers were more likely to register high citrus yield. In contrast, the regression model underlines no significant effect of educational level, farm size, applicator training, and irrigation type on citrus productivity.

Table 6 Percentage of each insecticide used against each identified target pests and their percentage of use

Citrus pests	Mite	Medfly	Scale insects	Snails	Aphids	Leafminer	Thrips	Total	%
Pyrethroids									
Bifenthrin	19.3	–	–	–	–	–	–	11.0	4.1
Deltamethrin	1.8	28.6	–	–	3.0	–	–	16.0	6.0
Lambda-cyhalothrin	–	34.7	–	–	–	–	–	17.0	6.3
Lambda-deltametrin	–	6.1	–	–	–	–	–	3.0	1.1
Cypermethrin	–	–	–	–	3.0	–	–	1.0	0.4
Thiazolidinon	–								
Hexythiazox	15.8	–	–	–	–	–	–	9.0	3.4
Quinoxalines	–	–	–	–	–	–	–		–
Clofentezin	8.8	–	–	–	–	–	–	5.0	1.9
Quinazolin	–	–	–	–	–	–	–		–
Fenazaquin	8.8	–	–	–	–	–	–	5.0	1.9
Avermectin									
Abamectin	24.6	6.1	–	–	–	25.0	–	23.0	8.6
Tetronic acid									
Spirodiclofen	14.0	–	–	–	–	4.2	–	9.0	3.4
Organophosphorus									
Malathion	3.5	24.5	–	–	3.0	–	–	15.0	5.6
Chlopyriphos-ethyl	–	–	81.2	–	12.1	–	–	60.0	22.4
Neonicotinoïds									
Acetamiprid	1.8	–	1.4	–	18.2	29.2	–	15.0	5.6
Imidacloprid	–	–	–	–	51.5	37.5	100.0	28.0	10.4
Pyridine derivatives									
Pyriproxyfen	1.8	–	2.9	–	–	–	–	3.0	1.1
Spinosyn									
Spinosad	–	–	1.4	–	–	–	–	1.0	0.4
Ketoenols									
Spirotetramat	–	–	13.0	–	–	–	–	9.0	3.4
Metaldehyde									
Metaldehyde	–	–	–	100.0	–	–	–	34.0	12.7
Pyridinecarboxamide	–	–	–	–	–	–	–		–
Flonicamid	–	–	–	–	6.1	–	–	2.0	0.7
Carbamates									
Methomyl	–	–	–	–	3.0	–	–	1.0	0.4
Limonoïd									
Azadirachtin	–	–	–	–	–	4.2	–	1.0	0.4
Total no	57.0	49.0	69.0	34.0	33.0	24.0	2.0	268.0	100

Farmers' perceptions of climate change

a. ***Effect on production***

According to Fig. 3a, we found that, in general, all the surveyed farmers were aware of the effects of climate change on production. In particular, 29% of respondents admitted not knowing any effect of climate change on production, 43% found that the delay in production dates is due to climate change. The rest reported that this hazard causes chlorosis (5%), decreases blooming (22%), and deteriorates quality (1%).

b. ***Effect on pests and pathogens***

According to (Fig. 3b), it was found that 65% of the surveyed farmers stated that they did not notice any effect of climate change on pathogen outbreaks, 15% confirmed that there was an increase in the number of mites, 8% declared aphids and snails outbreaks, 4% stated that pest cycles continued.

Table 7 Distribution of active ingredients of insecticides products used by region

	Region		Test	
Active ingredient (%)	Gharb	Tadla	Chi-square	V Cramer
Abamectin	32	9	Sig* = 0.011	V = 0.277
Acetamiprid	22	20	Sig = 0.824	V = 0.024
Befinazot	4	0	Sig = 0.231	V = 0.130
Bifenthrin	4	23	Sig* = 0.008	V = 0.288
Clofentezin	8	3	Sig = 0.321	V = 0.108
Deltamethrin	22	9	Sig = 0.1	V = 0.178
Fenazaquin	6	6	Sig = 0.956	V = 0.006
Hexythiazox	12	11	Sig = 0.936	V = 0.009
Malathion	18	3	Sig* = 0.033	V = 0.231
Pyriproxyfen	2	0	Sig = 0.4	V = 0.091
Spirodiclofen	16	3	Sig = 0.053	V = 0.21
Lambda-cyhalothrin	30	63	Sig* = 0.003	V = 0.326
Lambda-deltamethrin	0	6	Sig = 0.087	V = 0.186
Chlorpyriphos_ethyl	70	83	Sig = 0.176	V = 0.147
Spirotetramat	10	6	Sig = 0.479	V = 0.077
Metaldehyde	48	31	Sig = 0.127	V = 0.166
Cypermethrin	0	2.9	Sig = 0.229	V = 0.13
Imidacloprid	24	40	Sig = 0.115	V = 0.171
Flonicamid	4	3	Sig = 0.779	V = 0.03

