جامعة سيدي محمد بن عبد الله بفاس
UNIVERSITÉ SIDI MOHAMED BEN ABDELLAH DE FES

كلية العلوم والتقنيات فاس
FACULTÉ DES SCIENCES ET TECHNIQUES DE FÈS

N° d'ordre : 33/2023

Centre des Etudes Doctorales : Sciences et Techniques et Sciences Médicales

Formation Doctorale : **Sciences et Génie de la Matière, de la Terre et de la Vie**
Discipline : **Environnement et développement durable**
Spécialité : **Santé végétale, Biotechnologie et phytoressources**
Laboratoires : **1* Ecologie Fonctionnelle et Génie de l'Environnement (EFGE)**
2* Chimie Organique Appliqué (COA)

Thèse pour l'obtention de DOCTORAT

Elaboration de nouvelles méthodes de lutte contre certains ravageurs (insectes et acariens) des agrumes

Préparée par : Mr Amine ASSOUGUEM

Soutenue le 27 mai 2023 devant le jury :

Nom Prénom	Titre	Etablissement	
BELRHITI ALAOUI Aziz	PES	FST Fès	Président
Lahlali Rachid	PH	ENA Meknès	Rapporteur & examinateur
Kandri Rodi Youssef	PES	FST Fès	Rapporteur & examinateur
El-Haidani Ahmed	PH	FST Errachidia	Rapporteur & examinateur
MAZOUZ Hamid	PES	FS Meknès	Examinateur
BOUCHAMMA El Ouazna	PH	FST Fès	Examinateur
EZRARI Said	PA	FMP Oujda	Invité
Abderrahim LAZRAQ	PES	FST Fès – USMBA	Directeurs de thèse
Abdellah FARAH	PES	FST Fès – USMBA	

Laboratoire d'accueil : 1* Ecologie Fonctionnelle et Génie de l'environnement
2* De la Chimie Organique Appliquée
Etablissement : Faculté des Sciences et Techniques de Fès

Remerciements

En tout premier lieu, je remercie Dieu le tout puissant de m'avoir accordé la volonté, la patience et l'énergie pour la réalisation de cette thèse.

Je souhaite remercier Monsieur le Professeur Taoufiq ACHIBAT, Doyen par intérim de la Faculté des Sciences et Techniques (FST) de Fès.

Je tiens à exprimer ma gratitude et mes sincères remerciements à mes directeurs de thèse, Professeur Abderrahim Lazraq et Professeur Abdellah Farah de la Faculté des Sciences et Techniques de Fès pour leurs encouragements incessants, leur confiance et leur accueil toujours chaleureux. Je les remercie pour leurs grandes disponibilités, leurs soutiens incontestables et leurs réelles qualités humaines. Je leur serai reconnaissant pour leurs orientations et leurs conseils précieux tout au long de mon parcours universitaire.

Je tiens à remercier vivement Monsieur le Professeur Aziz BELRHITI ALAOUI qui m'a fait l'honneur d'accepter la présidence de ce jury de thèse.

Je suis très sensible à l'honneur que me font Monsieur le Professeur Rachid Lahlali, Monsieur le Professeur Youssef Kandri Rodi et Monsieur le Professeur Ahmed El-Haidani pour avoir accepté d'évaluer ce travail en qualité de rapporteurs.

Je tiens à vous exprimer toute ma gratitude pour l'intérêt porté à cette thèse et pour le temps consacré à l'étude de ces travaux. De même, je tiens à remercier Madame le Professeur El Ouazna BOUCHAMMA, Monsieur le Professeur Hamid MAZOUZ et Monsieur le Professeur Said EZRARI de participer à ce jury en tant qu'examinateur. Votre participation à mon jury de thèse est pour moi un plaisir ainsi qu'un grand honneur.

J'aimerais remercier très sincèrement l'ensemble du personnel de la FST de Fès et plus particulièrement du laboratoire de Chimie Organique Appliquée (COA) et du Laboratoire d'Ecologie Fonctionnel et Génie d'Environnement pour tout ce qu'ils m'ont apporté.

Je voudrais remercier ici, le Professeur El-Ghadraoui Lahsen directeur du laboratoire d'Ecologie Fonctionnel et Génie de l'Environnement à la Faculté des Sciences et techniques de Fès, pour l'attention qu'il a portée à mon travail, ses conseils et ses encouragements

Je remercie du fond du cœur mes parents, mes trois frères, ma femme, et ma belle famille pour leur soutien inconditionnel, leur compréhension et leur encouragement inestimable.

Je tiens à remercier très chaleureusement mes amis : Sezai Ercisli, Kara Mohammed, Saoussan Annemer, Riaz Ullah pour leur joie de vivre, leur bonne humeur, leur réconfort et leur soutien.

Enfin, je n'oublierais pas d'exprimer toute ma reconnaissance à ceux qui ont contribué, de près ou de loin, à l'élaboration de ce travail et qui ont pris de leur temps pour me soutenir et m'encourager tout au long de ces années de thèse.

Résumé

La gestion intégrée des ravageurs par l'usage des produits chimiques avec de faibles doses qui vont permettre de réduire le taux des ravageurs à des seuils acceptables sans provoquer des impacts néfastes sur les prédateurs, par l'usage des détergents classés non dangereux ou par les huiles essentielles peuvent constituer une stratégie alternative à la lutte chimique intensive dans les vergers d'agrumes. De ce fait, l'objectif de ce travail a consisté à évaluer l'impact de différentes méthodes de luttes intégrées contres certains insectes et acariens ravageurs des agrumes, en particulier les cochenilles diaspines et les acariens tétranyques.

L'impact du produit systémique à base de Spirotétramate sur les cochenilles diaspines (*Parlatoria ziziphi* et *Parlatoria pergandii*) et sur leur parasitoïde *Aphytus hispanicus* a été étudié sur agrume dans la région du Gharb. Plusieurs doses de ce produit ont été pulvérisé (T0 = 0 L/Ha traité seulement par l'eau, T1 = 0,625 L/Ha, T2 = 0,755 L/Ha, et T3 = 1 L/Ha), afin de détecter la dose qui va permettre de réduire la proportion de ces deux cochenilles diaspines sur la variété Valencia tardif (*Citrus sinensis*) et qui va permettre un taux de parasitisme très élevé. Sur *P. pergandii* et *P. ziziphi*, l''insecticide à base de Spirotétramate a été évalué sur deux stades larvaires (L1 et L2) et trois stades femelles, F1, F2 et F3. De même, les taux de parasitisme par *A. hispanicus* sur les femelles de *P. pergandii* de trois stades ont été suivis, notre étude met en évidence que toutes les concentrations testées de ce produit ont été efficaces sur le ravageur *P. pergandii et P. ziziphi.* Par ailleurs, le taux de parasitisme a été très élevé avec la faible concentration (0,625 L/Ha) par rapport aux fortes concentrations du pesticide (T2 = 0,755 L/Ha et T3 = 1 L/Ha),

Nous avons ensuite étudié l'impact des traitements écologiques à base de détergents classés non dangereux et de savon noir sur le ravageur *Tetranychus urticae* Koch 1836, et ses prédateurs (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromus* sp., *Phytoseiulus persimilis* Athias-Henriot, 1957) en comparaison avec le produit chimique à base de Spirodiclofen, différents traitements ont été appliqués dans des vergers d'agrumes plantés en Valencia tardif dans la région de Mechraa Belksiri (T0 = expérience témoin ; T1 = Spirodiclofen 0,5 L/Ha ; T2 = 125 L/Ha de savon noir ; T3 = détergent ; Oni + 2 L/Ha du produit Tide). Les résultats obtenus pendant toute la période de surveillance ont indiqué que les trois traitements utilisés, à savoir le Spirodiclofen, le savon noir et les détergents, ont assuré une réduction du taux du ravageur *T. urticae* par rapport à la parcelle non traitée. Sur les prédateurs (*E. stipulatus*, *P. persimilis,* et *Typhlodropmus* sp.), le savon noir et le traitement avec des détergents ont été moins nocifs par rapport au produit chimique à base de spirodiclofen. Nos résultats permettent de conclure que le savon noir et les deux détergents utilisés peuvent remplacer les pesticides et restent des outils importants de la lutte contre les acariens ravageurs d'agrumes.

Nous avons ainsi étudié l'activité de *T. urticae* et de ses prédateurs (*E. stipulatus*, *Typhlodromus* sp., et *P. persimilis*) sur deux variétés d'agrumes différentes (Nules (Mandarine) et Valencia tardif (Orange)).

Nous avons étudié l'effet acaricide de quatre huiles essentielles dérivées de plantes contre les adultes de deux ravageurs importants des cultures, *T. urticae* et *Eutetranychus orientalis* (Klein) 1936. La toxicité du fumigeant a révélé que toutes les huiles essentielles testées *Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., et *Origanum compactum* Benth présentaient un effet acaricide. Pour la combinaison binaire entre les HE et l'acaricide à base d'acéquinocyl, les résultats ont montré que le mélange HE *O. compactum* + acéquinocyl présente un effet acaricide important sur *T. urticae* et *E. orientalis*. Ces résultats prometteurs pourraient aider à développer des pesticides botaniques qui pourraient être utilisés dans la gestion intégrée des parasites.

Mots clés : luttes intégrées, huiles essentielles, ravageurs, prédateurs, détergents, savon noir,

Abstract

The integrated management of pests by the use of chemicals products with low doses that will reduce the rate of pests to acceptable rates without causing negative impacts on predators and agrosystem, by the use of detergents products classified as non-hazardous or by essential oils can constitute an alternative strategy to intensive chemical control in citrus orchards. Therefore, the objective of this work was to assess the impact of different integrated control methods against some insect pests of citrus.

The impact of the systemic product based on Spirotetramt on diaspine scale insects (*Parlatoria ziziphi* and *Parlatoria pergandii*) and on their parasitoid *Aphytus hispanicus* was studied on citrus in the Gharb region. Some doses of this product were pulverized (T0 = 0 L/Ha treated only by water, T1 = 0,625 L/Ha, T2 = 0,755 L/Ha, and T3 = 1 L/Ha), in order to detect the dose which will reduce the proportion of these two insects on the Valencia late variety (*Citrus sinensis*) and which will produce a very high rate of parasitism. On *P. pergandii* and *P. ziziphi*, the Spirotetramat insecticide was evaluated on two larval stages (L1 and L2) and three female stages, F1, F2 and F3. Similarly, parasitism rates by *A. hispanicus* on *P. pergandii* females of three female stages were monitored, our study highlights that all tested concentrations of this product were effective on the pest *P. pergandii* and *P. ziziphi*. Moreover, the rate of parasitism was very high with the low concentration (0.625 L/Ha) compared to the high concentrations of the pesticide (T2=0.755 L/Ha and T3 = 1 L/Ha),

We studied the impact of ecological treatments with detergents classified as non-hazardous and black soap on the *Tetranychus urticae* Koch 1836 pest, and its predators (*Euseius stipulatus*, *Typhlodromus* sp, *Phytoseiulus persimilis*) in comparison with the chemical product based on Spirodiclofen, different treatments were applied in citrus orchards planted in Valencia late at the region of Mechraa Belksiri (T0 = control experiment ; T1 = Spirodiclofen 0.5 L/Ha; T2 = 125 L/Ha of black soap; T3 = detergent; Oni + 2 L/Ha of Tide product). Obtained Results throughout the monitoring period indicated that all three treatments used, namely Spirodiclofen, black soap and detergents, provided a reduction in the rate of the *T. urticae* pest compared to the untreated plot. On predators (*E. stipulatus, P. persimilis*, and *Typhlodropmus* sp.), our results conclude that black soap and the two detergents used can replace pesticides and remain important tools in the control of citrus mite pests.

We studied the activity of *T. urticae*, and its predators (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*) on two different varieties of citrus (Nules (Mandarin) and Valencia late (Orange)).

We studied the acaricidal effect of four plant-derived essential oils against adults of two important pests, *T. urticae* and *Eutetranychus orientalis*. The fumigant toxicity revealed that all tested essential oils *Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., and *Origanum compactum* Benth demonstrated an acaricidal effect. For the binary combination between EOs and acequinocyl acaricide, the results showed that the *O. compactum* + acequinocyl EO mixture exhibited a significant acaricidal effect on *T. urticae* and *E. orientalis*. These promising results could help to develop botanical pesticides that could be used in integrated pest management.

Key words: integrated pest management, essential oils, pests, predators, detergents, black soap,

Liste des abréviations

CP1: First principal component

CP2: Second principal component

Eos: Essential oils

F1 : Premier stade femelle

F2: Deuxième stade femelle

F3: Troisième stade femelle

Ha: Hectare

HCA: Hierarchical cluster analysis

HE : Huiles essentielles

IPM : Integrated pest management

G : Gramme

GLM : General linear model

L : Liter

L1 : Premier stade larvaire

L2 : Deuxième stade larvaire

Mm: Millimètre

M : Mortality rate

P : Parasitsm rate

PCA : Principal component analyses

PIF : Predator in first

PIP : Protectants plant-incorporated

SD : Standard deviation

SIT : Sterile insect technique

T : Treatment

µl : Microlitre

V : Survival rate

W : Weak

Liste des tableaux

Table 1. Principaux ravageurs des agrumes au Maroc [7,58–60].....14
Table 2. A comparison of mortalities (M) and survival (V) rates among different larval stages of *Parlatoria pergandii* treated with Spirotetramat. 91
Table 3. The survival (V) and mortality (M) of two larval stages (L1 and L2) of *Parlatoria pergandii* treated with different concentrations of Spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha). 91
Table 4. Comparison of mortality (M), parasitism rates (P), and survival rates (V) of three female stages (F1, F2, and F3) of *Parlatoria pergandii* by one-way ANOVA during treatment dates.....92
Table 5. Survival (V), mortality (M), and parasitism (P) of *Parlatoria pergandii* females (F1, F2, and F3) treated with different concentrations of Spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha).....94
Table 6.Effect of treatment doses (T0: 0 L/Ha Spirotetramat (as a witness experiment), T1 = 0.625 L/Ha, T2 = 0.755 L/Ha, and T3 = 1 L/Ha) on the mortalities of *Parlatoria pergandii,* and the parasitoid Aphytis hispanicus. 95
Table 7. Relationship between the different stages of *P. ziziphi.* 106
Table 8. Survival (V) and mortality (M) of *Parlatoria ziziphi* larvae (L1,L2) treated with different doses of spirotetramat T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha. 107
Table 9. Survival (V) of *Parlatoria ziziphi* larvae treated with different doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha) according to different follow-up dates after treatment. 108
Table 10. Survival (V) and mortality (M) of *Parlatoria ziziphi* females (F1, F2, and F3) treated with different doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha)..109
Table 11. Survival (V) of *Parlatoria ziziphi* females treated with different doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha) according to different follow-up dates after treatment. 111
Table 12. The impact of different treatments used on the mites studied (TU: *T. urticae*; ES: *E. stipulatus*; TY: Typhlodromus sp.; PP: *P. persimilis*) in citrus orchards. Values in the same column with different superscripts are significantly different ($p < 0.05$).....122
Table 13. General linear model (GLM) of analysis of variance for the mean density of *T. urticae* (a), *Typhlodromus* sp. (b), *P. persimilis* (c), and *E. stipulatus* (d) according to the treatments, monitoring dates, and their interactions 126
Table 14. Fluctuation of the different species studied (TU: *T. urticae*; ES: *E. stipulatus*; TY: *Typhlodromus* sp.; PP: *P. persimilis*) in the four treated plots (T0 = control experiment; T1 = spirodiclofen 0.5 L/Ha; T2 = 125 L/Ha (5%) of black soap; T3 = detergents 4 L/Ha of Oni product + 2 L/Ha of Tide product) according to the different monitoring dates (W: week). 127
Table 15. Temperatures recorded during the monitoring period. 128
Table 16. Varietal impact on different mite populations in the first (2020) and second year (2021)...142
Table 17. Temperatures recorded during the monitoring period. 144
Table 18. Variance analysis of different mite densities using general linear model (GLM) according to follow-up dates, treatments and its interactions (M: Monitoring). 159
Table 19. Means of different species studied according to the products applied in Nules orchards. ..159
Table 20. Correlation matrix between the variables (Temperature, *P. citri, E. stipulatus, Typhlodromus* sp. and *P. persimili*s) 159
Table 21. Means of the different species studied (PC: *P. citr*i; ES: *E. stipulatus*; TY: *Typhlodromu*s sp.; PP: *P. persimilis*) in the four treatments used Control experiment (T0), spirodiclofen (T1), black soap (T2) and detergents (T3) according to follow-up dates 165

Table 22. Temperatures recorded during the monitoring period.....165
Table 23. The major chemical constituents of the four EOs 177
Table 24. LD50 values calculated for *Tetranychus urticae*, and *Eutetranychus orientalis*.....180
Table 25. Correlation matrix between the main compounds of the four essential oils and LD50 of *E.Orientalis* and *T.urticae* 184

Liste des figures

Figure 1. Production et répartition géographique des agrumes au Maroc. 10
Figure 2. Location of the orchard used. 88
Figure 3. A model of the orchard we monitored (divided into four small plots of 1 ha) with the doses of Spirotetramat we used. 89
Figure 4. A comparison of mortalities (M) and survival rates (V) during two larvae stages (L1 and L2) of *Parlatoria pergandii*. 91
Figure 5. Analysis of the the survival rates of *Parlatoria pergandi*i during stages larvae 1 and larvae 2. 91
Figure 6. A comparison of mortalities (M), parasitism rates (P), and survival rates (V) during three female stages (F1V: survived females of stage 1; F1M: dead females of stage 1; F1P: parasitized females of stage 1; F2V: surviving females of stage 2; F2M: dead females of stage 2; F2P: parasitized females of stage 2; F3V: surviving females of stage 3; F3M: dead females of stage 3; F3P: parasitized females of stage 3. 93
Figure 7. Location of studied orchards [23]. 103
Figure 8. Model of the monitored orchard (divided into four small plots of 1 ha) and used doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha). 104
Figure 9. Comparison of mortalities (M) and survival rates (V) during two larvae stages of *P. ziziph*i (L1V: Surviving larvae of stage 1; L1M: Dead larvae of stage 1; L2V: Surviving larvae of stage 2; L2M: Dead larvae of stage 2). 106
10. Principal component analysis (PCA) of the different stages of *P. ziziphi* according to the different treatment rates (A); double projection diagram for the two components (B). 107
Figure 11. Evolution of the larvae survival of *Parlatoria ziziphi* according to different follow-up dates after treatment. 108
Figure 12. Comparison of mortalities (M) and survival rates (V) during three female stages of *P. ziziphi*. (F1V: Survived females of stage 1; F1M: Dead females of stage 1; F2V: Surviving females of stage 2; F2M: Dead females of stage 2; F3V: Surviving females of stage 3; F3M: Dead females of stage 3... 109
Figure 13. Evolution of females' survival of *Parlatoria ziziphi* according to the different follow-up dates after treatment. 110
Figure 14. Location of experimental orchards. 118
Figure 15. The different types of treatments used in the citrus orchard. 120
Figure 16. The proportion of the different mites studied (the phytophagous mite *Tetranychus urticae* (TU) and their predators *Euseius stipulatus* (ES), *Typhlodromus* sp. (TY), and *Pytoseiulus persimilis* (PP)) according to the treatments used. 121
Figure 17. Comparison between the means of different mites according to the treatments (T0 = control experiment; T1 = spirodiclofen 0.5 L/Ha; T2 = 125 L/Ha (5%) of black soap; T3 = detergents; 4 L/Ha of Oni product + 2 L/Ha of Tide product). 122
Figure 18. Principal component analysis (PCA) of the different mites studied (*T. urticae*; *E. stipulatus; Typhlodromus* sp.; *P. persimilis*) according to the different treatments (A); double projection diagram for the two components (B). 123
Figure 19. Variation of the means of *T. urticae* and their predators (ES: *E. stipulatu*s; TY: *Typhlodromu*s sp.; PP: *P. persimilis*) in the four plots according to the interaction between different monitoring dates and treatments (d = dates). 125
Figure 20. Location of studied citrus orchards. 139
Figure 21 ; Abundance of the phytophagous mite *Tetranychus urticae* and their predators (*Euseius stipulatus*, *Typhlodromus* sp., and *Pytoseiulus persimilis*) during the whole monitoring period on the Valencia late variety. 140

Figure 22. Abundance of the phytophagous mite *Tetranychus urticae* and their predators (*Euseius stipulatus*, *Typhlodromus sp. and Pytoseiulus persimilis*) during the whole monitoring period on the Nules variety.....141
Figure 23. Comparison between the means of different mites, depending on the variety (V1: Valencia late variety; V2: Nules variety) in first year, 2020, and the second year, 2021.....142
Figure 24. Evolution of *T. urticae* and their predators on Valencia late (V1) (a) in the first year, 2020, and (b) second year, 2021, according to the different follow-up dates (Phytoseiid mites: *E Stipulatus* + *P. persimilis* + *Typhlodromus* sp.). 144
Figure 25. Evolution of *T. urticae* and its predators on Nules (V2) in first year, 2020, and second year, 2021, according to the different follow-up dates (Phytoseiid mites: *E. stipulatus* + *Typhlodromus* sp. + *P. persimilis*). 145
Figure 26. Geographical localisation of the studied orchard (Source: Administrative Division of Morocco, 2015). 154
Figure 27. The various types of control treatments employed in Nules orchards. 156
Figure 28. The proportion of different mites studied (*Panonychus citri* phytophagous mite and its predators*; Euseius stipulatus, Phytoseiulus persimilis* and *Typhlodromus* sp.) according to the different products applied T0= Control experiment, T1= Spirodiclofen, T3= black soap; T3= Oni + tide product) 157
Figure 29. Loading plot that presents the projection of the variables on the first and second principal components.....160
Figure 30. . Principal component analysis (PCA) presents the projection of the variables and the mite populations on the first and second principal components.....160
Figure 31. Fluctuation of *P. citri* and its predators in the four treatments used 163
Figure 32. Hierarchical Cluster analysis of samples of Nules variety using the squared Euclidean distance between classes.....164
Figure 33. Mortality rate (%) of *Tetranychus urticae* adults (a) according to mortality time. T1: 24h; T2: 48h, (b) according to various concentrations.....178
Figure 34. Mortality rate (%) of *Eutetranychus orientalis* adults (a) according to mortality time. T1: 24h; T2: 48h, (b) according to various concentrations. 179
Figure 35. Mortality rate (%) of *Tetranychus urticae* adults according to various binary mixture of Eos and acaricide.....182
Figure 36. Principal component analyses of the main compounds in regards to the four essential oils.. 185
Figure 37. Principal component analyses of acaricidal activity against *E. orientalis* and *T. urticae* adults in regards to the four essential oils and concentrations. 186
Figure 38. Biplot of the projection of the acaricidal activity against *T.urticae* and *E. orientalis* adults and the four mixtures on the first and second principal components. 187
Figure 39. Hierarchical cluster analysis of the four mixtures against *E. orientalis* and *T. urticae* adults. 188

Sommaire

Remerciements i
Résumé ii
Liste des abréviations iv
Liste des tableaux v
Liste des figures vii
Introduction générale 1
Partie I : Synthèse bibliographique approfondie sur l'état actuel des agrumes dans le monde, au Maroc ainsi que la situation actuelle des ravageurs associés aux agrumes au Maroc. 7
1 Données générales sur les Agrumes 7
1.1 Origine et Taxonomie 7
1.2 Ecologie des agrumes 8
1.3 Phénologie des agrumes 8
2 Importance des agrumes dans le monde 9
3 Importance des agrumes au Maroc 9
3.1 Production et répartition géographique des agrumes au Maroc. 10
3.2 Variétés 11
3.3 Contraintes phytosanitaires du secteur agrumicole au Maroc 12
3.4 Situation actuelle des ravageurs associés aux agrumes au Maroc 12
4 Les cochenilles Diaspines en vergers d'agrumes 15
4.1 *Parlatoria ziziphi* (pou noir) 15
4.1.1 Généralité sur *Parlatoria ziziphi* 15
4.1.2 Méthodes de lutte 16
4.1.2.1 Surveillance 16
4.1.2.2 Lutte chimique 16
4.1.2.3 Lutte Biologique 16
4.1.2.4 Les Huiles essentiels dans la lutte intégrée 17
4.2 *Parlatoria pergandii* (Cochenille violette) 18
4.2.1 Géneralité sur Parlatoria pergandii 18
4.2.2 Méthodes de Lutte 19
4.2.2.1 Lutte chimique 19
4.2.2.2 Lutte biologique : 20
4.2.2.3 Usage des Huiles essentiels dans la lutte intégrée 20
5 Les acariens tétranyques 22