Table 8 The main Criteria used by the surveyed farmers for the selection and adoption of the plant protection product

	Region		Test	
	Gharb	Tadla	Chi-square	V Cramer
Choice of product (%)			Sig* = 0.048	V = 0.408
Price	2.00	5.70		
Efficacy	36.00	20.00		
Advisor	0.00	14.30		
Diagnostic	10.00	11.40		
Price_efficacy	32.00	22.90		
Efficacy_advisor	12.00	20.00		
Price_diagnostic	6.00	0.00		
Price_advisor	2.00	5.70		

Discussion

The study carried out provided information on agricultural knowledge, perceptions, and practices of citrus growers in the regions of Gharb and Tadla. This study concerned farmers with orchards of different surface areas. By analyzing the data, it has been shown that citrus orchards in Morocco are dominated by large farms. As such, 26% of the surveyed farms had a surface area greater than 60 ha. ORMVAG (2018) recorded the percentage of orchards exceeding 50 ha as 11.7%

Table 9 Factors influencing citrus production in both surveyed regions

Yield (t/ha)	Coef	Std. Err
Age	−0.05	0.174
Level of education (scale from 1 to 4)	0.10	1.390
Farm size(ha)	0.22	0.018
Number of treatments	0.04*	0.259
Applicator training (yes = 1)	−0.38	3.135
Orchard's age	0.00*	0.656
Use of drip irrigation (yes = 1)	−0.11	2.738
Soil plowing (yes = 1)	−0.01*	3.580

*Denote statistical difference at the 5% level

Regarding the type of soil, citrus trees thrive well on soils with low clay alluvium (*Dess*). Clay soils (*Hamri*), sandy soils (*Rmels*), and very clayey black soils (*Tirs*) are all suitable for citrus production (Anonymous 2016). Our study shows that 88% of the surveyed orchards have a clayey-silt soil type, thus presenting a medium and balanced texture with good drainage. The survey shows that the majority of farmers tilled their soil, using a harrower called *cover-crop* with an average number of passages ranging from two to three. Soil tillage enables soil aeration and drainage. It has been noted that tillage between rows should not exceed 4 to 6 passages per year at most, at a depth not exceeding 20 cm to avoid disrupting the root system of citrus fruits (Anonymous 2016).

During our study, nearly 28 varieties were identified. By distribution, the Navel orange variety occupied the largest area (24% of the total area). An in-depth survey conducted on the entire citrus-growing region in 2018 showed that there are a total of 47 varieties of citrus fruits. The orange group occupied 41,729 ha (51.2%) followed by small fruits with 34,141 ha (41.9%), then lemons with 2828 ha (3.5%). Other citrus fruits represent 2850 ha (3.5%) (ORMVAG 2018).

The choice of rootstock is essential to improve fruit yield, size, and spread-out harvesting periods. The sour orange tree is the most dominant rootstock with 75% of the total area, as well as other rootstocks, namely Carrizo citrange rootstock (*Citrus sinensis* Osb. × *Poncirus trifoliata* L. Raf.), lemow (*Citrus macrophylla* Wester), and Volkamer Lemon (*Citrus volkameriana*) (ORMVAG 2018). These results are in line with the results of our study, which showed that the bitter orange tree is indeed the most used rootstock. It is found among 35% of the surveyed farmers. According to previous findings (Beniken et al. 2011; Benyahia et al. 2017), the choice of rootstocks is paramount in citrus production. The rootstocks must be certified to avoid disease transmission.