5.1 *Eutetranychus orientalis* 22
5.1.1 Généralité 22
5.1. Méthodes de lutte 23
5.1.2.1 Surveillance 23
5.1.2.2 Lutte chimique 23
5.1.2.3 Lutte biologique 23
5.1.2.4 Usage des huiles essentielles dans la lutte intégrée 24
5.2 *Panonychus citri* 25
5.2.1 Généralité 25
5.2.2 Méthodes de lutte 25
5.2.2.1 Surveillance 25
5.2.2.2 Lutte culturale 26
5.2.2.3 Lutte chimique 26
5.2.2.4 Lutte biologique 27
5.3 *Tetranychus urticae* 27
5.3.1 Généralité 27
5.3.2 Methode de lutte 28
5.3.2.1 Lutte chimique 28
5.3.2.2 Lutte Biologique 29
6 *Ceratitis capitata* 30
References 30
Résumé 47
Abstract 48
Introduction 49
1 *Tetranychus urticae* in North Africa 50
2 Levels of Infestation and Severity of Spread 51
3 Kind of Hosts 52
4 Control Methods 52
4.1 Chemical Control 52
4.2 Biological Control 53
4.2.1 Myco-Metabolites 54
4.2.2 Bacterial Metabolite 54
4.2.3 Protectants Plant-Incorporated (PIP) 55

4.2.4 Control with Predators 57
4.2.4.1 *Phytoseiulus persimilis* (Athias-Henriot, 1957) 57
4.2.4.2 *Neoseiulus californicu*s McGregor, 1954 57
4.2.4.3 *Euseius stipulatus* Athias-Henriot, 1960 58
4.2.5 Combined Releases 58
4.3 Physical Control 58
4.4 Genetic Control 59
4.5 Integrated Pest Management of Tetranychus Urticae 59
Conclusions 60
References 61
Revue I : La mouche méditerranéenne *Ceratitis capitata* (Diptera : Tephritidae) dans les vergers d'agrumes marocains : méthodes de lutte chimique et durable et priorités pour les futures recherches 69
Resumé 69
Abstract 70
Introduction 71
1 Methodology 72
2 Results and Discussions 72
2.1 Status of *C. capitata* in Morocco 72
2.2 Control approaches in Morocco 72
2.3 Unsustainable control 73
2.4 Sustainable approaches 74
2.4.1 Biological control 74
2.4.2 Use of biopesticides 74
2.4.3 Sterile insect technique 75
2.4.4 Mass trapping 75
2.4.5 Cold treatment 76
2.4.6 Sustained release of self-limiting medflies 77
2.5 Future research directions 77
2.5.1 Investigations on medfly 77
2.5.2 Investigations on new control methods 78
Conclusion 78
Reference 79

Chapitre I : Évaluation de l'effet de différentes concentrations de spirotétramate sur la cochenille diaspine *Parlatoria pergandii* 84
Résumé 84
Abstract 85
Introduction 86
1 Materials and Methods 87
1.1 Study Area 87
1.2 Sampling Design 88
1.3 Statistics 90
2 Results 90
2.1 Impact on Larvae 90
2.2 Impact on Females 93
3 Discussion and Conclusions 95
References 97
Chapitre II 100
Évaluation de l'effet de différentes concentrations de spirotétramate sur la cochenille diaspine *Parlatoria ziziphi* 100
Resumé 100
Abstract 101
Introduction 102
1 Materials and Methods 103
1.1 Study Area 103
1.2 Sampling Design 104
1.3 Statistics 105
2 Results 105
2.1 Impact on Larvae 105
2.2 Impact on Females 108
3 Discussion 111
Conclusions 112
References 113
Chapitre III: Évaluation de l'impact de différentes méthodes de lutte sur *Tetranychus urticae* (Acari : Tetranychidae) et sur ses prédateurs 115
Resumé 115
Abstract 116

Introduction 117
1 Materials and Methods 118
1.1 Study Area 118
1.2 Sampling Design 118
1.3 Statistics 120
2 Results 120
2.1 Leaf Occupancy Rate by Mites in the Different Plots 120
2.2 The Influence of Treatments on the Different Mites Studied 122
2.3 Fluctuation of Mites According to Treatments and Follow-Up Dates 124
3 Discussion 129
Conclusions 130
References 131
Chapitre IV: 135
Évaluation de l'impact variétal de deux espèces d'agrumes sur les fluctuations de *Tetranychus urticae* (Acari : Tetranychidae) et surles acariens phytoséiides 135
Résumé 135
Abstract 136
Introduction 137
1 Materials and Methods 138
1.1 Study Area 138
1.2 Sampling Design 139
1.3 Statistics 140
2 Results 140
2.1 Leaf Occupancy Rate by Mites in the Different Plots 140
2.2 Varietal Impact on Mite Populations 141
2.3 Evolution of Mites on the Two Varieties according to the Follow-Up Dates 143
3 Discussion 145
Conclusions 147
References 148
Chapitre V: Évaluation de l'effet de différentes méthodes de lutte écologiques sur le ravageur *Panonychus citri* [Acari : Tetranychidae] et sur ses prédateurs dans les vergers d'agrumes . 151
Cet article est en phase finale de publication dans la revue d'Open chemistry 151
Résumé 151
Abstract: 152

Introduction 153
1 Materials and Methods 154
1.1 Study area 154
1.2 Sampling Design 155
1.3 Statistics 156
2 Results 156
2.1 Leaf occupancy rate by mites in the different plots 156
2.2 The influence of treatments on the different mites studied 157
2.3 The evolution of the mites according to the treatments and the follow-up weeks. 161
3 Discussion 165
Conclusions 166
References 167
Chapitre VI 170
Résumé 170
Abstract: 172
Introduction 173
1 Materials and Methods 174
1.1 Plant material and extraction of essential oils 174
1.2 Chromatographic analysis 175
1.2.1 Gas chromatography (GC-FID) analysis 175
1.2.2 GC/MS analysis 175
1.3 Spider mites 175
1.4 Toxicity test 176
1.5 Statistical treatment 176
2 Results 176
2.1 Chemical composition of the four tested Eos 176
2.2 Toxicity of EOs on *Tetranychus urticae* and *Eutetranychus orientalis* 177
2.3 Toxicity of the EOs and the acaricide on *Tetranychus urticae* and *Eutetranychus orientalis* 181
2.4 Principal component analysis 182
2.4.1 The effect of the main compounds of the four tested Eos and the their acaricidal activity 182
2.5 The effect of the concentrations of the four tested Eos and their acaricidal activity 185

2.6..... The effect of the four mixture between acaricide and tested Eos and their acaricidal activity 186
2.7 The Hierarchical Cluster Analysis 187
3 Discussion 188
Conclusions 190
References 191
CONCLUSION ET PERSPECTIVES 195

Introduction générale

Les agrumes occupent une place importante de point de vue économique. La production mondiale des agrumes est de l'ordre de 139,80 millions de tonnes (Mt) [1]. La production des agrumes est très diversifiée avec 68 Mt d'oranges; 29 Mt des petits agrumes; 14 Mt de citrons et de limes et 5 MT de pomelos [2]. Au niveau du bassin méditerranéen, cette production est de l'ordre de 18 Mt dont 80% est destinée au marché du fruit frais. L'orange reste la production majeure avec respectivement 8,02 Mt et 2,25 Mt pour le fruit frais et la transformation [3].

Actuellement, au Maroc la production a augmentée de 25% par rapport à la campagne 2019-2020, elle atteindra 2,2 millions de tonnes en 2021-2022 par rapport à 1,7 million de tonnes d'agrumes en 2019-2020 [4]. Ce secteur revêt une grande importance pour le développement socio-économique puisqu'il génère annuellement un chiffre d'affaire de 3 milliards de Dh et près de 21 millions de journées de travail dont 12 millions au niveau des vergers et 9 millions au niveau de l'industrie de conditionnement et de transformation et des autres activités liées au secteur [5]. La production exportée, assure, l'équivalent de 3 milliards de dirhams de devise (644.000 Tonnes). En outre, l'industrie des agrumes constitue également une source importante de devises étrangères avec un montant d'environ 0,27 milliards d'euro par an [5].

La productivité nationale par hectare reste encore faible en comparaison à celles atteintes par certains pays de l'Europe et de l'Amérique. De multiples contraintes contribuent à cette faiblesse: l'âge des plantations, le non maitrise de certaines techniques de production et les contraintes biotiques, notamment les ravageurs tels que la cératite, les cochenilles, la mineuse des agrumes, les acariens, les escargots et les pucerons [6].

Ces dernières années, les cochenilles constituent le problème sanitaire principal en vergers d'agrumes au Maroc, l'extension des espaces cultivés par les agrumes a enregistré des phénomènes de pullulation non négligeable des cochenilles diaspines tels que la cochenille noir, cochenille violette, cochenille virgule et pou de Californie qui sont devenus actuellement des ravageurs d'une grande importance économique. Leur pullulation est favorisée notamment par une température chaude et un taux d'humidité élevé qui accélèrent le rythme du cycle biologique de ces cochenilles. Alors pour lutter contre ces cochenilles les pulvérisations d'insecticides (Organophosphorés, Carbamates, ou huiles blanche de pétrole,) sont fréquemment utilisées contre ces derniers en agrumiculture [7,8] mais en tous cas ces cochenilles restent les plus difficile à combattre par ces produits chimiques, car elles s'adhèrent fortement sur les feuilles et fruits et fabriquent un bouclier qui les protèges contre ces produits. Pour pallier à cette

problématique la recherche d'un nouveau produit chimique efficace pour lutter contre ces cochenilles s'avère indispensable.

Les acariens tétranyques étudiés dans notre travail (*Tetranychus urticae*, *Eutetranychus orientalis* et *Panonychus citri*) se nourrissent en suçant le contenu cellulaire des organes attaqués entraînant la déformation, la décoloration, le brunissement des feuilles et l'affaiblissement généralisé de la plante.

Au Maroc, comme dans d'autres pays méditerranéens, la mouche méditerranéenne *Ceratitis capitata* est considérée comme le ravageur tephritidae le plus abondant et constitue le ravageur le plus dangereux, avec une menace sévère pour la culture des agrumes.

C'est dans ce contexte que l'objectif principal de nos travaux est d'approfondir les connaissances sur ces ravageurs afin d'être en mesure de proposer des stratégies de contrôle plus efficaces. Les travaux menés et les résultats obtenus sont présentés dans le présent manuscrit sous forme d'une thèse par article et structuré en trois grandes parties :

Partie I : Etude bibliographique approfondie sur le statut actuel des agrumes dans le monde, au Maroc ainsi la situation actuelle des ravageurs associés aux agrumes au Maroc.

Cette partie comporte des données générales concernant les connaissances actuelles sur l'importance des agrumes dans le monde, au Maroc et sur l'état actuel des ravageurs les plus redoutable sur agrumes, en particulier ; la mouche méditerranéenne (*Ceratitis capitata*), les deux cochenilles diaspines (*P. ziziphi* et *P. pergandii)* et les trois acariens tétranhyque à savoir *T. urticae, P. citri* et *E. orientalis.*

Partie II: elle contient deux revues bibliographiques, la première portant sur la situation actuelle de l'acarien tétranyques *Tetranychus urticae* (Acari : Tetranychidae) en Afrique du Nord : Les méthodes de lutte durable et les priorités pour les futures recherches

Cette revue vise à présenter une synthèse des informations entourant les méthodes de contrôle de *T. urticae* en Afrique du Nord. Nous avons souligné les principaux résultats des études précédentes. Ensuite, nous avons discuté les méthodes de contrôles actuelles et nous avons proposé de nouvelles recherches innovantes et des approches durables afin de contrôler ce ravageur. Nous avons souligné dans cette étude les différentes méthodes de lutte durable qui peuvent diminuer la pullulation de ce ravageur, entre autres, les ennemis naturels, les myco-métabolites, les métabolites d'origine bactérienne, le contrôle physique et génétique.

Une deuxième revue bibliographique portant sur la mouche méditerranéenne *Ceratitis capitata* (Diptera : Tephritidae) dans les vergers d'agrumes marocains : méthodes de lutte chimique et durable et priorités pour les futures recherches.

Cette partie vise à fournir des informations sur les méthodes de lutte contre *Ceratitis capitata*, principalement dans les vergers d'agrumes au Maroc. Nous avons mis en évidence les principaux résultats des études précédentes, nous avons discuté les méthodes de contrôle actuelles chimiques et durables et nous avons proposé de nouvelles recherches innovantes et des approches durables pour contrôler *C. capitata*. Nous avons cité les différentes méthodes de lutte biologique, génétique et de piégeage, la technique de l'insecte stérile (SIT), les ennemis parasitoïdes comme *Diachasmimorpha longicaudata*, les agents pathogènes comme *Beauveria bassiana*.

Partie III : Etudes expérimentales

Cette partie d'étude étale les différents travaux réalisés durant mon projet de thèse, elle comporte 6 axes développés et présentés sous forme d'articles :

Chapitre 1 : Il porte sur l'évaluation de l'efficacité de différentes doses du produit chimique à base de spirotétramate sur la cochenille diaspine *Parlatoria pergandii* dans les vergers d'agrumes publiés dans Agronomy journal (IF= 3,95).

L'objectif était de sélectionner la dose faible la plus efficace contre ces deux ravageurs et la moins nocif sur le prédateur *Aphytis hispanicus*. Trois concentrations de Spirotétramate (T0 = 0 L/Ha, T1 = 0,625 L/Ha, T2 = 0,755 L/Ha, et T3 = 1 L/Ha) ont été appliquées sur 4 ha de verger de Valencia tardif (*Citrus sinensis*). L'insecticide du Spirotétramate a été évalué sur deux stades larvaires (L1 et L2) de *P. pergandii* et trois stades femelles, F1, F2 et F3. De même, les taux de parasitisme par *Aphytis hispanicus* sur les femelles ont été suivis pour évaluer l'impact du Spirotétramate sur cet ennemi naturel.

Chapitre 2 : Vise à évaluer l'effet des différentes concentrations de Spirotétramate sur le ravageur *P. ziziphi* dans les vergers d'agrumes de la région du Gharb publiés dans Agronomy journal (IF= 3,95).

L'objectif principal était d'utiliser la concentration minimale de pesticide nécessaire pour obtenir un contrôle efficace des cochenilles diaspines. Cette approche permettra d'utiliser moins de pesticides et d'éviter le développement de la résistance aux pesticides. Par conséquent, moins de résidus devraient rester sur les fruits et dans le sol.

Chapitre 3 : S'intéresse à l'évaluation de l'impact de différentes méthodes de luttes durables sur *Tetranychus urticae* (Acari : Tetranychidae) et leurs prédateurs dans les vergers d'agrumes marocains publié dans Plants journal (IF 4,66). L'efficacité des traitements écologiques à base de détergents classés non dangereux et de savon noir sur le ravageur *T. urticae*, et ses prédateurs (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromus* sp, *Phytoseiulus persimilis* Athias-Henriot, 1957) a été évalué, différents traitements ont été appliqués sur des vergers d'agrumes plantés par Valencia tardif dans la région de Mechraa Belksiri au Maroc (T0 = expérience témoin; T1 = spirodiclofen; 0,5 L/Ha ; T2 = 125 L/Ha (5%) de savon noir ; T3 = détergent ; 4 L/Ha du produit Oni + 2 L/Ha du produit Tide).

Chapitre 4 : Vise à étudier L'activité de *Tetranychus urticae* Koch, 1836, et de ses prédateurs (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromus* sp., et *Phytoseiulus persimilis* Athias-Henriot, 1957) sur deux variétés d'agrumes (Nules (Mandarine) et Valencia tardif (Orange)) dans des vergers d'agrumes dans la région du Gharb au Maroc (Machraa Belksiri) durant les années 2020-2021 publié dans Sustainability journal (IF 3.89). Dans cet essai, durant la première année de suivi (2020), nous avons détecté que sur la variété Valencia tardif (*Citrus sinensis*), l'occupation des feuilles par *T. urticae* était importante, avec 3200 formes mobiles (50%). Le prédateur *Typhlodromus* sp. a présenté la densité la plus élevé 1385 (22%), suivi par *E. stipilatus* avec 1186 formes mobiles (18%), tandis que *P. persimilis* a présenté le plus petit nombre avec 621 formes (10%). A l'inverse, sur la variété Nules (*Citrus Clementina*), nous avons trouvé (52%) 2475 formes pour le ravageur *T. urticae*. *E. stipulatus* était le prédateur le plus abondant avec 1344 (28%), suivi de *Typhlodromus* sp. avec 944 formes mobiles (22%); cependant, le prédateur *P. persimilis* était absent.

Au cours de la deuxième année de suivi (2021), dans la parcelle plantée avec la variété Valencia tardif, nous avons enregistré 2779 spécimens mobiles de *T. urticae* (45%). Pour le prédateur *Typhlodromus* sp., nous avons enregistré 1344 spécimens mobiles (22%). *E. stipulatus* a été enregistré avec 1240 spécimens mobiles (20%). *P. persimilis* a présenté le plus faible pourcentage, avec 14% (n = 847). Sur la variété Nules, nous avons eu 2573 spécimens mobiles de *T. urticae* (48%), 810 pour *Tyhphlodromus* sp. (15%), et 1412 pour *E. stipulatus*

(26%), et *P. persimilis* avait 547 spécimens mobiles (10%). De nos résultats, on peut conclure que la lutte synergique par ces prédateurs peut réduire le taux de *T. urticae* et constitue une méthode alternative durable dans l'absence de la lutte chimique.

En ce qui concerne l'effet de la variété sur les différents acariens étudiés, les variétés Nules et Valencia late n'ont montré aucun impact sur la densité d'*E. stipulatus* et de *T. urticae*, avec des moyennes relativement similaires, alors que sur le prédateur *Typhlodromus* sp. et *P. persimilis*, l'impact variétal était important.

Chapitre 5 : Cette étude vise à évaluer différentes méthodes de luttes écologiques contre le ravageur *Panonychus citri* [Acari : Tetranychidae] et ses prédateurs dans les vergers d'agrumes. Dans ce travail nous avons appliqué les mêmes traitements qu'on a étudiés dans l'article 3 sur le ravageur *T. urticae* (T0= traité par l'eau seulement, T1= spirodiclofen 0.5L/Ha, T2= 5% de savon noir 125L/Ha T3= mélange de deux détergents).

Chapitre 6 : La lutte contre les parasites à l'aide d'acaricides chimiques inquiète les écologistes et les professionnels de la santé, car ces produits chimiques endommagent l'écosystème et favorisent le développement de la résistance des acariens phytophage. De telles inquiétudes exigent une réaction rapide et approfondie en recherchant de nouvelles méthodes alternatives et écologiques. Ces dernières années, l'utilisation des huiles essentielles dans les pratiques de lutte antiparasitaire a fait son apparition. Les huiles essentielles ont été considérées comme des agents potentiels de lutte contre les nuisibles, car elles ont démontré qu'elles avaient une large gamme de bioactivité et qu'elles possédaient une toxicité de contact et de fumigation. En outre, les principaux avantages de nombreux acaricides à base de plantes résident dans leur faible toxicité pour les agroécosystèmes. Les acaricides botaniques composés d'huiles essentielles peuvent s'avérer être un bon choix pour remplacer les acaricides synthétiques plus persistants. Dans cette étude, l'effet acaricide de quatre huiles essentielles dérivées de plantes contre les adultes de deux ravageurs importants des cultures, *Tetranychus urticae* (Koch) 1836 et *Eutetranychus orientalis* (Klein) 1936 à été étudié.

Conclusion et perspectives

Cette partie sera sanctionnée par une conclusion générale percutante qui mettra en relief les résultats les plus probants issus de ce travail pour enfin, énumérer les différentes perspectives qu'apporte ce travail tant au niveau de la recherche académique, qu'au niveau des

applications pratiques sur le terrain. La présentation des travaux de thèse dans ce présent manuscrit s'articulera autour 2 revues bibliographiques, portant respectivement sur (i) La situation actuelle de *Tetranychus urticae* (Acari : Tetranychidae) en Afrique du Nord : Les méthodes de lutte durable et les priorités pour les futures recherches (ii) *Ceratitis capitata* Diptera : Tephritidae) dans les vergers d'agrumes marocains : méthodes de lutte chimique et durable et priorités pour les futures recherches publié en Tropical Journal of Natural Product Research IF 0,30 . Ces revues des données de la littérature scientifique nous ont permis de savoir l'état actuel de ces ravageurs au Maroc en 1er lieu et en Afrique du nord en 2eme lieu ce qui nous a permis de mettre les méthodes de luttes les plus appropriées développés dans la partie résultat (Articles). Les résultats de ces travaux sont ensuite présentés au travers de 6 articles dont 5 sont publiés dans les journaux Agronomy (IF= 3,95) Sustainability (IF 3.89), Plants (IF 4,66) et Evidence-Based Complementary and Alternative Medicine (IF 2,65), le 6 éme est soumis en MDPI journal. Après une conclusion générale et les nouvelles perspectives qu'ouvrent ces résultats seront présentées.

Partie I : Synthèse bibliographique approfondie sur l'état actuel des agrumes dans le monde, au Maroc ainsi que la situation actuelle des ravageurs associés aux agrumes au Maroc.

1 Données générales sur les Agrumes

1.1 Origine et Taxonomie

Les agrumes sont originaires du Sud-Est asiatique [18]. Cependant, les données historiques plaident en faveur de l'existence de trois centres de diversification primaire [19–21]. Le Nord-Est de l'Inde, les régions proches de la Birmanie et de la Chine, auraient abrités la diversification de *Citrus medica* et l'apparition de *C. aurantifolia*, *C. limon*, *C. aurantium* et *C. sinensis*. La Malaisie et l'Indonésie sont citées comme centre d'origine de *C. grandis*. Le Vietnam, le Sud de la Chine et le Japon seraient la zone de diversification de *C. reticulata* [22].

La diffusion des agrumes à travers le monde s'est faite très lentement. Le cédratier a été le premier connu en Europe (300 ans avant le Jésus-Christ) d'après [23,24]. Le bigaradier, le citronnier et l'oranger ont été introduits dans le bassin méditerranéen vers la moitié du XIIe siècle, et le mandarinier au XIXe siècle. Le bassin méditerranéen constitue à présent une importante zone de production pour ces trois dernières espèces [25,26].

Les agrumes appartiennent à trois genres botaniques: *Citrus*, *Fortunella* et *Poncirus* [18,26,27]. Ceux-ci forment avec 10 autres genres (*Atalantia, Burkillanthus, Citropsis, Clymenia, Eremocitrus, Hespertusa, Limnocitrus, Microcitrus, Pleiospermium* et *Severinia*) la sous-tribu des Citrinae [28]. Cette sous-tribu appartient à la tribu des Citreae, sous-famille des Aurantioideae dans la famille des Rutacées [29].

Le genre Citrus renferme la plupart des agrumes cultivés pour leurs fruits ou leurs huiles essentielles. Deux classifications du genre prévalent. Celle de Tanaka et al [30], qui a identifié 156 espèces, tandis que celle de Federici et al [31] n'en distingue que 16 espèces. En référence à cette dernière classification, les huit espèces cultivées sont : *C. sinensis* (L.) Osb., l'oranger ; *C. aurantium* L., le bigaradier ; *C. reticulata* Blanco, le mandarinier ; *C. paradisi* Macf., le pomelo ; *C. maxima* (Burn.) Merr., le pamplemoussier ; *C. limon* (L.) Burm., le citronnier ; *C. aurantifolia* (Christm.) Swing., le limettier et *C. medica* L., le cédratier. Ces espèces renferment un grand nombre de variétés [29,32].

Certaines études répartissent ces huit espèces d'importance économique dans trois grands groupes en fonction des similarités génétiques. Il s'agit du groupe des orangers et mandariniers, du groupe des pomélos et pamplemoussiers et du groupe des limes et citronniers [33]. D'autres travaux plus récents sur la diversité génétique et la structure des populations des

agrumes penchent plutôt en faveur de l'existence de 3 espèces « ancestrales » d'agrumes. Il s'agit du bigaradier (*C. medica*), du pamplemoussier (*C. maxima*) et du mandarinier (*C. reticulata*). Ces espèces seraient à l'origine de nombreuses espèces comptabilisées de nos jours, qui en réalité sont des hybrides issus de croisement entre les premières espèces [34,35].

1.2 Ecologie des agrumes

Les agrumes ont des grandes aptitudes d'adaptations à des conditions pédoclimatiques très différentes. Leur culture est réalisable partout où la température moyenne de l'année est supérieure à 14°C et inférieure à 40°C. Les agrumes se développent surtouts dans les climats maritimes des régions subtropicales. En terme de besoins en eau, 120 mm par mois, soit 1200 à 1500 mm par an, représentent une quantité d'eau au-dessous de laquelle la culture des agrumes nécessite une irrigation [36–38]. La lumière a une action très remarquée sur la qualité et la coloration des fruits [39]. Les arbres fruitiers d'agrumes sont plus exigeants sur les caractéristiques physiques du sol et non sur les caractéristiques chimiques qui peuvent être corrigées par des apports d'engrais et d'amendements. Les sols doivent être profonds et de préférence légers (sablo-argileux ou argilo-sableux), bien drainés [40,41].

Les agrumes craignent les eaux salines (au-dessus de 0,5%). Le PH idéal est situé entre 5,5 et 7,5 [42–44]. C'est à cet effet que le choix du porte-greffe est un des facteurs essentiels de réussite car il peut conférer à la plante une tolérance à des maladies et à des contraintes abiotiques (salinité, PH, froid, sécheresse, calcaire…) [45,46].

L'optimum d'altitude pour un bon développement des agrumes se situe entre 1000 et 1300 m car ces derniers ne doivent pas être trop exposés aux vents. Au-dessous de 800 m, les fruits manquent de saveur. La peau des oranges reste verte, les cloisons deviennent plus épaisses [47].

1.3 Phénologie des agrumes

Le développement de la frondaison des agrumes se fait sous forme de flux végétatif ou poussée foliaire. Ces flux végétatifs succèdent à des périodes d'arrêt végétatif. Ce phénomène s'observe même en climat tropical humide où les conditions permettent une activité végétative continue [48,49]. Il existe généralement 3 flux végétatifs par an. Ils commencent avec le début des pluies. Le premier flux, qui est de loin le plus important (longueur et nombre de rameaux

émis), débute en mars avec le retour des pluies. Le second se fait au mois d'août, il est également déclenché par le retour des pluies. Le dernier survient en octobre [48,50].

La floraison se produit en même temps que la pousse qui suit le repos végétatif. Les fleurs sont isolées ou en grappes et se forment sur le bois de l'année précèdent [49,51]. La floraison est continue tout au long de l'année sur les citronniers et limettiers. Sur les autres espèces on peut avoir une ou 2 périodes de floraisons par an. Sur un même arbre, on peut ainsi retrouver des feuilles, des fleurs et des fruits de différents âges [52].

2 Importance des agrumes dans le monde

Les agrumes sont l'une des principales cultures fruitières du monde et sont cultivés dans plus de 100 pays [2]. Il appartient à la famille des Rutaceae, qui compte 140 genres et 1300 espèces, dont des groupes fondamentaux comme l'orange, le citron, la mandarine et le pomelo. Ils sont cultivés dans les zones tropicales et subtropicales [61]. La production mondiale totale d'agrumes en 2021 est de 139,80 millions de tonnes [62].

Les productions d'agrumes proviennent essentiellement des régions méditerranéennes et tropicales. En 2021, la superficie totale plantée en agrumes a été évaluée à plus de 7.5 millions d'hectares répartie sur une aire très large située approximativement entre les 40° de latitudes Nord et Sud tout autour du Monde [63]. Les oranges représentent environ 60 % de la production totale d'agrumes. Les tangerines, mandarines et clémentines comptent pour 23 % du volume mondial. Environ 13,7 millions de tonnes de citrons et de limes, ainsi que 4,4 millions de tonnes de pamplemousses et pomelos sont produites annuellement [1]. Les pays producteurs forment une ceinture terrestre entre le 40ème parallèle nord et sud. Les Principaux pays producteurs d'agrumes (en 2022) étaient la Chine, le Brésil, la Grèce, la Turquie les pays du bassin méditerranéen, les Etats-Unis, l'Afrique du Sud, la Turquie et l'Inde [1,63].

3 Importance des agrumes au Maroc

Au Maroc, le secteur des agrumes joue un rôle socio-économique de premier ordre. Il est classé parmi les secteurs les plus importants de l'économie nationale. Selon le dernier recensement, les agrumes occupent une superficie de l'ordre de 128.000 hectare, soit près de 15% des superficies emblavées en arboriculture et produit annuellement environ 2,4 millions de tonnes [4,5,9]. Le secteur des agrumes est un levier vital de l'économie nationale.

L'agrumiculture génère en plus de 15,9 millions de journées de travail par an, dont 9 millions au niveau des vergers et 7 millions relatifs à l'industrie de conditionnement et de transformation ainsi que d'autres activités relevant du secteur agrumicole.[8,10,11].

3.1 Production et répartition géographique des agrumes au Maroc.

Les agrumes sont principalement cultivés dans les régions du Souss Massa 32 % (40 344 Ha), Rabat-Salé-Kénitra: 20 % (25 293 Ha), l'Oriental : 16 % (21 100 Ha), Béni Mellal-Khénifra: 14 % (17 426 Ha), Marrakech-Safi: 13 % (16 518 Ha), Autres régions: 5 % (6 645 Ha) [11,12]

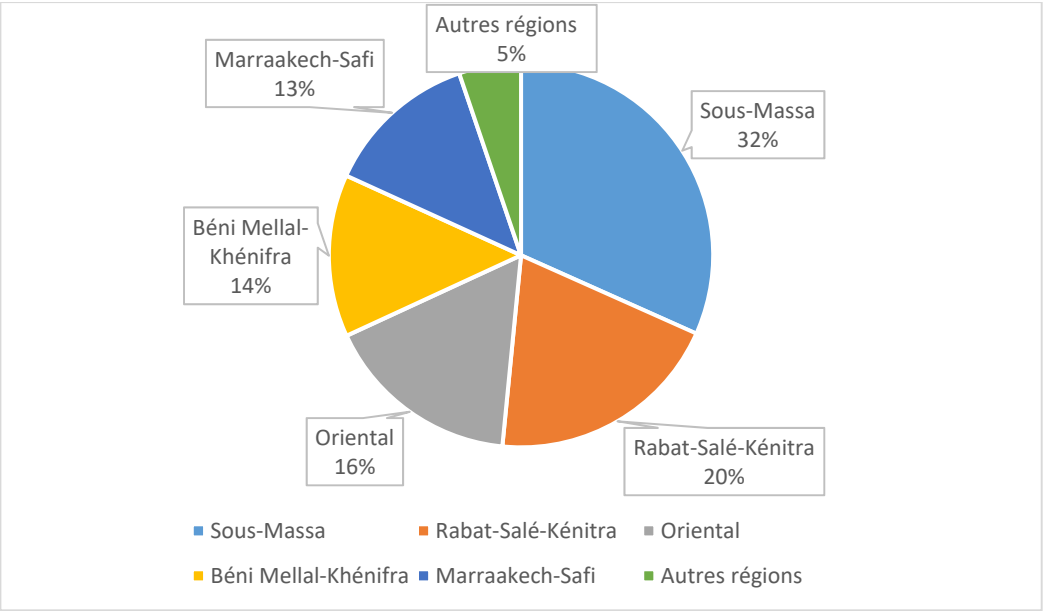


Figure 1. Production et répartition géographique des agrumes au Maroc.

Actuellement, le marché national des agrumes connaît un changement extraordinaire, avec une baisse significative des exportations vers l'Union européenne, qui sont passées de 70 % à seulement 25-30 %. En comparaison, les exportations vers la Russie ont énormément augmenté, passant de 45 à 50 % de l'ensemble des exportations marocaines [13].

Malheureusement, le manque de pluie, le rabattement du niveau de la nappe phréatique constituent les principales contraintes menaçant le secteur des agrumes au Maroc [14,15]. Ces éléments naturels qui ont affectés les plantations dans la plupart des régions agrumicoles du pays et en particulier la région de Guerdane dans le Souss qui représente, avec ses 10 000 hectares d'agrumes, 40% du potentiel productif du Maroc. Ce déficit pluviométrique a imposé un rationnement d'eau pour assurer, en priorité, les besoins en eau potable et en eau de breuvage pour le bétail. Le manque d'eau a affecté la majorité des vergers agricoles ce qui a bloqué

l'évolution du calibre des agrumes et par conséquent, un impact direct sur les exportations, puisque les fruits de petit calibre ne peuvent pas être exporté [4]. En revanche, dans les régions du Gharb, Marrakech, Beni-Mellal et l'Oriental, pour atténuer les effets de la sécheresse, les vergers ont été irrigués par les eaux des barrages.

Pour ce qui est des vergers irrigués par les puits, le rabattement du niveau de la nappe phréatique, spécifiquement dans le Sous, a induit des coûts supplémentaires pour les producteurs qui sont contraints de s'équiper en moto pompes puissantes pour aller creuser plus profondément d'une part, et, d'autre part, dépenser plus en carburant et en électricité [5]. Pour remédier à ces difficultés, l'ASPAM procède, en collaboration avec les offices de la mise en valeur agricole, à des actions d'encadrement et de sensibilisation des producteurs dans 10 régions à l'utilisation de la micro-irrigation qui, en dépit de son coût élevé, soit 20 000 et 25 000 DH pour l'hectare, permet d'éviter les déperditions d'eau. Toutefois, l'ASPAM souligne que les agrumiculteurs ont bénéficié, dans le cadre du Plan Maroc Vert, d'une subvention couvrant 80% à 100% du prix de l'irrigation [16]. Il est à noter que cette technique est certes onéreuse, mais elle permet, selon les professionnels, une utilisation rationalisée de l'eau dans une plantation et permet également une économie d'eau de 25 à 30% à l'hectare [17].

3.2 Variétés

Le matériel végétal est très diversifié. Au sein des grands groupes tels que les Navels, les Valencia Late et les Clémentines, des mutations spontanées ont été sélectionnées pour des caractères spécifiques qui apportent un progrès sensible au niveau de la qualité ou du rendement [29]. Ainsi par exemple à côté de Washington Navel, on trouve Nevelina et Newhall, deux Navel précoces et Navelate, une Navel tardive. Cadoux, Carte Noire, G. Pourreron, Caffin, Nour sont toutes des sélections marocaines de clémentinier. En matière de citronnier, on trouve Eureka, Lisbone, Santa Teresa mutant de Feminello etc...[27]

Le porte-greffe le plus utilisé au Maroc est le bigaradier qui présente une bonne résistance à la gommose, une compatibilité satisfaisante avec les grandes variétés commerciales, une production abondante de fruit de qualité [53]. Malheureusement, c'est un porte-greffe très sensible à la Tristeza, une maladie à virus qui sévit dans plusieurs pays méditerranéens en particulier en Espagne [54]. Ce pays a d'ailleurs complètement supprimé le Bigaradier de ses cultures d'agrumes. Les porte-greffes de remplacement sont les Citrange Troyer et Carrizo, les deux tolérants à la Tristeza [55,56].

3.3 Contraintes phytosanitaires du secteur agrumicole au Maroc

Malgré l'importance du secteur des agrumes dans l'économie nationale et de son intérêt particulier, ce secteur est touché depuis quelques années par des sérieux problèmes qui limitent son développement et qu'on peut les résumer dans les points suivants :

Φ Problèmes liés à la commercialisation ;

Φ Problèmes liés aux exigences du marché extérieur tant en ce qui concerne le calibre, les résidus et la forme de présentation des fruits ;

Φ Problèmes liés à la disponibilité de Main d'œuvre ;

Φ Problème liés aux choix du porte greffe, association variétale (pour chaque région);

Φ Problèmes liés à la complexité des statuts fonciers ;

Φ Nombre de traitements chimiques souvent trop élevé et par conséquent un coût de production élevé (la part de post phytosanitaire s'élève de 25% jusqu'à 30% des charges globales de l'exploitation);

Φ Problèmes liés aux stress biotiques et abiotiques ;

Φ Les taux élevés des écarts de triage au niveau des stations de conditionnement : (variables selon les conditions climatiques de la campagne, les zones de production et les variétés) ;

Φ Menace du développement de Tristeza (CTV) : Le porte-greffe le plus utilisée au Maroc (Bigaradier) est très sensible à la Tristeza;

Φ Menace de l'apparition du puceron vecteur de la maladie CTV (*Toxoptera citricida*)

Φ Menace du greening (Huanglongbing ou citrus greeningdisease) et son vecteur le psylle africain des agrumes *Trioza erythrae.*

Φ Menace du la maladie causée par la bactérie *Xyllela fastidiosa* (les agrumes représentent un deuxième hôte potentiel après l'olivier).

Φ Problème liés aux ravageurs, maladies virales, cryptogamique et aux marbrures [7,57,58].

3.4 Situation actuelle des ravageurs associés aux agrumes au Maroc

Le Maroc, par sa position géographique ainsi qu'à la diversité de ses cultures et l'importance des échanges du matériel végétal avec les pays riverains et éloignés, est constamment menacé par l'introduction des ravageurs redoutables à son patrimoine agrumicole. Cependant, le potentiel faunistique parait très restreint en comparaison avec d'autre pays. La majorité de ces espèces de ravageurs réels ou potentiels se rattachent principalement à l'ordre

des hémiptères, les acariens, néanmoins les diptères, les lépidoptères dont les principaux sont énumérés sur le tableau 1

Table 1. Principaux ravageurs des agrumes au Maroc [7,58–60].

Affiliation taxonomique	Espèces	Nom commun
Hemiptera :		
Diaspididae	*Aonidiella aurantii* Maskell (1878)	Pou de californie
	Parlatoria ziziphi Lucas (1853)	Pou noir
	Lepidosaphes beckii Newman (1869)	Cochenille virgule
	Parlatoria pergandii(Comstock, 1881)	Pou gris
Coccidea	*Coccus hesperidium* Limneus (1758)	Cochenille plate de l'oranger
Aleurodidae	*Paraleyrodes minei* Iaccarino (1989)	
	Aleurothrixus floccosus Maskell (1895)	Mouche blanche floconneuse
	Dialeurodes citri Ashmead (1885)	Mouche blanche des citrus
Aphididae	*Aphis spiraecola* Patch (1914)	Puceron vert de l'oranger
	Toxoptera aurantii Boyer (1841)	Puceron noir de l'oranger
Pseudococcidae	*Planococcus citri* Risso (1813)	
Cicadellidae	*Empoasca sp*.	
Lepidoptera :		
Gracillaridae	*Phyllocnistis citrella* Stainton (1856)	Mineuse des agrumes
Diptera		
Tephritidae	*Ceratitis capitata* Wiedemann (1824)	Mouche méditeranéenne
Acariens		
Tetranychidea	*Panonychus citri* MC Gregor (1919)	Acarien rouge des agrumes
	Tetranychus urticae Koch (1836)	Acarien jaune
	Eutetranychus orientalis Klein (1936)	Acarien jaune oriental
Gastéropode		
Helicidae	*Theba* (Helix) *pisana* Mueller (1774)	Escargot blanc
	Eobonia vermiculata	
	Helis spp.	Escargot gris

Parmi touts les ravageurs cités, dans notre étude nous avons travaillé sur les nuisibles les plus redoutables qui sont les deux cochenilles diaspines (*P.ziziphi* et *P. pergandii*), les trois acariens tétranyques cités dans le tableau ci-dessus, et puisque *T. urticae* reste le tétranyque le plus destructive dans le monde, nous avons développé une revue qui était publié dans sustainability journal (Revue 1). Une deuxième revue sur La mouche méditerranéenne *Ceratitis capitata* a fait l'objet d'une publication dans le journal Tropical Journal of Natural Product Research.

4 Les cochenilles Diaspines en vergers d'agrumes

4.1 *Parlatoria ziziphi* (pou noir)

4.1.1 Généralité sur *Parlatoria ziziphi*

La cochenille noire *Parlatoria ziziphi* (Lucas 1853) (Hemiptera : Diaspididae) est le ravageur le plus destructeur des agrumes. C'est une espèce cosmopolite et très abondante dans les vergers d'agrumes de plusieurs pays [64]. Elle est originaire d'Europe et, plus tard, des régions tropicales et subtropicales du monde ; détecté sur nombreux hôtes, en particulier sur les agrumes [65–67]. La cochenille noire *P. ziziphi* est l'un des ravageurs les plus importants qui attaquent les agrumes au Maroc [65,68].

Le bouclier est de couleur noire, avec une taille de 0,6 à 0,75 mm pour les larves et 1,25 à 1,4 mm pour les adultes. Une identification précise nécessite un examen microscopique. Les femelles adultes sont relativement faciles à distinguer des autres espèces du genre *Parlatoria* par la présence d'un lobe en forme d'oreille sur la tête [69].

Ce ravageur provoque des dégâts considérables sur les agrumes dans le bassin méditerranéen. Il provoque ainsi un impact économique négatif qui se traduit par une perte de production dans les pays du Maghreb, dont le Maroc [70]. Les dégâts causés par *P. ziziphi* se traduisent par l'affaiblissement et le dessèchement des parties aériennes de l'arbre, la décoloration des feuilles et des fruits et, surtout, une perte commerciale des fruits due aux écailles qui s'y fixent. Sa résistance spécifique au nettoyage des fruits aggrave ce préjudice esthétique. De plus, c'est l'une des cochenilles blindées les plus difficiles à contrôler avec des insecticides [71]. Le cycle de vie de *P. ziziphi* comprenant la durée de chaque larve (L1 : larve mobile sur la feuille ; L2 : Larves fixées sur la feuille), des femelles (F1 : jeune femelle de petite taille avec une petite couverture d'écailles noires ; F2 : femelle de taille moyenne avec une couverture d'écailles moyennes ; et F3 : femelle adulte avec une grande couverture d'écailles, portant souvent des œufs) et des mâles (pré-pupa, pupa et adulte) [72]. ce cycle de vie est souvent influencé par la plante hôte, les conditions climatiques et l'interaction avec les parasitoïdes [69,73]. Cette cochenille est biparentale et ovipares, le cycle de vie complet prend 30 à 40 jours en conditions favorables, *P. ziziphi* pond de 10 à 20 œufs. Il y a deux à cinq générations par an, parfois six dans les pays où les conditions sont plus favorables, une température chaude et un taux d'humidité élevé accélèrent le rythme du cycle biologique. [74–76].

Parlatoria ziziphi peut infester plusieurs genres d'agrumes : l'Oranger, le Citronnier, le Calamondin, le Pamplemoussier, le Bigaradier, le Mandarinier, le Lime, le Pomelo, le

Cédratier, le Poncirier, le Kumquat. C'est un ravageur polyphage. On le trouve aussi notamment sur les genêts, les acacias, le robinier et les Pittosporum, le murier, les Rutacées [77,78].

4.1.2 Méthodes de lutte

4.1.2.1 Surveillance

La petite taille de cette cochenille, sa couleur noire et son bouclier aplati contre le support peuvent la rendre difficile à voir, sauf si elle est présente en grand nombre [65]. Les femelles sont pourtant bien visibles sur un feuillage pale ou des fruits de couleur claire comme les oranges ou les citrons mais peuvent être facilement confondues avec les poussières sur fond sombre [65,76].

4.1.2.2 Lutte chimique

Actuellement les pulvérisations d'insecticides (Organophosphorés ou huiles blanche de pétrole) sont fréquemment utilisées contre les cochenilles Diaspines en agrumiculture [71]. Néanmoins, l'utilisation abusive de ces pesticides pourrait produire plusieurs effets néfastes sur l'agroécosystème [79]. La période d'intervention par des pesticides se situe au moment des essaimages des larves qui sont les stades les plus sensibles du ravageur vis-à-vis aux traitements (non protégées par le bouclier). *P. ziziphi* a été combattue d'une manière efficace grâce à diverses matières actives comme l'Ométhoate, le Chlorpyrifos, le Quinalphos, le Lambda-cyhalothrine, le Fenvalérate ou Cyperméthrine [80]. Des traitements inconsidérés, néfastes à la faune auxiliaire peuvent favoriser *P. ziziphi*, il faut donc veiller à une application raisonnée des insecticides contre les autres ravageurs des agrumes [81].

Dans les conditions marocaines, le contrôle chimique de *P. ziziphi* est souvent réalisé par l'application de deux principales matières actives, le chlopyriphos-Ethyl et le spirotétramate [72].

4.1.2.3 Lutte Biologique

Ennemis naturels :

Dans la région méditerranéenne occidentale des agrumes, la lutte biologique contre ce ravageur est principalement attribuée aux parasitoïdes spécialistes des cochenilles du genre

Aphytis (Hymenoptera : Aphelinidae) et à certaines espèces de coccinelles spécialisées telles que *Chilocorus bipustulatus* (Linnaeus, 1758), *Rhyzobius lophanthae* (Fabricius, 1787) et *Coccidophilus citricola* (Brèthes, 1905) [82–85]. Des stratégies de conservation et d'augmentation de ces ennemis naturels ont été développées et mises en œuvre dans de nombreuses régions productrices d'agrumes dans le monde [86,87]. Certains prédateurs généralistes indigènes tels que les neuroptères ont également été cités comme des ennemis naturels potentiels des cochenilles diaspines [88].

La coccinelle ***Chilocorus bipustulatus :*** est un prédateur répandu dans tout le bassin méditerranéen. Elle s'alimente essentiellement sur les cochenilles Diaspines (20 à 40 cochenilles par jour) inféodées aux arbres surtout aux agrumes (*Oceanaspidiotus sp*., *Pseudaulacaspis* sp. et *Parlatoria* sp.). Les larves de ce prédateur se nourrissent également de *P. ziziphi* [89–91]. Au Maroc, elle est observée sur *P. pergandii, P. ziziphi, L. beckii et A.aurantiii* à Belksiri, Sidi Sliman, Rabat et Kénitra [7].

Coniopteryx sp. : c'est une espèce appartenant à l'ordre des Nevroptera (Coniopteryx sp.) et à la famille des Coniopterygidae (fig. 18), qui vit sur *P. ziziphi* [90].

Chilocorus nigrita : Observée sur les nymphes et les adultes de *P. ziziphi* en USA [92]

Chilocorus bipustulatus : Observée sur les larves de *P. ziziphi* en chine [92]

Chilocorus kuwanae: attaque les nymphes et les adultes des cochenilles diaspines notamment *P. ziziphi* [93–95].

Leptodiplosis aonididiellae: attaque les nymphes et les adultes au Maroc) [7,96]

Encarsia citrina: attaque les nymphes, adultes, en Algérie, Chine, Hawaii, Egypt, Moroc et Hawaii [92].

Telsimia emarginata : attaque les nymphes et les adultes au Chine [92].

Exochomus quadripustulatus: C'est une espèce indigène Observée sur *A. aurantii; L. beckii, P. pergandii* et *P. ziziphi* à Larrache, Sidi Slimane et Kenitra [7].

4.1.2.4 Les Huiles essentiels dans la lutte intégrée

De nos jours, le marché a augmenté les restrictions législatives sur la présence de résidus d'insecticides sur les fruits, ce qui rend la gestion des ravageurs de plus en plus compliqués, de plus les alternatives à la lutte chimique (huiles essentielles) présentent plusieurs limites, entre autres coût très élevé, problème de volatilité etc., ce qui nécessite de grandes innovations pour les rendre applicable à grand échelle.

En Californie et dans différents pays méditerranéens comme l'Algérie, l'Égypte, le Maroc et la Tunisie, de nombreuses expériences ont été menées avec des huiles essentielles (Citrole, Misrona, Volk-Ete, Triona) afin d'améliorer la qualité des agroécosystème et réduire les populations de ravageurs [92,97]. [98] Dekle a recommandé de combiner des huiles et des insecticides, précisément du Malathion 0,05% plus de l'huile 0,01% dans des vergers d'agrumes de Floride. En Tunisie, Harrathi a démontré que l'huile minérale Citrole était aussi efficace que le méthidathion dans la lutte contre *P. ziziphi* sur les agrumes dans la région du nord-est [92]. Coll et Abd-Rabou [99] ont signalé que l'huile Triona était plus efficace que l'huile Shecrona et réduisait les populations de *P. ziziphi* jusqu'à 99 %. Les deux huiles de pulvérisation utilisées n'ont pas affecté de manière significative l'activité du parasitoïde *Encarsia citrina* Craw, le principal parasitoïde de *P. ziziphi* [99]. Une autre étude a démontré que l'huile Misrona et le régulateur de croissance des insectes buprofezin permettaient un contrôle à long terme des populations de *P. ziziphi* présentes sur les agrumes en Egypte [100]. Par conséquent, l'application d'huiles de paraffine avec des traitements à la buprofézine devrait être employée comme alternative aux autres insecticides synthétiques utilisés pour contrôler les cochenilles diaspines dans les vergers d'agrumes [92]. En Algérie, trois concentrations d'huile essentielle (0.4ml, 0.2ml, 0.1ml) extraites de feuilles de pamplemousse ont montré un effet insecticide très significatif contre lescochenilles diaspines sur agrumes, avec un taux de mortalité de 94,4% pour la dose 0,4 ml [90]. L'utilisation de l'huile pourrait être l'une des options de lutte les plus courantes et les plus efficaces utilisées en basse saison pour lutter contre les cochenilles [101].