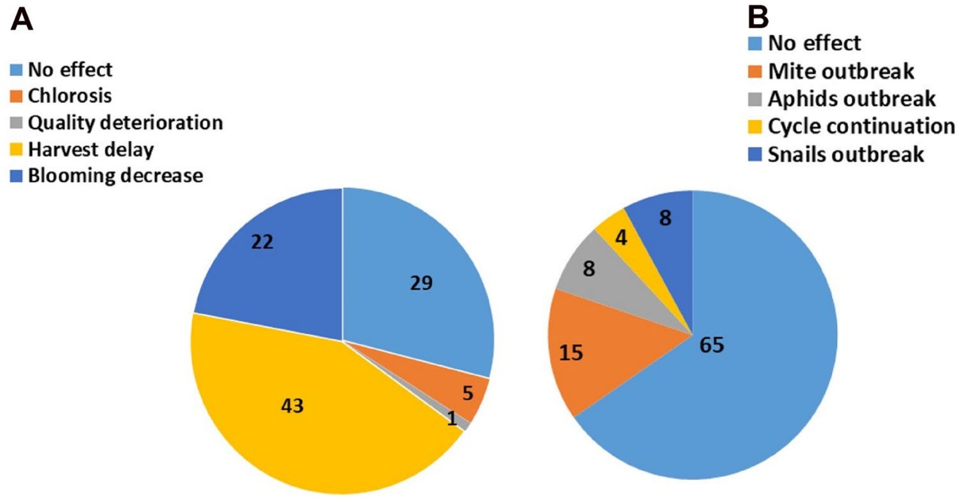

Fig. 3 Perception of the effects of climate change on production and citrus pests

The fundamental management principles of pests and diseases depend on the rootstock and cultivar selection, as well as sanitation practices in the orchard (Moinina et al. 2019; Beniken et al. 2011). Besides Benyahia et al. (2017) concluded that rootstock compatibility has effects on juice and brix contents of citrus fruits. Therefore, commercial citrus growers should choose their rootstocks based on the destination and consumer needs of the fruits.

The water requirements of citrus fruits are estimated at 1200 mm per year. In the Gharb region where rainfall reaches 550–600 mm from October to May, the 600–650 mm deficit must be filled through irrigation from May to September–October with adjusted inputs according to the values of potential evapotranspiration (ORMVAG 2018). According to our study, the most frequently used irrigation technique was localized (69% of producers use drip irrigation) which conforms with the findings of Allili (2013) who reported that 64% of farmers practiced drip irrigation. According to ORMVAG (2018), the area covered by drip irrigation in 2018 was estimated at 13,000 ha i.e. 54% of the total area of citrus orchards. Drip irrigation has been recommended for its numerous merits to citrus production (Abbas and Fares 2009). Besides, Laaroussi (2005) sensitizes citrus growers to adopt drip irrigation as a means of water management at the farm level. For mature orange trees, researchers (García-Tejero et al. 2010; Iván García-Tejero et al. 2012) explicitly explained that deficit irrigation affects citrus fruit yield and quality.

There are different methods of weed control, the combination of manual and mechanical weeding has been the most common in the surveyed orchards because small-scale citrus farmers adopt manual weed control method to feed their livestock. The management of grass cover can also be done by chemical control to avoid the repeated passage of implements that compact the soil, except that this becomes more complicated (Anonymous 2016). Therefore, the use of agro-ecological weed management methods such as mulching is essential. According to previous findings (Kitis et al. 2011; Gu et al. 2016; Bond and Grundy 2001), mulching brings different benefits to the farmer, such as improving soil fertility, conserving soil moisture, and improving soil microorganism content. As a good alternative to herbicides, mulching helps suppress weeds in the orchards (Day et al. 1957; Verdú and Mas 2007). Unfortunately, the respondents barely prioritize such an eco-friendly practice over the use of herbicides.