4.2 *Parlatoria pergandii* (Cochenille violette)

4.2.1 Géneralité sur *Parlatoria pergandii*

Parlatoria pergandii (Comstock, 1881) (Hemiptera : Diaspididae) est le ravageur des agrumes le plus largement dispersé, envahissant les agrumes dans le monde entier et au Maroc [10,11]. Les infestations causées par cet insecte ravageur peuvent être documentées par l'apparition de l'écaille sur les parties des agrumes, y compris les feuilles, les tiges et les fruits [12]. Cependant, les symptômes sont principalement liés à la gravité de l'infestation (densité du ravageur sur l'hôte) et à la résistance de l'hôte [13]. Les infestations sur les arbres d'agrumes, principalement sur les tiges et les feuilles, provoquent principalement flétrissement et rétrécissement des surfaces des pigments photosynthétiques sur les feuilles, entraînant des réductions des rendements et des revenus [14]. De manière générale, *P. pergandii* réduit la

quantité et la qualité des agrumes produits. Ce qui entraine la diminution des opportunités de commercialisation, en particulier sur les grands marchés, tels que l'Union européenne et les États-Unis, où les normes d'exportation sont plus complexes [15]. Pour lutter contre *P. pergandii*, de nombreuses approches, y compris des méthodes chimiques et écologiques, sont utilisées [16-18]. Alors que dans les pays de l'hémisphère nord, les méthodes durables sont encouragées, la lutte contre les ravageurs est profondément dépendante des traitements chimiques dans d'autres pays du sud [19]. Au Maroc, avant 2010, les approches durables étaient négligées et rudimentaires [20]. Cependant, avec les nouvelles normes imposées, principalement en termes d'utilisation de composés chimiques, les pesticides sont devenus un problème en raison des résidus restants sur les fruits. De plus, le développement de la résistance aux pesticides a eu un impact négatif sur la production, la récolte et l'exportation des agrumes [21]. Le cycle de développement de *P. pergandii,* y compris la durée de chaque larve (L1 et L2), femelle (F1, F2 et F3) et mâle (pré-pupa, pupa et adulte), la fécondité, le taux de ponte et le rapport des sexes, est largement influencé par la plante hôte et la température [22-24]. Le cycle de vie dure, en moyenne, 56,28 jours pour les citrons et seulement 45,33 jours pour les courges. La fécondité est de 86 larves par femelle pour les citrons et de 109 pour les courges [24]. D'autre part, le nombre de générations par an varie en fonction des conditions climatiques : trois générations au Maroc et en Espagne et trois à quatre en Israël [23,25].

Aphytis hispanicus (Mercet, 1912) (Hymenoptera : Aphelinidae) est un important parasite de *P. pergandii* au Maroc [22-24]. Il se développe exclusivement comme ectoparasitose primaire d'insectes diaspines à écailles [26]. La femelle adulte perce le bouclier de l'écaille avec son ovipositeur et pond un ou plusieurs œufs sur le corps de l'insecte à écailles [27].

4.2.2 Méthodes de Lutte

4.2.2.1 Lutte chimique

En absence d'ennemis naturels, les sprays insecticides sont souvent nécessaires. Deux traitements peuvent être appliqués en conformité avec le cycle de vie du parasite : le premier à la fin de mai / début Juin ; le deuxième au début de Septembre. Les principaux insecticides de sprays utilisés sont : l'azinphos-méthyl, le chlorpyrifos, pirimiphos-méthyl et quinalphos. En Espagne, des études ont montré que Chlorfenvinphos et quinalphos étaient les plus efficaces contre *P. pergandii*, donnant le contrôle de plus de 80% [102,103].

Dans les conditions marocaines, le contrôle chimique de ce ravageur est souvent réalisé par l'application de deux principales matières actives, le chlopyriphos- Ethyl et le spirotétramate [72,104].

4.2.2.2 Lutte biologique :

Ennemis naturels

Aphytis hispanicus: attaque les œufs, les nymphes et les adultes, en Italie; Espagne; Israël; Chine; Mexique; USA, Texas; Caucase; Ghana et Maroc [7,92,105].
Aphytis melinus: attaque les œufs, les nymphes et les adultes, en Inde, au Pakistan. Introduite en États-Unis (Californie), l'Afrique du Sud, l'Australie, l'Argentine, le Chili, Chypre, Israël, Italie. [106]
Encarsia citrina : attaque les nymphes et les adultes, au Japon, au Ghana. Introduite en USA ; Australie ; Bassin méditerranéen ; inde ; Italie, Indonésie (Bali), Tahiti, Fidji, les îles Cook et l'Afrique. [92,106].
Aleurodothrips fasciapennis : attaque les œufs, les nymphes et les adultes, en Indonésie. [106]
Chilocorus bipustulatus : attaque les nymphes et les adultes, en Israël, en Espagne, au Maroc et en Grèce. [57,106].
Hemisarcoptes coccophagus : attaque tous les stades en dehors des œufs en Israël [106].
Hyperaspis algirica (Crotch 1874) (Coleoptera : Coccinellidae) : C'est une espèce Introduite, Observée sur *L. beckii* et *P. pergandii* à Sidi Kacem [7].
Pharoscymnus setulosus : (Chevrolat 1861) (Coleoptera : Coccinellidae) : C'est une espèce Indigène. Observée sur P. *pergandii, L. beckii* et *A. aurantii* en 2011 à Tihli [9].

4.2.2.3 Usage des Huiles essentiels dans la lutte intégrée

Dans la plupart des régions du monde où la culture commerciale des agrumes est pratiquée, les huiles végétales sont utilisées pour lutter contre les insectes nuisibles tels que les homoptères, notamment les cochenilles et les pucerons, les lépidoptères et les acariens lorsque les ennemis naturels sont inefficaces [107] . Dans cette partie, nous montrons quelques aspects concernant l'utilisation de pulvérisations d'huile sur les agrumes dans le monde et leur potentiel dans la lutte contre *P. pergandii.* Certaines huiles offrent des avantages par rapport aux pesticides à large spectre; elles ont une faible toxicité pour les prédateurs ; elles ont des effets néfastes réduits sur les insectes bénéfiques [108]. Il est certain que les huiles sont une composante essentielle d'un programme de lutte intégrée contre les ravageurs des agrumes, la possibilité de mélanger des insecticides, des acaricides, des fongicides et/ou des composés nutritionnels avec les huiles essentielles permettra de réduire les coûts de pulvérisation [109].

Les huiles essentielles extraites des feuilles de henné *Lawsonia inermis* peuvent avoir un effet sur *Parlatoria blanchardi,* il reste à tester sur *P. pergandii* qui reste une espèce appartenant *au même genre de P. blanchardi* [110]. En Tunisie, Harrathi a démontré que l'huile minérale Citrole était aussi efficace que le méthidathion dans la lutte contre *P. ziziphi et P. ziziphi* sur les agrumes dans la région du nord-est [92]. Coll et Abd-Rabou [99] ont signalé que l'huile Triona était plus efficace que l'huile Shecrona et réduisait les populations de *P. ziziphi* jusqu'à 99 %. Les deux huiles de pulvérisation utilisées n'ont pas affecté de manière significative l'activité du parasitoïde *Encarsia citrina* Craw, le principal parasitoïde de ce dernier [99].

5 Les acariens tétranyques

5.1 Eutetranychus orientalis

5.1.1 Généralité

Eutetranychus orientalis (Klein) 1936 (Acari: Tetranychidae) est un ravageur majeur des agrumes dans de nombreux pays, dont le Maroc [111], ces deux ravageurs causent des pertes considérables aux cultures d'agrumes [112]. Ces dernières années, ces ravageurs sont devenus d'une grande importance économique [57]. il s'attaque à un grand nombre de cultures d'environ 220 plantes hôtes [113]. Les Citrus sont les principales plantes-hôtes d'importance économique [114]. En Egypte, le citronnier (*C. limon*), le mandarinier (*C. reticulata*) et l'oranger (*C. sinensis*) sont attaqués de la même manière par ce ravageur [115]. Cet acarien a été recensé sur une vaste gamme d'autres cultures parmi lesquelles ; amandier (*Prunus dulcis*), bananier (*Musa parasidica*), cognassier (*Cydonia oblonga*), cotonnier (Gossypium), figuier (*Ficus carica*), goyavier (*Psidium guyava*), manioc (*Manihot esculenta*), mûrier (Morus), olivier (*Olea europaea*), papayer (*Carica papaya*), pastèque (*Citrullus lanatus*), patate douce (*Ipomoea batatas*), pêcher (*Prunus persica*), Plumeria, poirier (Pyrus), *Ricinus communis*, tournesol (*Helianthus annuus*) [114]. En Inde, sur les sept espèces recensées sur agrumes, seul *E.orientalis* est déclaré comme un ravageur nuisible important dans toutes les régions [116].

L'acarien *E. orientalis* commence à se nourrir à la face supérieure de la feuille, le long de la nervure centrale puis se dispersent vers les nervures latérales, provoquant un début de chlorose des feuilles. Des rayures jaune pâle se développent le long des nervures. Lors d'infestations plus graves, les acariens se nourrissent et pondent sur toute la face supérieure des feuilles. Les infestations très graves sur agrumes provoquent un dépérissement des branches qui peuvent entraîner la défoliation des arbres [114].

Le tétranyque jaune orientale est ovipares avec un cycle de vie achevé en quatre stade active (larve, protonymphe, deutonymphe et adulte) et trois étapes de repos (nymphochrysalis, deutochrysalis et teleochrysalis) [117]. Les œufs sont pondus à la face supérieure de la feuille, mais avec de fortes infestations, les œufs peuvent être trouvés sur la face inférieure [113].

L'acarien *E. orientalis* commence à se développer quand la température dépasse les 10°C, et pour un bon développement le tétranyque rouge orientale exige 14 jours autour d'une température de 27°C. A l'EST méditerranéen le ravageur a environ 20 générations [118].
Les tétranyques se dispersent par le vent et ceci est probablement le principal mode de dissémination d*'E.orientalis* au champ. Au cours d'échanges internationaux, ils peuvent être transportés sur des plants d'agrumes. Comme ils n'infestent pas les fruits, ceux-ci ne présentent

un risque que s'ils sont accidentellement contaminés ou lors de transport des débris foliaires [119].

5.1.2 Méthodes de lutte

5.1.2.1 Surveillance

Une loupe suffit pour voir ces acariens. Les lieux à inspecter en priorité sont la nervure centrale en face supérieure des feuilles. La présence d'*E. orientalis* peut être détectée par une décoloration des feuilles et des stries jaune pâle le long des nervures médianes et des veines [120].

5.1.2.2 Lutte chimique

C'est actuellement la méthode la plus utilisée pour intervenir contre les pullulations de Tetranychidae. Les traitements ne devraient être entrepris qu'au-delà d'un seuil d'infestation déterminé par l'échantillonnage. Le seuil critique d'infestation est estimé à 80% de feuilles attaquées, mais étant donné qu'il est plus faible sur les jeunes plantations, on préfère retenir la valeur de 50 % de feuilles attaquées pour la période qui va de l'apparition des boutons floraux au premier stade de la maturation des fruits [121]. Parmi les acaricides qui sont utilisés couramment contre *E. orientalis* et d'autres tétranyques des agrumes, la flubenzimine et l'ométhoate ont donnés des bons résultats en Jordanie [121]. A Taïwan, le cyhéxatin est utilisé pour lutter contre l'acarien sur carambole [122]. Sur neuf pesticides testés en Inde, le dicofol (0,025%) a été le plus efficace contre *E. orientalis* [123].

5.1.2.3 Lutte biologique

Ennemis naturels

Les tétranyques sont attaqués par un grand nombre de prédateurs qui sont soit des insectes, soit d'autres acariens. Les insectes appartiennent aux ordres des Coléoptères, des Thysanoptères, des Diptères, des Hémiptères, des Neuroptères et des Dermaptères [124]. Seuls les trois premiers ordres comprennent en réalité des prédateurs spécifiques de ces acariens. Pour les Coléoptères, il s'agit de Staphylinidae du genre Oligota (une dizaine d'espèces citées par Chazeau, 1985 tel que *Oligota flavicornis*) ou de Coccinellidae du genre *Stethorus* (une

trentaine d'espèces citées par Chazeau [124]. Ces insectes prédateurs sont relativement indifférents à la plante hôte et leur faculté de voler leur permet d'intervenir sur de fortes concentrations de tétranyques [125].

Au Maroc, l'acarien phytoséiide, *Euseieus scutalis* a pu maintenir *E.orientalis* à des niveaux de populations inférieurs au seuil économique [7]. En Israël, *Amblyseius rubini* et *Euseius hibisci* se reproduisent lorsqu'ils sont élevés sur *E.orientalis* qui était le tétranyque préféré [126]. *Neoseiulus californicus (*Acarina: phytoseiidea*)* est observée sur *E. orientalis* à Beni Mellal [7].

5.1.2.4 Usage des huiles essentielles dans la lutte intégrée

Actuellement, la lutte contre les ravageurs à l'aide d'acaricides chimiques inquiète les écologistes et les professionnels de la santé, car ces produits chimiques endommagent l'écosystème et favorisent le développement de la résistance des acariens phytophage. Ces préoccupations exigent une réaction rapide et approfondie en recherchant de nouvelles méthodes alternatives et respectueuses de l'environnement [127]. Ces dernières années, l'utilisation des huiles essentielles dans les pratiques de lutte contre les ravageurs a fait son apparition. Les huiles essentielles ont été considérées comme des agents potentiels de lutte contre les nuisibles, car elles ont démontré qu'elles avaient une large gamme de bio activité et qu'elles possédaient une toxicité de contact et de fumigation [128]. En outre, les principaux avantages de nombreux acaricides à base de plantes résident dans leur faible toxicité pour les agroécosystèmes [129]. Les acaricides botaniques composés d'huiles essentielles peuvent s'avérer être un bon choix pour remplacer les acaricides synthétiques.

Les huiles essentielles (HE) de trois espèces de la famille des Lamiaceae poussant dans plusieurs régions du Maroc, ont été évaluées pour leurs propriétés acaricides contre l'acarien rouge oriental, *E. orientalis* (Acari : Tetranychidae). Dans cette étude, différentes concentrations d'huiles de thym, dont *Thymus satureioides* Coss., *T. maroccanus* Ball. et *T. atlanticus* Ball. EOs ont été utilisées pour évaluer l'effet adulticide, larvicide par la méthode de peinture sur feuilles. En outre, l'effet ovicide a été évalué par la méthode du disque pulvérisateur de feuilles. Les résultats obtenus ont montré que toutes les HE testées induisent une mortalité significative chez les femelles adultes et les larves d'*E. orientalis*, et la mortalité augmente avec la concentration des HE [128].

Une autre étude réalisée par Assouguem et al [127] a révélé l'effet acaricide de quatre huiles essentielles dérivées de plantes utilisé contre les adultes de deux importants ravageurs des cultures, *T. urticae* et *E. orientalis*. La toxicité du fumigeant a révélé que toutes les huiles

essentielles testées - *Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., et *Origanum compactum* Benth (famille des Lamiaceae) présentaient un effet acaricide. A la dose la plus élevée (625 µl/ml), les mortalités enregistrées se situaient entre 90-98% et 94-99% à 24h et 48h, respectivement pour *E. orientalis*. L'huile essentielle de *Mentha pulegium* L. représente la plus forte activité contre *E. orientalis*. Pour la combinaison binaire entre les HE (Huiles Essentielles) et l'acaricide à base de la matière active acéquinocyl, les résultats ont montré que le mélange HE (huile essentielle) *O. compactum* + acéquinocyl présente un effet acaricide important sur *E. orientalis* avec 99% à 24h et 100% à 48h de mortalité, suivi par *M. pulegium* EO + acéquinocyl avec 99% à 24h et 100% à 48h de mortalité pour *E. orientalis*. Alors que le mélange de *L. stoechas* EO + acéquinocyl a présenté la plus faible activité contre *E. orientalis* avec 87% à 24h et 90% à 48h, respectivement. Les mélanges (*M. pulegium* EO + acéquinocyl, *R.officinalis* EO + acéquinocyl, et *O. compactum* EO + acéquinocyl) ont exercé un effet acaricide élevé contre *E. orientalis*. Ces résultats prometteurs pourraient aider à développer des pesticides botaniques qui pourraient être utilisés dans la lutte intégrée contre les ravageurs [127].

5.2 Panonychus citri

5.2.1 Généralité

Panonychus citri ressemble à *Panonychus ulmi* mais chez le premier, les extrémités du corps sont rouges alors qu'elles sont blanches chez *P.ulmi* [130], Au Maroc, notamment dans la région du Gharb, *P. citri* (Acari : Tetranychidae) a été considéré comme un ravageur primaire avec des dégâts importants sur les arbres infectés [131]. Parmi toutes les espèces d'acariens, l'acarien rouge des agrumes est identifié comme un ravageur majeur [132]. Son contrôle est assuré par des acariens prédateurs naturels tels que *Euseius stipulatus*, *Typhlodromus* sp., *Phytoseiulus persimilis* Athias-Henriot, 1957 [133]. Malheureusement, les produits chimiques, tels que le spirodiclofen, utilisés contre divers ravageurs des agrumes sont considérés comme toxiques pour les phytoséiides et réduisent leur efficacité [109,134].

5.2.2 Méthodes de lutte

5.2.2.1 *Surveillance*

Pragmatiquement, le suivi visuel des acariens tétranyques constitue le seul moyen fiable d'évaluation des populations et du degré d'infestation des vergers d'agrumes. Il concerne à la

fois les acariens phytophages et leur prédateurs, il est réalisé la plupart du temps sur place des feuilles ayant atteint 50 à 100% de leur développement [9].

5.2.2.2 Lutte culturale

Les dégâts provoqués par *P. citri* sont plus sévères lorsque les plantes sont soumises à un stress hydrique ; il semble donc important d'irriguer les vergers avant que les arbres ne se retrouvent en déficit d'eau [135,136]. Ainsi le travail du sol et la destruction des mauvaises herbes sur lesquelles se réfugient certaines espèces polyphages telles que l'acarien *P. citri* permettent de réduire significativement les attaques de ce ravageur. Une fertilisation équilibrée confère à l'arbre une vigueur satisfaisante capable de limiter l'action de certain acariens phytophages [137].

5.2.2.3 Lutte chimique

L'application de pesticides peut aggraver les dommages économiques causés par l'acarien d'une part en décimant les populations d'auxiliaires et d'autre part, en induisant l'apparition de phénomènes de résistance dans les populations de l'acarien [138]. En Afrique du Sud, la lutte chimique contre *Aonidiella aurantii* a provoqué des infestations secondaires de *P. citri* qui est de ce fait considéré comme un ravageur important sur Citrus ; après l'allègement du calendrier de traitements chimiques, l'acarien n'a plus posé de problèmes [139]. Après une étude de 4 ans sur Citrus en Californie, [135] ont démontré que le seuil de dégâts économiques utilisé pour déclencher les traitements était une moyenne qui doit dépasser 10 femelles par feuille.

Les traitements réalisés avec les huiles blanches constituent un très bon traitement acaricide aussi bien sur les formes mobiles que sur les œufs tout en étant peu agressif sur la faune auxiliaire. Les travaux réalisés par la SASMA en 1996 au Maroc, ont montré que les applications à base d'huiles (au moins 1%) contre *P. citri*, avec un contrôle judicieux des adventices permettent une protection efficace pendant toute la compagne [140].

5.2.2.4 Lutte biologique

Les ennemis naturels sont en général suffisamment efficaces pour réguler les populations de *P. citri* **:**

Euseius stipulatus : C'est un prédateur efficace de *P. citri* en vergers d'agrumes au Maroc [7], il a été introduit aux Etats Unis en 1971 et s'y est établi. Ce Phytoseiidae est très efficace lorsque les populations de *P. citri* ne sont pas trop importantes mais peut se retrouver insuffisant dans le cas contraire [141,142].

Stethorus tridens : Récemment Reyes et al a détecté son activité prédatrice sur *P.citri* et *T. urticae* [143].

***Easeius rubini* :** Dans la région de Haouz ce ravageur a réalisé une prédation sur *P.citri* très satisfaisante et donc il a été noté comme un entomophage très important à ce phytophage [9].

***Amblyseius californicus* :** se nourrit principalement de tétranyques tisserands, mais aussi d'autres acariens nuisibles, comme l'araignée rouge (*Panonychus ulmi*), l'acarien rouge des agrumes (*Panonychus citri*). Le prédateur adulte vit environ 20 jours et pond des œufs pendant 14 jours (une moyenne de 3 œufs /jour). L'*A. californicus* adulte peut avaler 5 araignées rouges adultes par jour plus éventuellement quelques œufs et larves [7,144].

***Euseius tularensis* :** acariens rouges et thrips d'agrumes sont des proies communes [145].

5.3 Tetranychus urticae

5.3.1 Généralité

Tetranychus urticae Koch, 1836 (Acari : Tetranychidae) est un ravageur largement répandu dans le monde ; il s'agit d'un acarien phytophage de la famille des Tetranychidae. Cette espèce est un herbivore hautement polyphage et un ravageur agricole majeur dans le monde entier qui cause des dommages importants à l'économie [146]. Il est un ravageur notable des grandes cultures, des plantes ornementales et des plantes annuelles et pérennes [147] ; il s'attaque (i) aux espèces fruitières, notamment les agrumes, les pommes, les poires arbustives et les framboises [148], (ii) aux légumes, notamment l'aubergine, le concombre, le haricot, le gombo et la tomate [149–151], (iii) aux plantes ornementales, notamment le dahlia, la rose, le gerbera, le zinnia et le ganda [12] ; et les plantes médicinales, comme moringa (*Moringa oleifera*), le metel (*Datura metel*), la luzerne (*Medicago sativa*), la menthe poivrée (*Mentha piperita*), le romarin (*Rosmarinus oflicinalis*) et la verveine commune (*Verbena oflicinalis*) [152,153].

Tetranychus urticae est un ravageur cosmopolite. Il est présent dans la plupart des régions du monde en Europe, en Asie, en Afrique, en Australasie, dans les Caraïbes et en Amérique du Nord [154]. De plus, ce ravageur est adapté à différentes conditions climatiques. En particulier au Maroc, *T. urticae* est l'un des ravageurs les plus enregistrés sur diverses cultures, y compris les arbres fruitiers (pommiers et agrumes) et les plantes spontanées [151,155]. Des résultats similaires ont été cités en Algérie et en Tunisie, qui sont dans les mêmes conditions climatiques que le Maroc [156]. En Egypte, ce tétranyque a été trouvé dans les arbres fruitiers et la végétation ornementale, causant de sérieux dommages, selon les taux d'infestation sur ces plantes [157,158]. Les différences dans les taux d'infestation peuvent être attribuées à la variation des conditions environnementales, des dates de plantation et de l'âge des plantations [159]. Les populations de *Tetranychus* se multiplient rapidement dans les mauvaises herbes et migrent pour occuper les arbres fruitiers [160]. Cette dissémination n'est pas toujours passive mais a souvent lieu sous l'action de divers stimuli tels que la température, le vent, les précipitations et les pratiques agricoles [161,162]. Sur la clémentine, une étude a été menée dans la région du Gharb au Maroc, dans laquelle les vergers ont été isolés pour trois cultures annuelles et sans pratique de traitements acaricides, afin de connaître la sévérité du taux d'infestation par *T. urticae*. Cette étude a montré que le degré d'infestation des arbres était de 10% à la mi-avril, pour augmenter rapidement jusqu'à 87% en juillet. Selon cette étude, la propagation se produit lorsque les conditions climatiques et le développement phénologique de l'arbre sont favorables au déploiement de l'acarien [37]. *T. urticae* a été étudié dans des vergers marocains sur une période de dix semaines (du 25 mars au 2 juin 2002) sur des strates herbacées et sur deux variétés différentes de pommiers ("Golden" et "Anna"). Les plantes adventices telles que *Cuscuta epithymum, Malva neglecta*, *Sonchus asper*, *Convolvulus arvensis*, et *Urtica urens* (et, dans une moindre mesure, *Mentha pulegium, Sonchus oleraceus, Papaver rhoeas, et Sinapis arvensis*) semblent être les plantes hôtes les plus favorables à *T. urticae*. Elles doivent donc être considérées comme des sources potentielles d'infestation pour les arbres fruitiers [163].

5.3.2 Methode de lutte

5.3.2.1 Lutte chimique

Dans les vergers commerciaux du Maroc, la protection contre les ravageurs est actuellement assurée par la lutte chimique préventive et intensive. Malgré des avantages tels que la rapidité d'action dans la réduction du nombre de ravageurs et leur facilité d'utilisation par rapport aux extraits naturels de plantes [97], cette stratégie présente de nombreuses limites ;

l'examen du spectre d'action des composants actifs utilisés dans le monde révèle que 46% des acaricides, 72% des insecticides et 28% des fongicides sont globalement toxiques pour les arthropodes auxiliaires et la santé publique [51]. De plus, les tétranyques ont développé des résistances à plus de 80 acaricides dans plus de 60 pays autour du monde [164]. En particulier, *T. urticae* a développé des résistances à plus de 30 organophosphates et carbamates, cette résistance est due à des mutations dans la protéine mitochondriale du cytochrome b de ce ravageur [132]. En outre, une application non rationnelle de bénomyl [méthyl 1-(butylcarba-moyl) benzimidazole-2-ylcarba- mate] et d'autres pesticides a tué tous les prédateurs notables de ce ravageur [165]. Par conséquent, l'absence de contrôle par les ennemis naturels en raison de leur mort par les pesticides peut provoquer une augmentation considérable des populations de *T. urticae* [138].

Au Maroc, le Spirodiclofen (240 g/L), le Malathion (440 g/L), l'Abamectine (18 g/L), Bifénazate (480 g/L), Fenpyroximate (51,2 g/L), Fenazaquin (200 g/L), Tébufenpyrad (20%), Propargite (57%), Milbémectine (1%), Bifenthrine (100 g/L), Clofentézine (500 g/L), Pyridabène (100 g/L), Maltodextrine (27%), et Dicofol (18,5%) sont les acaricides les plus utilisés pour lutter contre les acariens tétranyques dans les serres et les vergers [166]. Dans la région du Loukkos au Maroc, pour prévenir *T. urticae*, la majorité des fraisiers sont traités à l'Abamectin [138]. D'autres effets ont été constatés, tels que des altérations de la physiologie et de la biologie des organismes vivants et la modification de la fécondité et du comportement [167]. Pour surmonter cette difficulté, les experts ne cessent d'explorer de nouveaux produits biologique, notamment les biopesticides [168].

5.3.2.2 Lutte Biologique

Ennemis naturels

Les agents de lutte biologique tels que les bactéries, les insectes prédateurs ou les champignons peuvent être utilisés comme des approches alternatives de la lutte chimique [169]. Les organismes bactériens, tels que *Yersinia entomophaga*, *Xenorhabdus* spp. *Pseudomonas entomophila*, *Burkholderia* spp. *Chromobacterium* spp. *Streptomyces* spp. *Saccharopolyspora* spp. et *Bacillus* spp. ont tous récemment acquis un intérêt commercial pour la production de divers métabolites qui agissent comme des insecticides efficaces [170]. Les métabolites secondaires de champignons, tels que *Aspergillus melleus*, *Emericella nidulans* G. Winter,

1884, *Alternaria terreus*, *Chaetomium globosum, Trichoderma viridae* et *Eurotium eurotiorum*, constituent une source prometteuse de lutte contre divers parasites agricoles [171,172]. Les prédateurs les plus importants qui ont lutté de manière significative contre *T. urticae* et d'autres tétranyques sont *Amblyseius swirskii*, *Typhlodromus rhenanoides* (Athias Henriot, 1960), *Phytoseiulus persimilis*, *Typhlodromus phialatus* (Athias Henriot, 1960), *Neoseiulus cucumeris* (Oudemans, 1930), *Neoseiulus stolidus* (Chaudhri, 1968), *Feltiella acarisuga* (Vallot, 1827), *Scolothrips longicornis* (Priesner, 1926), *Euseius scutalis* (Athias Henriot, 1958), *Euseius stipulatus* (Athias Henriot, 1960), et *Stethorus punctillum* (Julius Weise, 1891) [173].

6 Ceratitis capitata

Ceratitis capitata, ou la mouche méditerranéenne des fruits, se plaît essentiellement dans les régions au climat tempéré-chaud de type méditerranéen. Ce diptère a une large gamme d'hôtes tels que les agrumes, le pêcher, le poirier, le pommier, l'abricotier, le figuier, le prunier, le cognassier, la vigne, le cerisier doux, le fraisier... *C. capitata* infecte les fruits de plus de 300 espèces végétales, causant des pertes économiques substantielles s'élevant à des millions de dollars par an. Les mouches adultes pondent leur œufs sous l'épiderme des fruits, particulièrement là où la peau est déjà déchirée. L'œuf éclot au bout de trois jours, et la larve se développe à l'intérieur du fruit en se nourrissant de la pulpe.

References

1. FAO Citrus fruit Statistical bulletin. **2021**, *36*, 36-2167-36–2167, doi:10.5860/choice.36-2167.
2. Citrus Fruit Fresh and Processed Statistical Bulletin 2020 |Policy Support and Governance| Food and Agriculture Organization of the United Nations Available online: https://www.fao.org/policy-support/tools-and-publications/resources-details/fr/c/1439010/ (accessed on Jan 28, 2022).
3. Cadillat, r.m. h., wilbr.andt, :f. zito l'agrumiculture dans les pays du bassin méditerranéen. *comm. des communautes Eur. Dir.* **1967**.
4. ASPAM Campagne agrumicole 2020-2021 : les professionnels tablent sur des exportations de 630 000 tonnes - La Vie éco. *https://www.lavieeco.com/* **2021**.
5. MAPM Filière agrumicole | Ministère de l'agriculture Available online: https://www.agriculture.gov.ma/fr/filiere/agrumicole#block_text_media-0 (accessed on Aug 28, 2022).

6. Šunjka, D.; Araniti, F.; Assouguem, A.; Kara, M.; Mechchate, H.; Al-Mekhlafi, F.A.; Nasr, F.; Farah, A.; Lazraq, A. Evaluation of the Impact of Different Management Methods on *Tetranychus urticae* (Acari: Tetranychidae) and Their Predators in Citrus Orchards. **2022**, doi:10.3390/plants11050623.

7. Smaili, M.C.; Abbassi, M.; Boutaleb, J.A.; Blenzar, A. Richesse spécifique des ennemis naturels associés aux vergers d'agrumes au Maroc: Intérêt et implication pour la lutte biologique. *EPPO Bull.* **2013**, *43*, 155–166, doi:10.1111/epp.12013.

8. Mazih, A. Status of citrus IPM in the southern mediterranean basin Morocco, North Africa. *Acta Hortic.* **2015**, *1065*, 1097–1104, doi:10.17660/ActaHortic.2015.1065.138.

9. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial insect community of Moroccan citrus groves: assessment of their potential to enhance biocontrol services. *Egypt. J. Biol. Pest Control* **2020**, *30*, doi:10.1186/s41938-020-00241-0.

10. Afechtal, M.; Djelouah, K.; Cocuzza, G.; D'Onghia, A.M. Large Scale Survey of *Citrus Tristeza* Virus (CTV) and Its Aphid Vectors in Morocco. *Acta Hortic.* **2015**, *1065*, 753–757, doi:10.17660/ActaHortic.2015.1065.94.

11. Ministry of agriculture Filière agrumicole | Ministère de l'agriculture Available online: https://www.agriculture.gov.ma/fr/filiere/agrumicole (accessed on Aug 15, 2022).

12. Assouguem, A.; Kara, M.; Benmessaoud, S.; Mechchate, H.; Jabboury, Z. El; Farah, A.; Lazraq, A. Tropical Journal of Natural Product Research *Ceratitis capitata* Wiedemann (Diptera : Tephritidae) in Moroccan Citrus orchards : Chemical and Sustainable Control Methods and Priorities for Future Research. **2021**, *5*, 1703–1708.

13. Montaigne, E.; Hadad-Gauthier, F. El; Khefifi, L. Challenges in Citrus Market Chains in Tunisia and Morocco. In; Springer, Cham, 2015; pp. 227–253.

14. Sraïri, M.T. New challenges for the moroccan agricultural sector to cope with local and global changes. *Morocco Environ. Soc. Econ. Issues 21st Century* **2017**, 165–188.

15. Oubelkacem, A.; Scardigno, A.; Choukr-Allah, R. Treated Wastewater Reuse on Citrus in Morocco: Assessing the Economic Feasibility of Irrigation and Nutrient Management Strategies. *Integr. Environ. Assess. Manag.* **2020**, *16*, 898–909, doi:10.1002/ieam.4314.

16. Trade, F. Les chiffres clés de la filière Agrumiculture Available online: https://www.fellah-trade.com/fr/filiere-vegetale/chiffres-cles-agrumiculture (accessed on Dec 11, 2021).

17. INRA 21/06/2021 | Maroc : la production d'agrumes bénéficie d'une météo clémente | Available online: https://www.inra.org.ma/fr/content/21062021-maroc-la-production-d'agrumes-bénéficie-d'une-météo-clémente (accessed on Nov 16, 2021).

18. Serra, D.D.R.; Ollitrault, P. L ' amélioration des agrumes : **1992**.

19. Sawamura, M.; Thi Minh Tu, N.; Onishi, Y.; Ogawa, E.; Choi, H.S. History and development of the citrus industry. *Citrus Ind.* **1967**, *68*, 1–37, doi:10.1271/BBB.68.1690.

20. Reuther, W.; Batchelor, L.; I, H.W.-T.C.I.V.; 1967, undefined The Citrus Industry. Vol. I. History, World Distribution, Botany and Varieties.. *cabdirect.org*.

21. Citrus, R.S.-P. of the sixth I.; 1988, U. Biochemistry, taxonomy and evolution of modern cultivated citrus.. *ci.nii.ac.jp*.

22. Zhong, G.; Nicolosi, E. Citrus Origin, Diffusion, and Economic Importance. **2020**, 5–21, doi:10.1007/978-3-030-15308-3_2.

23. Liu, Y.; Heying, E.; Tanumihardjo, S.A. History, Global Distribution, and Nutritional Importance of Citrus Fruits. *Compr. Rev. Food Sci. Food Saf.* **2012**, *11*, 530–545, doi:10.1111/J.1541-4337.2012.00201.X.

24. industry, H.W.-T. citrus; 1967, undefined History and development of the citrus industry. *ci.nii.ac.jp*.

25. Wu, G.A.; Terol, J.; Ibanez, V.; López-García, A.; Pérez-Román, E.; Borredá, C.; Domingo, C.; Tadeo, F.R.; Carbonell-Caballero, J.; Alonso, R.; et al. Genomics of the origin and evolution of Citrus. *Nature* **2018**, *554*, 311–316, doi:10.1038/nature25447.

26. Spiegel-Roy, P.; Goldschmidt, E. The biology of citrus*1996* ..

27. Reuther, W.; Batchelor, L.D.; Webber, H.J. The Citrus Industry. Vol. I. History, World Distribution, Botany and Varieties. *Citrus Ind. Vol. I. Hist. World Distrib. Bot. Var.* **1967**.

28. Garcia-Lor, A.; Curk, F.; Snoussi-Trifa, H.; Morillon, R.; Ancillo, G.; Luro, F.; Navarro, L.; Ollitrault, P. A nuclear phylogenetic analysis: SNPs, indels and SSRs deliver new insights into the relationships in the 'true citrus fruit trees' group (Citrinae, Rutaceae) and the origin of cultivated species. *Ann. Bot.* **2013**, *111*, 1–19, doi:10.1093/AOB/MCS227.

29. Nicolosi, E. Origin and taxonomy. *Citrus Genet. Breed. Biotechnol.* **2007**, 19–43, doi:10.1079/9780851990194.0019.

30. Tanaka, S.; Yamada, S. Citrus Virus Diseases in Japan. *Int. Organ. Citrus Virol. Conf. Proc.* **1961**, *2*, doi:10.5070/c56k3783j4.

31. Federici, C.T.; Fang, D.Q.; Scora, R.W.; Roose, M.L. Phylogenetic relationships within the genus Citrus (Rutaceae) and related genera as revealed by RFLP and RAPD analysis. *Theor. Appl. Genet. 1998 966* **1998**, *96*, 812–822, doi:10.1007/S001220050807.

32. Gmitter, F.G.; Chen, C.; Nageswara Rao, M.; Soneji, J.R. Citrus Fruits. *Fruits Nuts* **2007**, 265–279, doi:10.1007/978-3-540-34533-6_14.

33. Cabasson, C.M.; Luro, F.; Ollitrault, P.; Grosser, J.W. Non-random inheritance of mitochondrial genomes in Citrus hybrids produced by protoplast fusion. *Plant Cell Reports 207* **2001**, *20*, 604–609, doi:10.1007/S002990100370.

34. Luro, F.; Gatto, J.; Costantino, G.; Pailly, O. Analysis of genetic diversity in Citrus. *Plant Genet. Resour.* **2011**, *9*, 218–221, doi:10.1017/S1479262111000189.

35. Barkley, N.A.; Roose, M.L.; Krueger, R.R.; Federici, C.T. Assessing genetic diversity and population structure in a citrus germplasm collection utilizing simple sequence repeat markers (SSRs). *Theor. Appl. Genet.* **2006**, *112*, 1519–1531, doi:10.1007/S00122-006-0255-9.

36. Benyahia, H.; Talha, A.; Fadli, A.; Chetto, O.; Omari, F.E.; Beniken, L. Performance of 'Valencia late' sweet orange (*Citrus sinensis*) on different rootstocks in the gharb region (Northwestern Morocco). *Annu. Res. Rev. Biol.* **2017**, *20*, 1–11, doi:10.9734/ARRB/2017/37924.

37. Saitta, D.; Consoli, S.; Ferlito, F.; Torrisi, B.; Allegra, M.; Longo-Minnolo, G.; Ramírez-Cuesta, J.M.; Vanella, D. Adaptation of citrus orchards to deficit irrigation strategies. *Agric. Water Manag.* **2021**, *247*, 106734, doi:10.1016/J.AGWAT.2020.106734.

38. CASSIN, J.. Influence Du Climat Sur La Floraison Des Citrus. **1958**, *13*.

39. Mademba-Sy, F.; Cao Van, P.; Pancarte, C. Use of dwarfing citrus rootstocks for the establishment of high-density orchards under tropical climatic conditions. **1993**, doi:10.3/JQUERY-UI.JS.

40. Found, w.c. the relation of the distribution of citrus to soil type and winter temperature in orange county, FLorida. *Can. Geogr. / Le Géographe Can.* **1965**, *9*, 63–73, doi:10.1111/J.1541-0064.1965.TB00809.X.

41. Caballero, M.; Caballero, H.; Cobeña, G.; Solórzano, C. Reproductive development of lemon (*Citrus aurantifolia* Swingle) under different soil moisture levels. *Peruvian J. Agron.* **2019**, *3*, 6, doi:10.21704/pja.v2i3.1228.

42. Ndo, E.G.D.; Bella-Manga, F.; Ndindeng, S.A.; Ndoumbe-Nkeng, M.; Fontem, A.D.; Cilas, C. Altitude, tree species and soil type are the main factors influencing the severity of Phaeoramularia leaf and fruit spot disease of citrus in the humid zones of Cameroon. *Eur. J. Plant Pathol. 2010 1283* **2010**, *128*, 385–397, doi:10.1007/S10658-010-9660-7.

43. Abdelhakim, H. Ecological study for groups of citrus weeds in the Skikda region, Algeria. *J. Res. Weed Sci.* **2019**, *2*, 216–223, doi:10.26655/JRWEEDSCI.2019.2.3.4.

44. Loudyi, W. Fiches techniques: Le bananier, la vigne et les agrumes. In Transfert des technologies en agriculture, Available online: https://scholar.google.com/scholar?hl=ar&as_sdt=0%2C5&q=Walali+Loudyi%2C+D.+E.+M.

%2C+Skiredj%2C+A.%2C+%26+Hassan%2C+E.+%282003%29.+Fiches+techniques%3A+Le+bananier%2C+la+vigne+et+les+agrumes.+In+Transfert+des+technologies+en+agriculture%2C+Institut+Agrono (accessed on Aug 18, 2022).

45. Blondel, L. Influence des porte-greffe sur la qualité des fruits de citrus. *Fruits* **1974**, *29*, 285–290.

46. Blondel, L. Quelques aspects généraux du remplacement du bigaradier et de l'utilisation de porte-greffe nouveaux. *Fruits* **1967**, *22*, 19–26.

47. Loussert, R. Citrus. Volume 1: arboriculture. *Citrus. Vol. 1 Arboric.* **1989**.

48. Audoin, E. Rapport de stage Etude de la phénologie et des traits de réponse aux pratiques culturales des espèces végétales d ' intérêt pour la lutte biologique en vergers d ' agrumes à la Réunion. *Cirad* **2016**.

49. Agusti, M.; Zaragoza, S.; Bleiholder, H.; Buhr, L.; Hack, H.; Klose, R.; Staub, R.; Vera, U.P.C. de Adaptation de l'échelle BBCH à la description des stades phénologiques des agrumes du genre Citrus. *Fruits* **1997**, *52*, 287–295.

50. Fitchett, J.M.; Grab, S.W.; Thompson, D.I.; Roshan, G. Spatio-temporal variation in phenological response of citrus to climate change in Iran: 1960–2010. *Agric. For. Meteorol.* **2014**, *198–199*, 285–293, doi:10.1016/J.AGRFORMET.2014.08.010.

51. Hutton, R.J.; Landsberg, J.J.; Sutton, B.G.; Hutton, R.J.; Landsberg, J.J.; Sutton, B.G. Timing irrigation to suit citrus phenology: a means of reducing water use without compromising fruit yield and quality? *Aust. J. Exp. Agric.* **2007**, *47*, 71–80, doi:10.1071/EA05233.

52. Micheloud, N.G.; Castro, D.C.; Buyatti, M.A.; Gabriel, P.M.; Gariglio, N.F. FACTORS affecting phenology of different *citrus* varieties under the temperate climate conditions of santa fe, Argentina. *Rev. Bras. Frutic.* **2018**, *40*, doi:10.1590/0100-29452018315.

53. Smaili, M.C.; El Ghadraoui, L.; Gaboun, F.; Benkirane, R.; Blenzar, A. Impact of some alternative methods to chemical control in controlling aphids (Hemiptera: Sternorrhyncha) and their side effects on natural enemies on young Moroccan citrus groves. *Phytoparasitica* **2014**, *42*, 421–436, doi:10.1007/s12600-013-0379-9.

54. Moreno, P.; Ambrós, S.; Albiach-Martí, M.R.; Guerri, J.; Peña, L. *Citrus tristeza* virus: a pathogen that changed the course of the citrus industry. *Mol. Plant Pathol.* **2008**, *9*, 251–268, doi:10.1111/J.1364-3703.2007.00455.X.

55. Germanà, M.A.; Micheli, M.; Chiancone, B.; Macaluso, L.; Standardi, A. Organogenesis and encapsulation of in vitro-derived propagules of Carrizo citrange [*Citrus sinensis* (L.) Osb. × *Poncirius trifoliata* (L.) Raf]. *Plant Cell, Tissue Organ Cult. 2011 1062*, *106*, 299–307, doi:10.1007/S11240-011-9921-Y.

56. Benyahia, H.; Beniken, L.; Omari, F.E.; Benazzouze, A.; Handaji, N.; Msatef, Y.; Olitrault, P. Evaluation of the resistance of few citrus rootstocks to alkalinity by applying a faste test of secreening. *AFRICAN J. Agric. Res.* **2011**, *6*, 780–784.

57. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial insect community of Moroccan citrus groves: assessment of their potential to enhance biocontrol services. *Egypt. J. Biol. Pest Control* **2020**, *30*, 0–15, doi:10.1186/s41938-020-00241-0.

58. Benziane, T.; Abbassi, M.; Bihi, T. Evaluation de deux méthodes de lutte intégrée contre les ravageurs en vergers d'agrumes. *J. Appl. Entomol.* **2003**, *127*, 51–63, doi:10.1046/j.1439-0418.2003.00713.x.

59. Smaili MC, Afellah M, A.A. Contribution à la mise en place d'un système de lute intégrée sur Clémentinier dans la région du Gharb Available online: https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili+MC%2C+Afellah+M%2C+Aarab+A+%282001%29+Biologie%2C+écologie+et+lutte+biologique+contre+Phyllocnistis+citrella+Stain.+sur+clémentinier+dans+la+région+du+Gharb.+In+%3A+Abstracts+of+the+"I+Coll+de (accessed on Jul 10, 2021).

60. Abassi Presence of *Spiroplasma citr*i, the causal agent of stubborn Citrus disease in periwinkles (*Vinca rosea* L.) grown next to a diseased Citrus orchard in Morocco, and probable contamination of *Cynodon dactylon* (L.) pers. by the Spiroplasma Available online: https://agris.fao.org/agris-search/search.do?recordID=XE7931481 (accessed on Aug 18, 2022).

61. Bora, H.; Kamle, M.; Mahato, D.K.; Tiwari, P.; Kumar, P. Citrus essential oils (CEOs) and their applications in food: An overview. *Plants* **2020**, *9*, 1–25, doi:10.3390/plants9030357.

62. Tahir, R. Impact of Foliar Application of Zn on Growth Yield and Quality Production of Citrus: A Review. *Indian J. Pure Appl. Biosci.* **2020**, *8*, 529–534, doi:10.18782/2582-2845.8496.

63. USDA/FAS Citrus: World Markets and Trade. U.S. Production and Exports Forecast Down Despite Global Gains. *United States Dep. Agric. Foreing Agric. Serv.* **2021**, 1–13.

64. Ragusa, E. Some ecological and behavioral aspects of the black parlatoria , *Parlatoria ziziphi* (Lucas) (Hemiptera : Diaspidid ... Related papers.

65. Awadalla, S.; Bayoumy, M.H.; El-Metwally, M.; Alhussieny, R. Population and Mortality Studies on the Black Scale Insect, *Parlatoria ziziphi* (Lucas) (Hemiptera: Diaspididae) in an Egyptian Citrus Orchard. *J. Plant Prot. Pathol.* **2021**, *12*, 197–202, doi:10.21608/jppp.2021.153273.

66. Tawfeek, M.E.; Abu-shall, A.M.H. Seasonal Population Dynamics of *Parlatoria ziziphus* (Lucas) (Homoptera: Diaspididae) in Menoufia Gavernorate, Egypt. *Alexandria Sci.*

Exch. J. An Int. Q. J. Sci. Agric. Environ. **2010**, *31*, 331–338, doi:10.21608/asejaiqjsae.2010.2327.

67. Ferris, G.F. Atlas of the Scale Insects of North America. *Atlas Scale Insects North Am.* **1937**.

68. Abbassi, M.I. Notes bio-écologiques sur Parlatoria pergandii au Maroc. **1975**.

69. Kemayou, C.M.; Nono, C.T.; Audrey, V.V. Bio-ecology of black scale insects *Parlatoria ziziphi* Lucas (Homoptera : Bio-ecology of black scale insects *Parlatoria ziziphi* Lucas (Homoptera : Diaspididae) on three varieties of mandarin trees in a Foumbot orchard (West Cameroon). **2020**.

70. Tena, A.; García-Marí, F. Current situation of citrus pests and diseases in the Mediterranean Basin. *IOBC/wprs Bull* **2011**, *62*, 365–378.

71. N. Haddad, D. Sadoudi, F.G.-M. Management of a main citrus pest black parlatoria scale *Parlatoria ziziphi* (lucas) (hemiptera: diaspididae) in the mediterranean basin. *scifed virol. res. j.* **2018**, *1*, doi:10.23959/sfjv-1000006.