Our survey made an inventory of scale insects (86%), the Mediterranean fruit fly, *C.capitata* (78%), and mites (66%) as key insect pests affecting citrus production in the surveyed regions. According to previous results (Tena and Garcia-Marí 2011; Mazih 2008), the most important insect pests of citrus crops in the Mediterranean are the California red scale, *Aonidiella aurantii* Maskell and medfly, *C. capitata*. Other important pests are the mites (*T. urticae* and *P.citri*), the aphids (*Aphis spiraecola* Patch and *Aphis gossypii* Glover), and the mealybug, *Planococcus citri* Risso (Franco et al. 2004, 2006; Mazih 2008). Anonymous (Anonymous 2016) reported that the California red scale is the most serious citrus insect pest of all citrus fruits in Morocco, while the Mediterranean fruit fly is a real problem for clementine variety. Regarding fungal diseases, our study showed that Phytophthora disease was present in 44% of the studied orchards, followed by dry root rot (12%), and other fungal diseases such as *Alternaria* spp., grey spot, and fruit rot which were encountered but less frequently. These fungal diseases have been reported by Khanchouch et al. (2017). Tena and Garcia-Mari (2011) ranked Phytophthora root rot (*Phythopthora citropthora*, R.E. Smith and E.H. Smith) as the main disease of orange and clementine.

With regards to phytosanitary protection of citrus trees, Ait Houssa et al. (2020) emphasize that crop protection starts at the nursery level. Therefore, citrus growers are advised to obtain certified citrus seedlings. This will help prevent a wide range of diseases. Monitoring in citrus orchards is of major importance to ensure better phytosanitary protection, 46% of the investigated producers monitored the appearance of pests in their orchards. The trapping technique has thus been adopted for monitoring pests, particularly Mediterranean fruit fly, which is the pest that requires the most observation. Traps for males contain an attractant and an insecticide product, while traps for females contain a food attractant and an insecticide (Anonymous 2019). Lahlali et al. (2020) recommend that farmers carry out disease scouting and consider the action threshold before applying fungicide sprays. For medfly, the threshold is 1 individual/day/plot for males and 0.5 individuals/day/plot for females, and if the percentage of fruit with fly bites is greater than 1%. For mealybug, *P. citri,* Franco et al. (2004) proposed thresholds of 5% to 10% and 15% of fruits infested with colonies of young nymphs in the summer and the autumn, respectively. Monitoring California red scale is done by using a sticky plate containing a sex pheromone. Other trapping methods are used such as sexual confusion which consists of occupying the environment with a sexual pheromone and disorienting the males (Anonymous 2019).

Biological control of citrus pests has not been well implemented among the respondents. The constraints relating to little knowledge and perception of natural enemies in their orchards remain a major problem. The pest control methods adopted by the respondents were not diversified, related to the principles of integrated pest management. In citrus production, many botanical pesticides can be used to control insect pests, more especially the scale insects, mites, and aphids (Pekas 2011). Talbi et al. (2014) confirmed that plant extracts are alternative substances because of their antimicrobial activity, non-phytotoxicity, systemic action, and biodegradability. As this is a suitable alternative to the unpleasing environmental effect of synthetic pesticides, essential oils have proven to be effective against the California red scale (Pekas 2011). However, Smaili et al. (2013) showed the great potentials and chances of having multiple natural enemies in the citrus orchards in Morocco. The good news is that all the key insect pests of citrus can be managed biologically. For instance, the parasitism of the California red scale by *Aphytis melinus* DeBach has been reported to significantly reduce California red scale populations. Applying *A. melinus* at 100,000 insects/ha/year could maintain the scale insect population below economic injury level (Moreno and Luck 1992). Unfortunately, the natural activity of *A. melinus* under the Tadla conditions has been insufficient to control the economical incidence of the California red scale (Guirrou et al. 2003; Kaoutari and Boumezzough 2004).