72. Assouguem, A.; Kara, M.; Mechchate., H.; Alzain, M.N.; Noman, O.M.; Imtara, H.; Hano, C.; Ibrahim, M.N.; Benmessaoud, S.; Farah, A.; et al. Evaluation of the Effect of Different Concentrations of Spirotetramat on the Diaspine Scale *Parlatoria ziziphi* in Citrus Orchards. *Agronomy* **2021**, *11*, 1–11, doi:10.3390/agronomy11081562.

73. Polaszek, A. The Egyptian species of Encarsia (Hymenoptera: Aphelinidae): a preliminary review. *Zool. ...* **1999**, *73*, 131–163.

74. Sweilem, S. M. ; El-Bolok, M. M. ; Abdel-Aleem, R.Y. Biological studies on *Parlatoria zizyphus* (Lucas) (Homoptera - Diaspididae). Available online: http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=orton.xis&method=post&formato=2&cantidad=1&expresion=mfn=073700 (accessed on Aug 23, 2021).

75. Bennett, F.D.; Brown, S.W. Life History and Sex Determination in the Diaspine Scale, *Pseudaulacaspis pentagona* (Targ.) (Coccoidea). *Can. Entomol.* **1958**, *90*, 317–324, doi:10.4039/ENT90317-6.

76. Kim, D.S.; Seo, Y.D.; Lee, J.H. A review of biology and ecology of Diaspine scales in Japan (Homoptera : Coccoidea). *Mushi* **1970**, *43*, 65–114, doi:10.1303/AEZ.2008.553.

77. Iparraguirre, M.. Particularidades biológicas de *Parlatoria ziziphi* (Lucas) en los cítricos de Ciego de Ávila y sus enemigos naturales. Available online: https://agris.fao.org/agris-search/search.do?recordID=CU2006102074 (accessed on Aug 20, 2022).

78. El Choubassi, W. Dinámica poblacional de *Parlatoria ziziphi* (Lucas) (Homoptera: Diaspididae) y de sus enemigos naturales en el naranjo Valencia Available online:

https://agris.fao.org/agris-search/search.do?recordID=CU2009100598 (accessed on Aug 20, 2022).

79. de Bon, H.; Huat, J.; Parrot, L.; Sinzogan, A.; Martin, T.; Malézieux, E.; Vayssières, J.F. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. *Agron. Sustain. Dev.* **2014**, *34*, 723–736, doi:10.1007/s13593-014-0216-7.

80. Tabatadze, E.S.; Yasnosh, V.A. Population dynamics and biocontrol of the japanese scale, lopholeucaspis japonica (cockerell) in georgia. *Entomologica* **1999**, *33*, 429–434, doi:10.15162/0425-1016/870.

81. Assouguem, A.; Kara, M.; Mechchate, H.; Korkmaz, Y.B.; Benmessaoud, S.; Ramzi, A.; Abdullah, K.R.; Noman, O.M.; Farah, A.; Lazraq, A. Current Situation of *Tetranychus urticae* (Acari: Tetranychidae) in Northern Africa: The Sustainable Control Methods and Priorities for Future Research. *Sustainability* **2022**, *14*, 2395, doi:10.3390/su14042395.

82. Hattingh, V.; Samways, M.J. Prey choice and substitution in *Chilocorus* spp. (Coleoptera: Coccinellidae). *Bull. Entomol. Res.* **1992**, *82*, 327–334, doi:10.1017/S0007485300041109.

83. Obrycki, J.J.; Kring, T.J. Coccinellidae are important natural enemies of pest species. *Annu. Rev. Entomol* **1998**, *43*, 295–321.

84. Sorribas, J.; Garcia-Marí, F. Comparative efficacy of different combinations of natural enemies for the biological control of California red scale in citrus groves. *Biol. Control* **2010**, *55*, 42–48, doi:10.1016/J.BIOCONTROL.2010.06.012.

85. Murdoch, W.; Briggs, C.J.; Swarbrick, S. Ecology: Host suppression and stability in a parasitoid-host system: Experimental demonstration. *Science (80-.).* **2005**, *309*, 610–613, doi:10.1126/SCIENCE.1114426/SUPPL_FILE/MURDOCH.SOM.PDF.

86. Dao, H.T.; Meats, A.; Beattie, G.A.C.; Spooner-Hart, R. Mortality on fruit in citrus orchards caused by naturally occurring enemies of red scale *Aonidiella aurantii*: relation to spatial distribution of patch density and season. *Entomol. Exp. Appl.* **2017**, *162*, 218–233, doi:10.1111/EEA.12525.

87. Vanaclocha, P.; Urbaneja, A.; Verdú, M.J. Natural mortality of the California red scale, *Aonidiella aurantii* in citrus of eastern Spain and its parasitoids associated. *Bol. Sanid. Veg. Plagas* **2009**, *35*, 59–71.

88. Profile, S.E.E. Identificación y abundancia de artrópodos depredadores en los cultivos de cítricos valencianos- Identification and abundance of predatory arthropods in citrus crops of Valencia (Sp... **2015**.

89. Kaufmann, T. Bionomics of *Chilocorus bipustulatus* and Its Future for the Biological Control of the Date Palm Scale, *Parlatoria blanchardi* , in Niger, W. Africa. *Environ. Entomol.* **1977**, *6*, 559–562, doi:10.1093/EE/6.4.559.

90. Khaldi, M.; Socolovschi, C.; Benyettou, M.; Barech, G.; Biche, M.; Kernif, T.; Raoult, D.; Parola, P. Rickettsiae in arthropods collected from the North African Hedgehog (Atelerix algirus) and the desert hedgehog (Paraechinus aethiopicus) in Algeria. *Comp. Immunol. Microbiol. Infect. Dis.* **2012**, *35*, 117–122, doi:10.1016/J.CIMID.2011.11.007.

91. Mohamed Biche, Abderahmane Siafa, R.A. et R.G. biologie de *Aonidiella aurantii* (homoptera, diaspididae) sur citronnier dans la région de rouiba Mohamed. *Leban. Sci. Journal,* **2011**, 59–64.

92. Sogut, m.; Tekelioglu, B.K. *Book of procedings (AgroSym)*; 2021; ISBN 9789997678799.

93. Bié, A.O.; Orlova-Bienkowskaja, M.J.; Severtsov, A.N. Rigorous Morphological Studies Confirm That the Classical Object of Pest Control Chilocorus kuwanae Is the Same Species as Ch. renipustulatus (Coleoptera: Coccinellidae)., doi:10.3390/insects11060368.

94. Jefferson, D.K.; Schultz, P.B.; Bryan, M.D. Distribution of Natural Enemies of Euonymus Scale, Unaspis euonymi (Comstock), in Virginia. *J. Entomol. Sci.* **1995**, *30*, 273–278, doi:10.18474/0749-8004-30.2.273.

95. Kim, D.S.; Seo, Y.D.; Choi, K.S. Seasonal Development and Population Fluctuations of Arrowhead Scale, Unaspis yanonensis (Homoptera: Diaspididae), in Citrus orchards in Jeju, Korea. *J. Asia. Pac. Entomol.* **2007**, *10*, 363–367, doi:10.1016/S1226-8615(08)60377-5.

96. García Morales, M.; Denno, B.D.; Miller, D.R.; Miller, G.L.; Ben-Dov, Y.; Hardy, N.B. ScaleNet: a literature-based model of scale insect biology and systematics. *Database* **2016**, *2016*, 118, doi:10.1093/DATABASE/BAV118.

97. Attia, S.; Grissa, K.L.; Lognay, G.; Bitume, E.; Hance, T.; Mailleux, A.C. A review of the major biological approaches to control the worldwide pest Tetranychus urticae (Acari: Tetranychidae) with special reference to natural pesticides: Biological approaches to control Tetranychus urticae. *J. Pest Sci. (2004).* **2013**, *86*, 361–386, doi:10.1007/s10340-013-0503-0.

98. Dekle, G.W. Florida armored scale insects. *Florida armored scale insects.* **1976**, *3*.

99. Coll, M.; Abd-Rabou, S. Effect of oil emulsion sprays on parasitoids of the black parlatoria, Parlatoria ziziphi, in grapefruit. *BioControl 1998 431* **1998**, *43*, 29–37, doi:10.1023/A:1009974330554.

100. Mangoud, a.a.h.; halawa, a.m. effect of different plant extracts against two- spotted spider mite, *Tetranychus urticae* koch and predatory mite, *phytoseiulus persimilis* a.- h. *Egypt. J. Agric. Res.* **2008**, *86*, 871–883, doi:10.21608/EJAR.2008.208944.

101. Belguendouz-Benkhelfa, R.; Biche, M.; Adda, R.; Allal-Benfekih, L. Bio-ecology of a citrus pest (*Aonidiella aurantii* Maskell) (Hemiptera, Diaspididae): spatiotemporalrelationship with its host plants Citruslimon and C.sinensis in Algiers region. *Am. J. Sustain. Agric.* **2013**, 14–21.

102. Soto, A.M.; Chung, K.L.; Sonnenschein, C. The pesticides endosulfan, toxaphene, and dieldrin have estrogenic effects on human estrogen-sensitive cells. *Environ. Health Perspect.* **1994**, *102*, 380–383, doi:10.1289/EHP.94102380.

103. Marcić, D.; Kljajić, P.; Perić, P.; Krnjaji ć, S.; Peri ć, I. Experimental evaluation of insecticide efficacy in controlling Brevicoryne brassicae L. in cabbage. *Acta Hortic.* **2007**, *729*, 471–475, doi:10.17660/ACTAHORTIC.2007.729.80.

104. Assouguem, A.; Kara, M.; Mansouri, I.; Imtara, H.; Alzain, M.N.; Mechchate, H.; Conte, R.; Squalli, W.; Farah, A.; Lazraq, A. Evaluation of the Effectiveness of Spirotetramat on the Diaspine Scale *Parlatoria pergandi*i in Citrus Orchards. **2021**, 1–12.

105. Assouguem, A.; Kara, M.; Mansouri, I.; Imtara, H.; Alzain, M.N.; Mechchate, H.; Conte, R.; Squalli, W.; Farah, A.; Lazraq, A. Evaluation of the effectiveness of spirotetramat on the diaspine scale *Parlatoria ziziphi* in citrus orchards. *Agronomy* **2021**, *11*, 1–11, doi:10.3390/agronomy11081562.

106. Rosen, D.; DeBach, P. Collecting and Mounting Specimens. *Species of Aphytis of the World* **1979**, 14–17, doi:10.1007/978-94-009-9603-8_4.

107. Basaid, K.; Chebli, B.; Mayad, E.H.; Furze, J.N.; Bouharroud, R.; Krier, F.; Barakate, M.; Paulitz, T. Biological activities of essential oils and lipopeptides applied to control plant pests and diseases: a review. *Int. J. Pest Manag.* **2020**, *0*, 1–23, doi:10.1080/09670874.2019.1707327.

108. Hamdi, S.H.; Hedjal-Chebheb, M.; Kellouche, A.; Khouja, M.L.; Boudabous, A.; Ben Jemâa, J.M. Management of three pests' population strains from Tunisia and Algeria using Eucalyptus essential oils. *Ind. Crops Prod.* **2015**, *74*, 551–556, doi:10.1016/j.indcrop.2015.05.072.

109. Masui, S.; Katayama, H.; Kaneko, S. Status and use of biological control of insect pests in citrus IPM. *Japanese J. Appl. Entomol. Zool.* **2018**, *62*, 137–148, doi:10.1303/jjaez.2018.137.

110. Benaissa, K.; Belhamra, M. Contribution to a study of the effect of the essential oil of henna (Lawsonia inermis L), on the biological aspect of white scale (Parlatoria blanchardi targ) of date palm. *Indian J. Pharm. Educ. Res.* **2017**, *51*, S309–S312, doi:10.5530/ijper.51.3s.36.

111. Afzal, M.; Ullah, M.I.; Bashir, M.H.; Mukhtar, S.N.; Arshad, M.; Altaf, N. Diversity and Abundance of Mite Species in Citrus Orchards of Sargodha, Pakistan. *Punjab Univ. J. Zool.* **2021**, *36*, 37–46, doi:10.17582/JOURNAL.PUJZ/2021.36.1.37.46.

112. Ferragut, F.; Navia, D.; Ochoa, R. New mite invasions in citrus in the early years of the 21st century. *Exp. Appl. Acarol.* **2013**, *59*, 145–164, doi:10.1007/s10493-012-9635-9.

113. Imani, Z.; Shishehbor, P. Effect of temperature on life history and life tables of *Eutetranychus orientalis* (Klein) (Acari: Tetranychidae). *https://doi.org/10.11158/saa.14.1.2* **2009**, *14*, 11–18, doi:10.11158/SAA.14.1.2.

114. walter, d.e.; halliday, r.b.; smith, d. The Oriental Red Mite, *Eutetranychus orientalis* (Klein) (Acarina: Tetranychidae), in Australia. *Aust. J. Entomol.* **1995**, *34*, 307–308, doi:10.1111/J.1440-6055.1995.TB01345.X.

115. Zaher, M.A.; Gomaa, E.A.; El-Enany, M.A. Spider mites of Egypt (Acari: Tetranychidae). *Int. J. Acarol.* **1982**, *8*, 91–114, doi:10.1080/01647958208683284.

116. Dhooria, M.S.; Butani, D.K. Citrus mite, *Eutetranychus orientalis* (Klein) and its control. *Pesticides* **1984**, *18*, 35–38.

117. L, La. Studies on the biology of the mite *Eutetranychus orientalis* (Klein) (Tetranychidae: Acarina) Available online: https://agris.fao.org/agris-search/search.do?recordID=US201301279919 (accessed on Aug 21, 2022).

118. Rasmy, A.H. Biology of the citrus brown mite, *Eutetranychus orientalis* as affected by some citrus species. *Acarologia* **1978**, *19*, 222–224.

119. LR Jeppson, HH Keifer, E.B. Mites Injurious to Economic Plants Available online: https://books.google.co.ma/books?hl=ar&lr=&id=RlE1_jsBtbAC&oi=fnd&pg=PR21&dq=Jeppson+et+al.,+1975&ots=AnUaLqzBQ3&sig=NBDUhJjAcFn890rKNhKcTg0eqak&redir_esc=y#v=onepage&q=Jeppson et al.%2C 1975&f=false (accessed on Aug 21, 2022).

120. El-Halawany, A. Survey of eriophyid mites on some fruit trees, with re-descriptions of two newly recorded species and a checklist of eriophyid mites in Egypt (Acari: Eriophyoidea). *Egypt. Acad. J. Biol. Sci. A, Entomol.* **2012**, *5*, 205–216, doi:10.21608/eajbsa.2012.14833.

121. Sharaf, A.; Ahmed, F.A.; El-Saadany, S.S. Biochemical changes in some fruits at different ripening stages. *Food Chem.* **1989**, *31*, 19–28, doi:10.1016/0308-8146(89)90147-7.

122. Chang, D.C.; Leu, T.S. Seasonal population changes of spider mites on carambola and their chemical control. *Plant Prot. Bull. Taiwan* **1986**, *28*, 263–272.

123. Krishna Kumar, K.; Rupa Kumar, K.; Ashrit, R.G.; Deshpande, N.R.; Hansen, J.W. Climate impacts on Indian agriculture. *Int. J. Climatol.* **2004**, *24*, 1375–1393, doi:10.1002/JOC.1081.

124. Chazeau, J. Predaceous Insects. *Spider Mites; Their Biol. Nat. Enemies, Control. vol. B.* **1985**, *1*, 211–246.

125. De Roos, A.M.; McCauley, E.; Wilson, W.G. Mobility versus density-limited predator-prey dynamics on different spatial scales. *Proc. R. Soc. London. Ser. B Biol. Sci.* **1991**, *246*, 117–122, doi:10.1098/RSPB.1991.0132.

126. Gerson, U.; Cohen, E. Resurgences of spider mites (Acari: Tetranychidae) induced by synthetic pyrethroids. *Exp. Appl. Acarol. 1989 61* **1989**, *6*, 29–46, doi:10.1007/BF01193231.

127. Assouguem, A.; Kara, M.; Ramzi, A.; Annemer, S.; Kowalczyk, A.; Ali, E.A.; Moharram, B.A.; Lazraq, A.; Farah, A. Evaluation of the Effect of Four Bioactive Compounds in Combination with Chemical Product against Two Spider Mites *Tetranychus urticae* and *Eutetranychus orientalis* (Acari : Tetranychidae). **2022**, *2022*.

128. Mohamed, O.; Alahyane, H.; Aboussaid, H.; Oufdou, K.; Messoussi, S. El; Costa, J.; Majidi, L. Acaricidal Properties of Essential Oils from Moroccan Thyme Against Oriental Red Mite, *Eutetranychus Orientalis* (Klein) (Acari: Tetranychidae). *https://doi.org/10.1080/0972060X.2021.1927854* **2021**, *24*, 329–341, doi:10.1080/0972060X.2021.1927854.

129. Elhalawany, A.S.; Abou-Zaid, A.M.; Amer, A.I. Laboratory Bioassay for the Efficacy of Coriander and Rosemary Extracted Essential Oils on the Citrus Brown Mite, *Eutetranychus orientalis* (Actinidida: Tetranychidae). *Acarines J. Egypt. Soc. Acarol.* **2019**, *13*, 15–20, doi:10.21608/AJESA.2019.164149.

130. Damavandian, M.R. Laboratory and field evaluation of mineral oil spray for the control of citrus red mite, *Panonychus citri* (McGregor). *http://dx.doi.org/10.1080/09064710500407836* **2007**, *57*, 92–96, doi:10.1080/09064710500407836.

131. Elaini, R.; Asadi, R.; Naish, N.; Koukidou, M.; Ahmed, M. Evaluation of rearing parameters of a self-limiting strain of the mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). *Insects* **2020**, *11*, 1–11, doi:10.3390/insects11100663.

132. Vicente, C.; Boutaleb, A.; Lebrun, P. Quelles stratégies de lutte contre les acariens ravageurs du pommier au Maroc. *Parasitica* **2003**, *59*, 25–41.

133. Ferragut, F.; Laborda, R.; Costa-Comelles, J.; García-Marí, F. Feeding behavior of Euseius stipulatus and *Typhlodromus phialatus* on the citrus red mite *Panonychus citri* [Acari: Phytoseiidae, Tetranychidae]. *Entomophaga* **1992**, *37*, 537–544, doi:10.1007/BF02372323.
134. McMurtry, J.A. Some predaceous mites [Phytoseiidae] on citrus in the mediterranean region. *Entomophaga* **1977**, *22*, 19–30, doi:10.1007/BF02372986.
135. Hare, D.E.; Sorensen, C.M. Interoscillator coupling effects on the OH stretching band of liquid water. *J. Chem. Phys.* **1998**, *96*, 13, doi:10.1063/1.462852.
136. Pan, D.; Dou, W.; Yuan, G.R.; Zhou, Q.H.; Wang, J.J.; Anderson, T. Monitoring the Resistance of the Citrus Red Mite (Acari: Tetranychidae) to Four Acaricides in Different Citrus Orchards in China. *J. Econ. Entomol.* **2020**, *113*, 918–923, doi:10.1093/jee/toz335.
137. Boutaleb Joutei, A.; Bassy, F. Essais de lutte chimique et biologique contre les acariens (*Tetranychus urticae* Koch) et les pucerons (Myzus persicae Sulzer) sur cultures maraîchères dans la région du Saïs. *Trav. l'Institut Sci. Série Zool.* **2009**, *45*.
138. Roy, M. État Actuel De La Lutte Biologique Contre Les Acariens Phytophages Par Des Acariens Prédateurs. *Phytoprotection* **2005**, *74*, 41–49, doi:10.7202/706035ar.
139. Bedford, E.C.G., Van den berg, M.A.& D.V. Tropical and Subtropical Crops, Nelspruit, and Outspan, Hennopsmeer, South Africa. *Citrus Pests Repub. South Africa* **1998**.
140. Bodie, Z.; Kane, A.; Marcus, A.J. Contrôle de la gestion des traitements phytosanitaires. *SASMA* **1996**, 454.
141. Xiao, Y.; Fadamiro, H.Y. Functional responses and prey-stage preferences of three species of predacious mites (Acari: Phytoseiidae) on citrus red mite, *Panonychus citri* (Acari: Tetranychidae). *Biol. Control* **2010**, *53*, 345–352, doi:10.1016/J.BIOCONTROL.2010.03.001.
142. McMurtry, J.A. Dynamics and potential impact of 'generalist' phytoseiids in agroecosystems and possibilities for establishment of exotic species. *Exp. Appl. Acarol. 1992 143* **1992**, *14*, 371–382, doi:10.1007/BF01200574.
143. Reyes, J.; González, G.; Kondo, T. First Record of the Spider Mite Predator, *Stethorus Tridens* Gordon (Coleoptera: Coccinellidae) Preying Upon the Red Avocado Mite, *Oligonychus Yothersi* Mcgregor (Acari: Tetranychidae). *Boletín del Mus. Entomol. la Univ. del Val.* **2010**, *11*, 15–19.
144. Oatman, E.R.; McMurtry, J.A.; Gilstrap, F.E.; Voth, V. Effect of Releases of Amblyseius californicus on the Twospotted Spider Mite on Strawberry in Southern California. *J. Econ. Entomol.* **1977**, *70*, 638–640, doi:10.1093/JEE/70.5.638.
145. SWIRSKI1, E.; M. GOKKES2; AMITAI1, and S. PHENOLOGY AND NATURAL ENEMIES OF THE CITRUS RED MITE,. *Isr. J. Entomol.* **1986**, *XX*, 37–44.

146. Lagziri, M.; Benicha, M.; M'rabet, R.; Amrani, A. El Influence de l'usage préventif des pesticides sur les acariens *Tetranychus urticae* et *Phytoseiulus persimilis* (Acari : Tetranychidae, Phytoseiidae) présents en cultures de fraisiers du Nord du Maroc. *Biotechnol. Agron. Soc. Environ.* **2015**, *19*, 355–363.

147. Sim, C.; Seo, E.; Cho, K. Life Table and Sensitivity Analysis as Fitness Evaluation Method of Fenpyroximate and Pyridaben Resistant Twospotted Spider Mite (*Tetranychus urticae* Koch). *J. Asia. Pac. Entomol.* **2003**, *6*, 193–199, doi:10.1016/S1226-8615(08)60186-7.

148. J. Mariéthoz, M. Baillod, Christian Linder, Ph. Antonin, C.M. Distribution, méthodes de contröle et stratégies de lutte chimique et biologique contre l' acarien jaune, "Tetranychus urticae" Koch, dans les cultures de framboisiers - Dialnet Available online: https://dialnet.unirioja.es/servlet/articulo?codigo=2984817 (accessed on Apr 16, 2021).

149. Gulati, R. Incidence of *Tetranychus cinnabarinus* (Boisd.) infestation in different varieties of *Abelmoschus esculentus* L. Available online: https://agris.fao.org/agris-search/search.do?recordID=IN2004000229 (accessed on Apr 16, 2021).

150. Reddy, G.V.P.; Baskaran, P. Damage potential of the spider mite *Tetranychus ludeni* (Acari: Tetranychidae) on four varieties of eggplant. *Int. J. Trop. Insect Sci.* **2006**, *26*, 48–56, doi:10.1079/IJT2006102.

151. Haque, M.; Islam, T.; Naher, N.; Mainul Haque, M. Seasonal abundance of spider mite *Tetranychus urticae* Koch on vegetable and ornamental plants in Rajshahi. *Univ. J. Zool. Rajshahi Univ.* **2011**, *30*, 37–40, doi:10.3329/ujzru.v30i0.10745.

152. Logan, J.G.; Birkett, M.A. Juvenile hormonal activity of mono- and polyenehomobenzenes in Drosophila virilis, Spodoptera frugiperda and Araschnia levana. *Pest Manag. Sci.* **2007**, *63*, 809–814, doi:10.1002/ps.

153. Abdallah, A.M.; Ismail, M.S.M.; AboGhalia, A.H.; Soliman, M.F.M. Factors affecting population dynamics of *Tetranychus urticae* and its predators on three economic plants in Ismailia, Egypt. *Int. J. Trop. Insect Sci.* **2019**, *39*, 115–124, doi:10.1007/s42690-019-00008-7.

154. Migeon, A.; Nouguier, E.; Dorkeld, F.; Cbgp, U.M.R.; Ird, I.; Montpellier, C.; Cedex, M. Spider Mites Web: A comprehensive database for the *Tetranychidae Alain*. *Trends Acarol.* **2010**, 557–560, doi:10.1007/978-90-481-9837-5.

155. Hmimina, M.; Allam, L.; Ougass, Y.; Marmouche, A. Circonstances des pullulations de *Tetranychus urticae* Koch (Tetranychidae: Acarina) en verger d'agrumes. *IOBC/wprs Bull.* **1995**, *18*, 35.

156. FAO STRATEGIE EN AFRIQUE FAO 2018-2021.

157. Mohammed, K.; Karaca, İ.; Agarwal, M.; Newman, J.; Ren, Y. Age-specific life tables of *Aonidiella aurantii* (Maskell) (hemiptera: Diaspididae) and its parasitoid *Aphytis melinus* debach (hymenoptera: Aphelinidae). *Turkish J. Agric. For.* **2020**, *44*, 180–188, doi:10.3906/tar-1905-36.

158. Baiomy, F. Efficiency of modern methods for controlling some vegetable pests in greenhouses in Egypt and Morocco .Thesis, Ins. African Res. Studies, Cairo Univ. 154pp. 7. Available online: https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Baiomy%2C+Fatina%2C+A.+M.+2008.+Efficiency+of+modern+methods+for+controlling+some+vegetable+pests+in+greenhouses+in+Egypt+and+Morocco.PhD+.Thesis%2C+Ins.+African+Res.+Studies%2C+Cairo+Univ.+154pp.+7. (accessed on Jun 28, 2021).

159. Shalaby, F.F.; Ali, F.A.; Hafez, A.A.; Saad, H.M. Planting Date in Relation To Insect and Animal Pests Attacking Cucumber Plants Under Protected Cultivation At Giza Governorate. *Egypt. J. Agric. Res.* **2013**, *91*, 1347–1360, doi:10.21608/ejar.

160. Brandenburg, R.L.; Kennedy, G.G. Intercrop relationships and spider mite dispersal in a corn/peanut agro-ecosystem. *Entomol. Exp. Appl.* **1982**, *32*, 269–276, doi:10.1111/j.1570-7458.1982.tb03217.x.

161. Gerson, U.; Aronowitz, A. Feeding of the carmine spider mite on seven host plant species. *Entomol. Exp. Appl.* **1980**, *28*, 109–115, doi:10.1111/j.1570-7458.1980.tb02995.x.

162. Chandler, L.D.; Archer, T.L.; Ward, C.R.; Lyle, W.M. Influences of irrigation practices on spider mite densities on field corn. *Environ. Entomol.* **1979**, *8*, 196–201, doi:10.1093/ee/8.2.196.

163. Vicente, C.; Joutei, A.B.; Lebrun, P. What strategies to use against mite pests of apple in Morocco? **2004**, *59*, 25–41.

164. İçli, N.; Tahmas Kahyaoğlu, D. Investigation of pesticide residues in fresh sultani grapes and antioxidant properties of fresh/sun-dried/oven-dried grapes. *Turkish J. Agric. For.* **2020**, *44*, 350–360, doi:10.3906/tar-1904-49.

165. Ball, J.C. *Impact of Fungicides and Miticides on Predatory and Phytophagous Mites Associated with Pecan Foliage 1*; 1982;

166. ONSSA Commission des Pesticides à Usage Agricole Available online: http://eservice.onssa.gov.ma/CPUA.aspx (accessed on Apr 10, 2021).

167. Gashout, H.A.; Goodwin, P.H.; Guzman-Novoa, E. Lethality of synthetic and natural acaricides to worker honey bees (*Apis mellifera*) and their impact on the expression of health

and detoxification-related genes. *Environ. Sci. Pollut. Res. 2018 2534* **2018**, *25*, 34730–34739, doi:10.1007/S11356-018-3205-6.

168. Mishra, J.; Arora, N.K. Secondary metabolites of fluorescent pseudomonads in biocontrol of phytopathogens for sustainable agriculture. *Appl. Soil Ecol.* **2018**, *125*, 35–45, doi:10.1016/j.apsoil.2017.12.004.

169. Hamza, A.; Mohamed, A.; Derbalah, A. Unconventional alternatives for control of tomato root rot caused by Rhizoctonia solani under greenhouse conditions. *J. Plant Prot. Res.* **2016**, *56*, 298–305, doi:10.1515/jppr-2016-0046.

170. Ruiu, L. Insect pathogenic bacteria in integrated pest management. *Insects* **2015**, *6*, 352–367, doi:10.3390/insects6020352.

171. Osman, M.E.; Abo Elnasr, A.A.; Nawar, M.A.; Hefnawy, G.A. Myco-metabolites as biological control agents against the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). *Egypt. J. Biol. Pest Control* **2019**, *29*, doi:10.1186/s41938-019-0166-0.

172. Osman, M.E.; Abo Elnasr, A.A.; Nawar, M.A.; Hefnawy, G.A. Myco-metabolites as biological control agents against the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). **2018**, doi:10.1186/s41938-019-0166-0.

173. Castagnoli, M.; Liguori, M.; Simoni, S.; Duso, C. Toxicity of some insecticides to *Tetranychus urticae*, *Neoseiulus californicus* and Tydeus californicus. *BioControl* **2005**, *50*, 611–622, doi:10.1007/s10526-004-8121-7.

174. Isman, M.B.; Wan, A.J.; Passreiter, C.M. Insecticidal activity of essential oils to the tobacco cutworm, Spodoptera litura. *Fitoterapia* **2001**, *72*, 65–68, doi:10.1016/S0367-326X(00)00253-7.

175. Hance, T.; Attia, S.; Grissa, K.; Ghrabi-Gammar, Z.; Mailleux, A.; Lognay, G.; Goff, G. Contrôle de *Tetranychus urticae* par les extraits de plantes en vergers d'agrumes. *Entomol. Faun. = Faun. Entomol.* **2010**, *63*, 229–235.

176. C Daniel, E Wyss, C.L. Applications de soufre en automne: une nouvelle manière de lutter contre lériophyide à galles du poirier. *Rev. suisse Vitic. Arboric. Hortic.* **2004**, *36*.

177. Han, J.; Kim, S. Il; Choi, B.R.; Lee, S.G.; Ahn, Y.J. Fumigant toxicity of lemon eucalyptus oil constituents to acaricide-susceptible and acaricide-resistant *Tetranychus urticae*. *Pest Manag. Sci.* **2011**, *67*, 1583–1588, doi:10.1002/ps.2216.

178. Hamdi, S.H.; Hedjal-Chebheb, M.; Kellouche, A.; Khouja, M.L.; Boudabous, A.; Ben Jemâa, J.M. Management of three pests' population strains from Tunisia and Algeria using Eucalyptus essential oils. *Ind. Crops Prod.* **2015**, *74*, 551–556, doi:10.1016/j.indcrop.2015.05.072.

179. Attia, S.; Grissa, K.L.; Lognay, G.; Heuskin, S.; Mailleux, A.C.; Hance, T. Chemical composition and acaricidal properties of Deverra scoparia essential oil (Araliales: Apiaceae) and blends of its major constituents against *Tetranychus urticae* (Acari: Tetranychidae). *J. Econ. Entomol.* **2011**, *104*, 1220–1228, doi:10.1603/EC10318.

180. Laborda, R.; Manzano, I.; Gamón, M.; Gavidia, I.; Pérez-Bermúdez, P.; Boluda, R. Effects of Rosmarinus officinalis and Salvia officinalis essential oils on *Tetranychus urticae* Koch (Acari: Tetranychidae). *Ind. Crops Prod.* **2013**, *48*, 106–110, doi:10.1016/j.indcrop.2013.04.011.

181. Ahmadi, Z.; Saber, M.; Bagheri, M.; Mahdavinia, G.R. Achillea millefolium essential oil and chitosan nanocapsules with enhanced activity against *Tetranychus urticae. J. Pest Sci. (2004).* **2018**, *91*, 837–848, doi:10.1007/s10340-017-0912-6.

Revue I:

La situation actuelle de l'acarien tétranyque *Tetranychus urticae* (Acari : Tetranychidae) en Afrique du Nord : Les méthodes de lutte durable et les priorités pour les futures recherches

Cette étude a fait l'objet d'une publication dans sustainability Journal : (IF= 3,89)

Assouguem, A.; Kara, M.; Mechchate, H.; Korkmaz, Y.B.; Benmessaoud, S.; Ramzi, A.; Abdullah, K.R.; Noman, O.M.; Farah, A.; Lazraq, A. Current Situation of *Tetranychus urticae* (Acari: Tetranychidae) in Northern Africa: The Sustainable Control Methods and Priorities for Future Research. Sustainability 2022, 14, 2395, doi:10.3390/su14042395.

Résumé

En Afrique du Nord, *Tetranychus urticae* Koch, 1836 représente l'un des ravageurs le plus destructeur parmi les acariens herbivores. Malheureusement, il est à l'origine d'importantes pertes annuelles en production végétale. C'est un acarien phytophage qui peut se nourrir sur des centaines de plantes hôtes et produire des dégâts importants. Le contrôle de *T. urticae* en Afrique du Nord a été principalement basé sur des pulvérisations d'acaricides. Cependant, de nouvelles méthodes alternatives ont montré des résultats efficaces dans d'autres pays européens, comme les ultraviolets-B artificiels, les ennemis naturels, et l'introduction de nouvelles méthodes génétiques. Nous avons souligné les principaux résultats des études précédentes. Ensuite, nous avons discuté ces méthodes de contrôle actuelles et nous avons proposé de nouvelles recherches innovantes et des approches durables pour contrôler ce ravageur, ces méthodes de luttes peuvent potentiellement être extrapolées dans les pays d'Afrique du Nord en raison de ces résultats écologiques positifs. En outre, ces études ont prouvé l'utilisation d'ennemis naturels, de myco-métabolites, de métabolites d'origine bactériens et l'introduction d'une méthode génétique dans un programme intégré durable à long terme qui peuvent vaincre avec succès les pullulations de *T. urticae*. Nous avons discuté également des orientations de recherche hautement prioritaires pour étudier de nouvelles stratégies de gestion durable. En conclusion, on peut dire que la mise en place d'un programme intégré de surveillance écologique à long terme dans les différents pays d'Afrique du Nord et l'incorporation de nouvelles technologies dans les programmes de surveillance reste un besoin urgent pour lutter contre ce ravageur.

Review I:
Current Situation of *Tetranychus urticae* (Acari: Tetranychidae) in Northern Africa: The Sustainable Control Methods and Priorities for Future Research

Amine Assouguem 1,2* , Mohammed Kara 3 , Hamza Mechchate 4,* , Yesim Bulak Korkmaz 5 , Safaâ Benmessaoud 3 , Amal Ramzi 2 , Khaled R. Abdullah 6 , Omar Mohammed Noman 7 , Abdellah Farah 2 and Abderahim Lazraq 1

1 Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco; assougam@gmail.com (A.A.); lazraqab@gmail.com (A.L.)
2 Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco; ramzi.amal@usmba.ac.ma (A.R.); farah.abdellah1@gmail.com (A.F.)
3 Laboratory of Biotechnology and Conservation and Valorization of Natural Resources (LBCVRN) (ex LBPRN), Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco; mohammed.kara@usmba.ac.ma (M.K.); safaa.benmessaoud@usmba.ac.ma (S.B.)
4 Laboratory of Inorganic Chemistry, Department of Chemistry, University of Helsinki, P.O. Box 55, FI-00014 Helsinki, Finland
5 Department of Plant Protection, Faculty of Agriculture, Ataturk University, Erzurum 25240, Turkey; yesim.bulak@atauni.edu.tr
6 Department of Medicinal Chemistry, Faculty of Pharmacy, Sana'a University, Sana'a 13078, Yemen; khaledraweh0@gmail.com
7 Department of Pharmacognosy, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia; onoman20@gmail.com
* Correspondence: Hamza.mechchate@helsinki.fi, (H.M) assougam@gmail.com (A.A)

Abstract

In North Africa, *Tetranychus urticae* Koch, 1836 represents one of the most destructive generalists among mite herbivores. Unfortunately, it is a source of important annual casualties in crop production. It is a phytophagous mite that can feed on hundreds of host plants and produces significant damage. The control of *T. urticae* in North Africa has been principally based on acaricide sprays. However, new alternative methods have shown effective results, such as artificial ultraviolet-B, natural enemies, and the introduction of new genetic methods. This review aims to present a synthesis of information surrounding control methods of *T. urticae* in North Africa. We highlight the principal findings of previous studies. Then, we discuss current control methods and propose new innovative research and sustainable approaches to controlling this pest. The control method can potentially extrapolate in North African regions due to its positive ecological results. Further, studies proved the use of natural enemies, myco-metabolites, bacteria metabolites, and the introduction of a genetic method in an integrated long-term sustainable program that can successfully defeat the populations of *T. urticae*. We also discuss high-priority research guidelines to investigate new sustainable management strategies. Setting up an integrated long-term ecological monitoring program in different

Northwest African countries and incorporating new technologies into monitoring programs is an urgent need to fight this devastating pest.

Keywords: *Tetranychus urticae*; propagation; environment; crop protection; acaricide; biological control; integrated; management

Introduction

Maghreb countries share most of the phytosanitary problems [**1**]. North Africa's agricultural productivity is harshly restricted by multiple constraints. These constraints include lack of manpower, maturity of orchards, biotic, and abiotic constraints. The negative impact caused by pests reduces the quantity and quality of production. Indeed, spider mites, aphids, medflies, and diaspine scales are pests of primary economic importance [**2**]. When conditions are favorable and in the absence of adequate methods of control, significant damage is often observed on fruits, twigs, leaves, and young shoots [**1**]. The effective control of insects in food products has long been the object of producers and the industry sector [**3**]. Its pests are resistant to most groups of acaricides [**4**].

Tetranychus urticae Koch, 1836 (Acari: Tetranychidae) is one of the most important pest species that is widely distributed globally; it is a phytophagous mite from the family of *Tetranychidae*. This species is a highly polyphagous herbivore and a major agricultural pest worldwide that causes hard damages to economics. It is a cosmopolitan species [**2**]. It presents a notable pest of field crops, ornamentals, and annual and perennial plants [**5**,**6**]; it attacks (i) fruit species, including citrus, apple, pear shrubs, and raspberry [**7**], (ii) vegetables, including eggplant, cucumber, bean, okra, and tomato [**8**,**9**,**10**,**11**], (iii) ornamentals, especially dahlia, rose, gerbera, zinnia, and ganda [**12**]; and medicinal plants, such as moringa (*Moringa oleifera*), metel (*Datura metel*), Alfalfa (*Medicago sativa*), Peppermint (*Mentha piperita*), rosemary (*Rosmarinus oflicinalis*), and common vervain (*Verbena oflicinalis*) [**13**,**14**].

In Egypt, *T. urticae* causes principal damage, such as defoliation, leaf yellowing, and leaf burning [**14**,**15**], plus the indirect damage by diminishing photosynthesis, transpiration, and a significant decline in yield productivity [**6**,**16**]. In Morocco, *T. urticae* is undoubtedly remembered for its significant damages in agriculture and its redoubtable capacity to elaborate resistance to pesticides [**17**]; it causes qualitative and quantitative yield losses every agricultural season. All mobile stages of this mite preferentially feed on the lower surface of the leaf and extract the contents of mesophyll cells [**14**,**18**]. This pest attacks the cells of the parenchyma of which they absorb the contents with their cheliceral stylets, and provokes the appearance of

yellow-greenish patches on the upper face of the leaves, thus producing the destruction of the foliage and the reduction of the period of filing of the ear [**19**]. Moreover, *T. urticae* causes severe damages in the Tunisian territory, particularly prevalent in the majority of orchards. During mid-March to June and from September to December; the citrus species of orange, lemon, tangerine, and pomelo are most susceptible [**20**].

Between mites' pests, *T. urticae* has the most significant proportion of pesticide resistance. In conventional chemical control management of *T. urticae*, broad-spectrum acaricides are often sprayed to diminish population levels. Nevertheless, they can additionally eliminate natural enemies, including auxiliary fauna [**21**]. Furthermore, multiple features of the spider mite biology, including incredibly high fecundity, rapid development, and haplodiploid sex determination, seem to facilitate the development of pesticide resistance [**22**]. The control of multi-resistant mites has become frequently difficult in North Africa [**23**]. This review aims to summarize North Africa's diverse current and prospective methods used to control *T. urticae* populations and motivate implementation of an integrated management strategy based on environmentally friendly practices, such as developing new biopesticides, physical control, or the use of a genetic approach. The goal of this study, on the one hand, is to describe the various control methods available *for T. urticae* in North African countries. On the other hand, it highlights the key findings from previous studies and overviews current and sustainable approaches used to manage this pest.

1 *Tetranychus urticae* in North Africa

Tetranychus urticae is a problematic pest of several global crops [**24**,**25**]. It is a generalist species that can feed on hundreds of host plants and produces significant damage to the field, greenhouse, and horticultural crops, as well as ornamental and fruit-bearing trees [**26**,**27**,**28**,**29**]. It can produce silk threads to protect itself from predators or to disperse from plant to plant. In Egypt, the generations of *T. urticae* follow one another at a rapid pace (approximately 27 generations per year) [**30**], *T. urticae* on Hood pear variety; the highest mean number of eggs laid by a female was 143.6 eggs/female with a daily rate of 16.7 eggs/female/day at 30 ° C [**31**]. In Moroccan conditions, this pest presents an optimal development at temperatures of 30 °C. The female can generate a high number of eggs in a short time; for instance, on clementine, they can lay about 34 eggs in a period of 17 days (the biological cycle takes from 8 to 12 days in optimal condition) [**32**,**33**]. The drying up of leaves due to *T. urticae*, can negatively affect the crop's green matter (GM) yield. However, a reduction in potassium, nitrogen, and

phosphorus has been detected on *Chrysanthemum* infested by *T. urticae*. Additionally, [**19**] observed a reduction in amylase activity and proteolytic enzyme, and reduced the total amount of proteins. In Tunisia, the economic importance of this mite has expanded on many crops, principally because of its resistance to acaricides [**34**]. *Tetranychus urticae* in citrus orchards are mainly active during summer and autumn. The highest population density is recorded in July and August. On lemon, the attack can be observed throughout the year if the winter is mild. The varieties of the clementine groups are the joint susceptible to mite attacks causing significant defoliation. In Algeria, *T. urticae* is listed as one of the most dangerous pests that cause immense damage to vegetable plants [**35**].

2 Levels of Infestation and Severity of Spread

Tetranychus urticae is a cosmopolitan pest. It occurs in most parts of the world; in Europe, Asia, Africa, Australasia, Caribbean islands, and North America [**36**]. Further, this pest is adapted to different climatic conditions. In North Africa, especially in Morocco, *T. urticae* is one of the most recorded pests on various crops, including fruit trees (apple and citrus) and spontaneous plants [**37**,**38**]. Similar results were cited in Algeria and Tunisia, which are under the same climatic conditions as Morocco [**39**]. In Egypt, spider mite was found in fruit trees and ornamental vegetation, causing serious damage, according to the infestation rates on these plants [**40**,**41**]. The differences in infestation rates can be attributed to the variation of environmental conditions, planting dates, and age of plantation [**42**].

Tetranychus populations multiply fast in the weeds and orchards surrounding vegetation and migrate to occupy the fruit trees [**43**]. This spread is not always passive but often takes place under the action of various stimuli counting temperature, wind, rainfall, and farming practices [**44**,**45**]. On clementine, a study was conducted in the Gharb region of Morocco, in which the orchards were isolated for three cropping annuals and without practice of acaricide treatments, in order to know the severity of infestation rate by *T. urticae*. This study showed that the infestation degree of the trees was 10% in mid-April, to increase rapidly to 87% in July. According to this study, the spread occurs when the climatic conditions and the phenological development of the tree are favorable for the deployment of the mite [**37**]. *T. urticae* have been studied in Moroccan orchards over a period of ten weeks (from 25 March to 2 June 2002) on herbaceous strata and on two different varieties of apple trees (“Golden” and “Anna”). Adventitious plants such as *Cuscuta epithymum*, *Malva neglecta*, *Sonchus asper, Convolvulus arvensis*, and *Urtica urens* (and, to a lesser extent, *Mentha pulegium, Sonchus oleraceus,*

Papaver rhoeas, and *Sinapis arvensis*) appear to be the most favorable host plants to *T. urticae*. Hence, they must be considered as potential sources of infestation for the fruit trees. In the North African countries, therefore, we suggest conducting this kind of research to estimate the infestation rates and propagation ways [**46**].

3 Kind of Hosts

Tetranychus urticae represents one of the most destructive generalists among mite herbivores [**33**]. It is considered a major pest decreasing plant growth and yield on different crops [**47**]. Among these, in North Africa, it attacks flowering plants and fruit crops, such as apricot, cherry (*Prunus* sp.), apple (*Malus domestica*), *Citrus* sp., strawberry (*Fragaria ananassa*), blackcurrant (*Ribes nigrum*), quince (*Cydonia oblonga*), plums (*Prunus domestica*), pear (*Pyrus communis*), cotton (*Gossypium hirsutum*), clover (*Trifolium* sp.), sunflower (*Helianthus* sp.), grapevine, eggplant (*Solanum melongena*), moringa (*Moringa oleifera*), melons, watermelons (*Citrullus* sp.), baby marrow (*Zucchini* sp.), cucumber (*Cucumis sativus*), green beans (*Phaseolus vulgaris*), carrots (*Daucus carota*), peanut (*Arachis hypogaea*), bindweed (*Convolvulus aryensis*), metel (*Datura metel*), alfalfa (*Medicago sativa*), peppermint (*Mentha piperita*), rosemary (*Rosmarinus oflicinalis*), common vervain (*Verbena oflicinalis*), and (*Rosa* sp.) have been recorded [**31**,**48**,**49**].

4 Control Methods

4.1 Chemical Control

In the commercial orchards of Northern Africa, the protection against pests is currently assured by preventive and intensive chemical control. Despite benefits such as rapid action in the reduction of pests numbers and their easy use when compared to natural extracts from plants [**50**], this strategy has many limitations; the examination of the action spectrum of the active components used throughout the world reveals that 46% of acaricides, 72% of insecticides, and 28% of fungicides are globally toxic towards auxiliary arthropods and public health [**51**]. Additionally, spider mites have developed resistances to more than 80 acaricides in more than 60 countries [**34**]. Particularly, *Tetranychus urticae* has developed resistances to more than 30 organophosphates and carbamates in 40 countries, this resistance is due to mutations in the mitochondrial cytochrome b protein of this pest [**52**]. Besides, a non-rational application of benomyl [methyl 1-(butylcarba-moyl) benzimidazole-2-ylcarba- mate] and other pesticides killed all noticeable predators of the pest [**53**]. Therefore, the absence of control by natural

enemies due to their death by pesticides can cause a considerable increase in *T. urticae* populations [**54**].

In Morocco, the Spirodiclofen (240 g/L), Malathion (440 g/L), Abamectine (18 g/L), Bifenazate (480 g/L), Fenpyroximate (51,2 g/L), Fenazaquin (200 g/L), Tébufenpyrad (20%), Propargite (57%), Milbémectine (1%), Bifenthrine (100 g/L), Clofentézine (500 g/L), Pyridabène (100 g/L), Maltodextrine (27%), and Dicofol (18,5%) are the most acaricides used to control the tetranychid mites in greenhouses and orchards [**55**]. In the Loukkos Morocco area, to prevent the *T. urticae*, the majority of strawberry plants are treated with Abamectin [**2**,**54**]. In Tunisia, the main acaricides used to fight *T. urticae* on diverse crops are Hexythiazox 10% WP, Fenpyroximate 50 g/L SC, Abamectin 18 g/L EC, and Pyrethrin 40 g/L EC [**56**]. In Egypt, the use of the Abamectin revealed excellent results and important toxicity on *T. urticae* [**57**]. However, the intensive Abamectin applications have diminished the efficacy and shortened their effect, indicating a potential resistance development problem [**57**,**58**]. The effects of acaricides on *T. urticae* are extensively studied [**59**,**60**]. The intensive and abusive use of acaricides to control this mite has driven an increasingly important resistance against carbamates, cyclodiene organochlorine, organophosphates pyrethroids, organotin miticides, benzoylureas, organochlorines, hydrazine carbazate, macrocyclic lactones, and other chemical products [**61**]. Other effects have been noticed, such as alterations in the physiology and biology of living organisms and modification of fecundity and behavior [**62**]. To overcome this difficulty, the experts are constantly exploring new products based on biological control, particularly biopesticides [**23**,**63**].