A wide range of active ingredients has been reported for the management of various phytosanitary problems. Chemical families such as pyrethroids, avermectin, and neonicotinoids have been commonly used to control pest mites in orchards. However, resistance problems are caused by excessive acaricide use (Gerson and Cohen 1989; Grafton-Cardwell et al. 2014) and have become more toxic to natural enemies. Depending on climatic and environmental conditions, the necessary treatments should be carried out at the appropriate time using approved products, respecting manufacturers' recommendations, and using appropriate personal protective equipment. The California red scale has been largely controlled by chlorpyrifos-ethyl, spirotetramat, pyriproxyfen, etc. Jacas et al. (2010) have shown that other integrated pest management methods such as the spraying of mineral oils are used to control citrus scale insects. The Mediterranean fruit fly is a major challenge for citrus orchards, which requires chemical treatments based on organophosphates (Malathion/Dimethoate) and harvesting with pyrethroids because of the residues (Urbaneja et al. 2009). The use of synthetic insecticides has resulted in insecticide resistance, toxicity to non-target organisms, food residues, and environmental pollution (Desneux et al. 2007). Concerning fungal disease control, fosetyl-aluminum has been widely used as a curative treatment for the control of Phytophthora root rot, wood mastication with copper is also one of the disease control methods. It has been shown that fosetyl-aluminum has completely controlled the disease, as well as the combination of metalaxyl and fosetyl-aluminium. Copper was also widely used for the effective control of *Phytophthora* spp. Liquid copper formulations gave better results than wettable powders (Timmer et al. 2003). The citrus farmers should note that the presence of *P. citropthora* and other fungal diseases is influenced by water use in the orchard. More precisely, stagnation of water poses serious problems for the occurrence of these diseases (Khanchouch et al. 2017; Siddiqui et al. 2019). Through disease scouting, *P. citropthora* is checked by observing soil moisture content and shaking citrus trees. The weaker the root system is, the more prone is the infection. Besides, the adoption of drip irrigation with an appropriate volume by the majority of farmers has significantly contributed to reducing the occurrence of Phytophthora root rot (*Phythopthora citropthora*, R.E. Smith and E.H. Smith) in the major citrus-growing areas. Edaphoclimatic conditions are the key factors determining citrus production in Morocco. Ait Houssa et al. (2020) indicate that yield depends neither on the amount of the fertilizers applied nor the pesticides, but on the climate and the type of soil in a given orchard. With regards to fungal disease management, Khanchouch et al. (2017) emphasize that the Mediterranean climate is not conducive to epidemic infections of fungal diseases, and therefore chemical control method could be unjustifiable. Cultural practices influence productivity. Previous findings (Iván García-Tejero et al. 2012; Moinina et al. 2019) clarify that water shortage is a great extreme weather situation in arid and semiarid regions that has a significantly negative effect on commercial fruit growers. To manage accurately irrigation water, Hadria et al. (2019) suggest the use of satellite images to detect water requirements by citrus plants. However, this could be costly and inaccessible to small-scale citrus farmers. Seif-Ennasr et al. (2016) indicate that water demand has led to the reduction of the water table. This calls for the sustainable use of water resources by farmers.

One of the disadvantages of unchecked chemical control methods is that the fruits contain residues of pesticides (Calvaruso et al. 2020). This could be avoided if the citrus farmers' knowledge of pesticide use is enhanced. According to the Moroccan Association for Health, Environment and Toxico-vigilance (AMSETOX 2020), the pesticides registered in Morocco are in conformity with laws promulgated by the Moroccan National Office for Sanitary Safety of Food Products (ONSSA). About forty-four pesticides are used in citrus production. Pesticides such as bifenthrin, malathion and methomyl are among the list of highly harzadous pesticides (HPPs). However, this is no report on the national volume of use of the HPPs. Furthermore, activities such as the pre-harvest interval of every pesticide sprayed should be maintained.

To disseminate innovative approaches toward pest management practices to citrus farmers and enhance their knowledge in farm-level management operations, farmer field school (FFS) could be adopted at the institutional level. Victor et al. (2017) prove that FFS has shown positively immense results to citrus farmers' objectives in terms of farm sanitation practices, thereby improving fruit yield, and thus income. According to Franco et al. (2006), integrated citrus production is practiced by a few farmers in Morocco. This practice needs to be adopted because of its numerous advantages to sustainable agricultural development.

Conclusions

Our findings following the survey among citrus farmers highlighted, for the first time that citrus production is subject to many phytosanitary problems, including pests, plant pathogens, and weeds.

The citrus growers should be sensitized to do the needful in terms of pest and disease management. These growers are diverting toward chemical control due to mechanized farming without perceiving health and environmental impacts. The citrus yields should be optimized to meet the demand of the increasing population. To achieve this in an eco-friendly approach, integrated pest management should be well defined and implemented in the citrus orchards. Furthermore, the best agricultural and phytosanitary practices should be observed along the citrus value chain in the country. The citrus farmers require profound knowledge about the pesticide application and handling, and overall, crop management practices that are adaptable to climate change. This will help achieve the premium quality of our citrus fruits on the global stage.

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