4.2 Biological Control

Biological control agents such as bacteria, predatory insects, or fungi can be used as alternative approaches for control [**64**]. Bacterial organisms, such as *Yersinia entomophaga*, *Xenorhabdus* spp. *Pseudomonas entomophila*, *Burkholderia* spp. *Chromobacterium* spp. *Streptomyces* spp. *Saccharopolyspora* spp., and *Bacillus* spp. have all recently gained commercial interest for the production of diverse metabolites that act as effective insecticides [**65**]. Secondary metabolites of fungi, such as *Aspergillus melleus*, *Emericella nidulans* G. Winter, 1884, *Alternaria terreus*, *Chaetomium globosum*, *Trichoderma viridae*, and *Eurotium eurotiorum* are a promising source of control against various agricultural pests [**66**].

The most important predators that have significantly managed *T. urticae* and other spider mites are *Amblyseius swirskii* (Athias-Henriot, 1962), *Typhlodromus rhenanoides* (Athias Henriot, 1960), *Phytoseiulus persimilis* (Athias-Henriot,1957), *T. phialatus* (Athias Henriot, 1960), *Neoseiulus cucumeris* (Oudemans, 1930), *Neoseiulus stolidus* (Chaudhri, 1968), *Feltiella acarisuga* (Vallot,1827), *Scolothrips longicornis* (Priesner, 1926), *Euseius scutalis* (Athias Henriot, 1958), *Euseius stipulatus* (Athias Henriot, 1960), and *Stethorus punctillum* (Julius Weise, 1891) [**5**,**59**].

4.2.1 Myco-Metabolites

The fungal isolates of *Aspergillus melleus*, *Emericella nidulans*, *Chaetomium globosum*, and *Aspergillus terreus* presented practical control activities against females and eggs of two-spotted spider mite [**66**]. The effect of culture filtrates of fungal isolates showed mortality rates of 52.4%, 52.4%, 48.4%, and 50.4%, exhibited by *Alternaria terreus*, *A. alternata, Trichoderma viridae*, and *Eurotium eurotiorum*, respectively [**67**]. Further, the laboratory evaluation showed these secondary metabolites of *A. melleus*; (nodulisporic acid, mellamide; ochratoxin C, 7-oxocurvularin,6-(4′-hydroxy-2′-methyl phenoxy)- (−)-(3R)-mellein and 7-oxocurvularin can be used as biopesticides in the biological control of *T. urticae* [**66**]. Similarly, the *Azadirachta indica* (neem oil) extract registered that the mortality proportion of adults was 100% at all tested concentrations after 72 h of application [**68**]. In Spain, *Beauveria bassiana* gave impressive results in the control of *T. urticae*, and therefore is a candidate to be included in integrated pest management programs with triflumuron against *T. urticae* [**69**].

4.2.2 Bacterial Metabolite

The essential secondary metabolites implicated in biocontrol by fluorescent pseudomonads are pyoluteorin (PLT), phenazines (PHZ), 2, 4-diacetylphloroglucinol (DAPG), cyclic lipopeptides (CLPs), pyrrolnitrin (PRN), and volatile natural composites (VOCs) such as hydrogen cyanide (HCN). These metabolites are recognized for antibacterial, antifungal, antiviral, antitumor, and antinematicidal properties [**63**]. A study in Morocco at the laboratory showed that all three fluorescent pseudomonas isolates Q110B, Q036B, and Q172B from tomato rhizospheric soil were potential biological control agents for *T. urticae*. In particular, *Pseudomonas fluorescens* isolate Q036B was the most promising applicant for biological control of *T. urticae* with a mortality rate of approximately 99% 72 h after application. For the other two strains (Q172B and Q110B), the mortality rates were similar 72 h after application and varied from 54 to 89% [**23**]. Besides, the *P. fluorescens* produces

bacterial chitinases, which are efficient in controlling the mites by hydrolyzing their chitinous exoskeleton, the culture with cent percent of *P. fluorescens* produced 100% mortality of spider mite in 24 h after application, whereas 75% culture yielded 100% mortality in 72 h, when 48 h, 50% culture was found to be least effective [**70**]. In Turkey, under laboratory conditions, *Pseudomonas putida* isolated from tomato soils produced high mortality rates of *T. urticae*. This bacterial application significantly diminished the total number of eggs and egg hatch compared to the control [**71**]. Thus, multiple *Agrobacterium* strains, *Streptomyces*, *Bacillus*, *Pseudomonas*, *Alcaligenes*, and others have been notified as help bacterial control agents. To fight against pests, they employ many biotechniques, for example competition, parasitism, antibiosis, and cross-protection [**72**,**73**].

4.2.3 Protectants Plant-Incorporated (PIP)

The extracts of plants are remarkably rich in toxins and inhibitors and can be the source of many insecticidal and acaricidal substances exploitable in the control of pests [**74**,**75**]. Black soap, brown in color, is biodegradable, non-polluting, and an excellent insecticide. This product is active on some insects such as mealy bugs, aphids, whiteflies, thrips, mites, etc. Through simple contact, it asphyxiates them while blocking the respiratory pores. Besides, it does not produce toxic residues and does not affect natural predators. These products are authorized by the specifications of organic agriculture (EEC regulation 2092/91) [**76**,**77**]. A study conducted in the Saïs region of Morocco showed that black soap was effective against several pest populations on the bell pepper crop compared to the control block [**77**].

The utilization of Sulfur on tomato leaves diminished *T. urticae* from 31.5 ± 6.5 individuals/15 leaves before treatment to 4 ± 0.3 [**78**]. This reinforces the results observed on the grapevine [**79**], according to which sulfur can be used to control mites while presenting low toxicity to predators. Another study under laboratory conditions confirms that sulfur is toxic against eggs of *T. urticae* [**80**]. In the field, the lime sulfur reduced *T. urticae* fecundity and fertility. It showed selectivity against naturally occurring predatory mites, which increases its potential as a mechanism for integrated mite management [**78**].

The pesticide effects of the diverse specific components of *Achillea mellifolium* essential oil have been assessed in recent studies. Piperitone [**81**], cymene, borneol [**82**], bornyl acetate [**83**], 1,8-cineole, α-pinene [**84**], α-terpinolene [**85**], camphene [**86**], α-terpinene [**87**], and carvacrol [**88**] revealed prospective pesticidal effects. Besides, the susceptibility of *T. urticae* to some monoterpenes has been reported [**82**,**84**,**86**,**89**]. According to the apparent results in the laboratory condition, it can be concluded that the major component of essential oil of *A.*

millefolium is responsible for the acaricidal action against *T. urticae* and may be useful in the exploration of the effective natural products such as acaricide [**90**]. *Mentha* sp. essential oils can be used in sustainable pest control. In Egypt, under greenhouse conditions, *Mentha longifolia* showed 100% toxicity to *T. urticae* [**91**]. In Algeria, the essential oils obtained from *Mentha spicata* presented a better insecticidal impact against most pests [**92**]. The sesquiterpenoids isofuranodiene and germacrone from the crucial oil of *Smyrnium olusatrum* (Apiaceae) recorded significant oviposition inhibition, and they can be used to produce adequate acaricides [**93**]. In Tunisia, field experiments, the extracts of three plant species (*Allium sativum*, *Allium cepa*, and *Deverra scoparia*) produced an effective control of *T. urticae* population more than 15 days compared with the untreated control and with classical synthetic acaricides (spirodiclofen and fenbutatin oxide) [**75**,**94**]. Besides, the tests have revealed that the extract of *A. sativum* was efficient on the population of *T. urticae* was diminished to 1.7 mites per leaf for more than 21 days after treatment compared with the untreated control at 3.7 mites per leaf [**50**].

The laboratory tests showed that the fumigant toxicity of 24 essential oils from lemon eucalyptus was effective against females of *T. urticae* menthol being the maximum toxic compound, followed by citronellyl acetate [**95**]. The two eucalyptus essential oils, specifically *Eucalyptus lehmani* and *Eucalyptus astringens*, showed a positive effect against strains from Tunisia and Algeria of three stocked beetles: *Rhyzopertha dominica*, *Callosobruchus maculatus*, and *Tribolium castaneum* [**96**]. In Tunisia, the ten principal constituents of *Deverra scoparia* oil were individually tested against *T. urticae* females. The greatest toxicity was found with alpha-pinene, 3-carene, and terpinen-4-ol. pinene. The presence of all elements together in the artificial mixture caused a notable reduction in the number of eggs laid by females of *T. urticae*. The essential oil of *D. scoparia* showed that female mortality increased with growing oil concentrations, and a decline in fecundity had been observed. *Deverra scoparia* might add to the arsenal of programs for controlling mites in open field and in greenhouses. However, further studies are needed to evaluate the cost, efficiency, and safety of the oil, besides knowing each constituent's role in the toxicity and effects on fecundity [**97**]. In laboratories growing wild in the Mediterranean area, the mortality rates of 95–100% were observed at all the sage oil dosages and when rosemary emulsions contained at least 0.20% essential oils [**98**]. In the laboratory sage, the essential oil had raised mortality (toxicity to adult females of *T. urticae*) and diminished fecundity (production and viability of eggs) [**98**]. The essential oils lose their force against environmental conditions. Nanoformulation is a method that may preserve the pesticide

performance of plant essential oils. The Chitosan nanocapsules loaded with the essential oil of *Achillea millefolium* against adult *T. urticae* showed a beneficial effect [**99**].

4.2.4 Control with Predators

The main predators encountered in North Africa are *Typhlodromus rhenanoides*, *Phytoseiulus persimilis* (Athias-Henriot), 1957, *Typhlodromus phialatus*, *Neoseiulus cucumeris*, *Neoseiulus stolidus*, *Feltiella acarisuga, Scolothrips longicornis, Euseius scutalis,* and *Euseius stipulatus.*

4.2.4.1 Phytoseiulus persimilis (Athias-Henriot, 1957)

Phytoseiulus persimilis (Acari: Phytoseiidae) is a specialist predator that feeds particularly on *Tetranychus* species and whose survival depends on the presence and quality of its prey [**50**]. In Morocco, *P. persimilis* is the principal predators of *T. urticae* in the open field and in greenhouses [**100**], according to faunal estimations performed in 2009–2010 on strawberry plants in the Loukkos region which revealed that the mite pest *T. urticae* and its natural enemy, the predatory mite *P. persimilis*, are habitually encountered [**2**]. In Egypt, this predator is one of the most significant biological control agents against the two-spotted spider mite. This predator can control *T. urticae* on different crops when it releases at low infestation [**6**]. In Turkey, the greenhouse tests were conducted to discover the efficiency of single and combined releases of two predatory, *P. persimilis* and *Neoseiulus californicus* (McGregor, 1954) to control the *T. urticae* on the Soybean plant; the authors concluded that releasing of *P. persimilis* was the best control method among the other combined releases tested to control spider mites. The similar results were found [**101**] in Spain, the release of *P. persimilis* alone was better than combined releases. Generally, *P. persimilis* is an efficient natural enemy in the Mediterranean greenhouse crops to the mite *T. urticae* [**102**].

4.2.4.2 *Neoseiulus californicus* McGregor, 1954

The *Neoseiulus californicus* (Acari: Phytoseiidae) is a cosmopolitan species of Mediterranean climates that tolerate the higher temperatures of semi-arid to arid areas [**103**,**104**]. In Egypt, the *N. californicus* is the natural enemies associated with *T. urticae* [**57**]. In Morocco, the predatory mite *N. californicus* feeds on all stages of the weaver mite *T. urticae* on citrus crops [**105**]. In Tunisia, the *N. californicus* is a predatory Phytoseiidae widely utilized in integrated pest management programs to control the tetranychid mites in citrus,

apple, fruit, and vegetable crops [**106**]. This predator plays a key role in the regulation of *T. urticae* in Spanish citrus orchards [**107**].

4.2.4.3 *Euseius stipulatus* Athias-Henriot, 1960

This species was described from North Africa in Algeria, Morocco, Tunisia [**108**]. It feeds on the red spider and eriophyid mites and consumes pollen [**108**]. In Tunisia, *E. stipulatus* was the most abundant species found on citrus trees (82%) [**20**]. Generally, this species is well represented in Mediterranean citrus orchards [**109**].

4.2.5 Combined Releases

In Egypt, the releasing of predators *Chrysoperla carnea* (Steph, 1836), *Orius albidipennis* (Reuter, 1884), and *P. persimilis* showed significant control of *T. urticae*, and it also assured increased crop yield as compared to pesticide application [**110**]. In Morocco, the new introduction in citrus orchards, such as the predators *Neoseiulus californicus* and *Amblyseius swirskii* against *Eutetranychus orientalis* (Klein, 1936) and *T. urticae* have produced good results [**111**]. Similarly, in Spain, the control of *T. urticae* through releases of the predatory mites *Phytoseiulus persimilis, Neoseiulus californicus, Amblyseius swirskii*, and *Orius laevigatus* Fieber, 1860 (Hemiptera: Anthocoridae) showed significant results. Besides, the combined release of *O. laevigatus* with *A. swirskii* gave efficient control of sweet pepper principal pests [**112**]. The use of *F. acarisuga* (Diptera: Cecidomyidae) and *S. longicornis* (Thysanoptera: Thripidae) play an important role in the control of spider mites populations in different crops [**113**]. In Spain, *Stethorus punctillum* (Weise, 1891) is an important predator of spider mites, especially *Panonychus citri* (McGregor, 1916) and *T. urticae* in citrus orchards [**114**]. *Amblyseius andersoni* (Acari: Phytoseiidae) is an important predator species found in multiple crops. The nymphs and adults of *A. andersoni* are predaceous, feeding on different spider mite species [**115**]. A study confirmed that the use of this predator alone or in combination with other phytosides mites provides better control of spider mites [**116**].

4.3 Physical Control

Integrated pest management should rely on an array of tactics. In reality, the use of physical control methods must be part of an integrated pest management approach. Physical controls can be classified as passive (e.g., fences, organic mulch, trenches, particle films, inert dust, and oils), active (e.g., thermal shocks, electromagnetic radiation, mechanical shocks, and pneumatic

control), and miscellaneous (e.g., cold storage, heated air, flaming, hot-water immersion) [**117**]. Some physical methods such as oils have been used successfully for preharvest treatments for decades [**118**]. Another recently invented method for preharvest situations is particle films [**119**]. As we move from production to the consumer, legal constraints restrict the number of alternatives available. Consequently, several physical control methods are used in postharvest situations. Two notable examples are the entoleter, an impacting machine used to crush all insect stages in flour [**120**], and hot-water immersion, used to kill tephritid fruit flies [**121**].

Over the past decade, UV Perspective, the solar and artificial ultraviolet-B (UVB) radiation, has frequently been shown to exert deleterious impacts on the survival and egg production of mites [**122**]. The eggs and larvae of *T. urticae* are more vulnerable to UVB radiation than adult females, and mortality is directly proportional to the cumulative UVB irradiance [**123**]. Additionally, using the ultraviolet-B method control of spider mites showed excellent results, especially for greenhouse horticultural crops such as strawberries; performing it is a favorable IPM strategy [**124**]. Conversely, the enhanced UV-B radiation increases the deleterious effects on insect behavior and health and affects their interactions with plants via induction of defensive material products and photomorphogenic variations. Insect suction devices, insect glue, and electromagnetic energy suppress insect populations. Generally, the physical control methods are environmentally safe, fit well into IPM strategies, and significantly reduce chemical control [**125**]. These methods are not yet explored in North Africa, but with the similarity of Mediterranean context recorded, we suppose that the good results documented in South Europe could be extrapolated to North Africa.

4.4 Genetic Control

Genetic control is one of the methods that can replace the application of insecticides [**126**]. The examination of the sequenced genome of *T. urticae* will reveal the resistance mechanisms used by the mites. Moreover, the complete sequencing revealed that this genome, considered small with its 90 million bases, includes unique genes that have not yet been identified in other arthropods [**17**]. The researchers also identified numerous genes implicated in detoxification and digestion of toxins, which help explain the mite's unparalleled resistance to toxic compounds produced by certain plants to defend themselves, opening up the prospect of developing naturally resistant plants [**127**].

4.5 Integrated Pest Management of *Tetranychus Urticae*

Integrated pest management through predator and a compatible synthetic acaricide may provide an alternative strategy to chemical control of the pest [**128**]. Experiments were conducted on greenhouse roses to evaluate the efficacy of the nC24 petroleum spray oil (PSO), D-C-Tron in combination with *Phytoseiulus persimilis* (Acarina: Phytoseiidae) against *Tetranychus urticae* in the context of developing an integrated management program. Results showed that 0.5% PSO applied fortnightly to roses provided excellent protection against *T. urticae* infestation and did not affect the population density of *P. persimilis* in the upper and lower foliage [**129**]. In Brazil, on strawberry crops, control of T. urticae in the program based on release of *Neoseiulus californicus* (McGregor) and reduction of the frequency of acaricide applications (IPM) was effective in maintaining a significantly lower level of pest infestation, resulting in a six-fold reduction in the frequency of acaricide applications and, consequently, a reduction in selection pressure for acaricide resistance [**130**]. Another field experiment in hops using b-acid sprays with a release of the predatory mite *P. persimilis* ensured significant control of *T. urticae* [**131**].

Conclusions

This review highlights the current knowledge and prospects of sustainable control approaches against *T. urticae* used in North Africa, to clarify the current situation of this pest and inspire specialists in other countries to control it. In addition, it serves as a roadmap for scientists to expand their research. In terms of plant protection, it is clear from the discussions, developed in our study, that integrated pest management remains the most appropriate sustainable method for better crop protection. Practiced by the majority of Maghrebian countries, chemical control is the most widely used method in commercial agriculture. This is essentially due to economic and technical reasons. Henceforth, the control methods must be based on the use of biopesticides, genetic control, and physical control in an integrated long-term sustainable program. The development of physical control provides interesting opportunities as mechanical control, thermal control, electromagnetic control, and pneumatic controls. Their inclusion in an integrated pest management program can contribute greatly to the achievement of the pesticide reduction objectives set by several countries and organizations. In this context, responsible agricultural organizations should actively support the development and implementation of physical control methods in integrated pest and plant protection management programs. Genetic modifications of plants and mites could be performed to improve the molecular mechanisms that control the plant–mite interplay. An advanced understanding of the mite–plant interaction will be an effective tool for protection. The

advances are also expected in light of pest control due to these technological developments in lighting. Finally, the current trend is to combine all these methods in an integrated pest management strategy. These programs must take into count the climate conditions, phenology of pests, infestation rates, and propagation speed of pests in each North African country. All these elements are suggested to control pests, respect the environment and public health.

Author Contributions
Conceptualization, A.A. and A.L.; methodology, M.K., A.R., S.B. and Y.B.K.; data curation, H.M.; writing—original draft preparation, A.A.; writing—review and editing K.R.A. and O.M.N.; supervision, A.L. and A.F. All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by the Deanship of Scientific Research Sana'a University.

Institutional Review Board Statement
Not applicable.

Informed Consent Statement
Not applicable.

Data Availability Statement
Data are available upon request.

Acknowledgments
Open access funding provided by University of Helsinki.

Conflicts of Interest
The authors declare no conflict of interest.

References

1. La FAO et l'UMA Signent Un Accord d'assistance Technique Pour Lutter Contre Les Ravageurs et Les Maladies Des Cultures En Afrique Du Nord. 2016. Available online: **https://www.fao.org/neareast/news/view/fr/c/418095/** (accessed on 30 January 2022).
2. Lagziri, M.; Benicha, M.; M'rabet, R.; Amrani, A. El Influence de l'usage Préventif Des Pesticides Sur Les Acariens *Tetranychus urticae* et *Phytoseiulus persimilis* (Acari: Tetranychidae, Phytoseiidae) Présents En Cultures de Fraisiers Du Nord Du Maroc. *Biotechnol. Agron. Soc. Environ.* **2015**, *19*, 355–363.
3. Xue, W.; Snoeck, S.; Njiru, C.; Inak, E.; Dermauw, W.; Van Leeuwen, T. Geographical Distribution and Molecular Insights into Abamectin and Milbemectin Cross-Resistance in European Field Populations of *Tetranychus urticae*. *Pest Manag. Sci.* **2020**, *76*, 2569–2581.
4. Vacante, V. The Handbook of Mites of Economic Plants: Identification, Bio-Ecology. Available online: **https://books.google.co.ma/books?hl=fr&lr=&id=yc4_CwAAQBAJ&oi=fnd&pg=PR3&dq=Vacante+V.+2016+—+The+handbook+of+mites+of+economic+plants++Wallingford:+CABI+Publishing.+p&ots=owucks8JhR&sig=1Q-_htz0V9EuSINyaxQ7C7D9RPs&redir_esc=y#v=onepage&q&f=false** (accessed on 17 October 2021).
5. Sim, C.; Seo, E.; Cho, K. Life Table and Sensitivity Analysis as Fitness Evaluation Method of Fenpyroximate and Pyridaben Resistant Twospotted Spider Mite (*Tetranychus urticae* Koch). *J. Asia-Pac. Entomol.* **2003**, *6*, 193–199.
6. Seham, A.; El-Dein, E.; Azouz, H.A.A.; Amira, E.M.; Doaa, A.A.E.-A. Provided for Non-Commercial Research and Education Use. Not for Reproduction, Distribution or Commercial Use. *Hepatoprotective Agents Rats* **2020**, *12*, 25–40.
7. Mariéthoz, J.; Baillod, M.; Christian Linder, P.; Antonin, C.M. Distribution, Méthodes de Contröle et Stratégies de Lutte Chimique et Biologique Contre l'acarien Jaune, "*Tetranychus urticae*" Koch, Dans Les Cultures de Framboisiers-Dialnet. Available online: **https://dialnet.unirioja.es/servlet/articulo?codigo=2984817** (accessed on 16 April 2021).
8. Gulati, R. Incidence of Tetranychus cinnabarinus (Boisd.) Infestation in Different Varieties of *Abelmoschus Esculentus* L. Available online: **https://agris.fao.org/agris-search/search.do?recordID=IN2004000229** (accessed on 16 April 2021).

9. Reddy, G.V.P.; Baskaran, P. Damage Potential of the Spider Mite *Tetranychus ludeni* (Acari: Tetranychidae) on Four Varieties of Eggplant. *Int. J. Trop. Insect Sci.* **2006**, *26*, 48–56.
10. Acari, K.; Tomato, T. Growth Stage Based Economic Injury Levels for Two Spotted Spider *Lycopersicon Esculentum* Mill. *Trop. Agric. Res.* **2010**, *22*, 54–65.
11. Haque, M.; Islam, T.; Naher, N.; Mainul Haque, M. Seasonal Abundance of Spider Mite Tetranychus *urticae* Koch on Vegetable and Ornamental Plants in Rajshahi. *Univ. J. Zool. Rajshahi Univ.* **2011**, *30*, 37–40.
12. Silva, E.A.; Reis, P.R.; Carvalho, T.M.B.; Altoé, B.F. *Tetranychus urticae* (Acari: Tetranychidae) on Gerbera Jamesonii Bolus and Hook (Asteraceae). *Braz. J. Biol.* **2009**, *69*, 1121–1125.
13. Logan, J.G.; Birkett, M.A. Juvenile Hormonal Activity of Mono- and Polyenehomobenzenes in *Drosophila virilis*, Spodoptera Frugiperda and Araschnia Levana. *Pest Manag. Sci.* **2007**, *63*, 809–814. [**CrossRef**]
14. Abdallah, A.M.; Ismail, M.S.M.; AboGhalia, A.H.; Soliman, M.F.M. Factors Affecting Population Dynamics of *Tetranychus urticae* and Its Predators on Three Economic Plants in Ismailia, Egypt. *Int. J. Trop. Insect Sci.* **2019**, *39*, 115–124.
15. Youssef, A.T.A.; El-Badry, E.A.; Heykal, I.H. Mites Inhabiting Cotton and Associated Weeds in Egypt (Acarina). Available online: **https://agris.fao.org/agris-search/search.do?recordID=US201301297861** (accessed on 17 April 2021).
16. Shaabow, A.; Ahmad, M.; Zidan, R. The Biological Control of Two Spotted Spider Mites Using the Predatory Mite on Bean Grown under Greenhouse Conditions. *Int. J. Agric. Environ. Sci.* **2019**, *6*, 63–69.
17. Grbić, M.; Van Leeuwen, T.; Clark, R.M.; Rombauts, S.; Rouzé, P.; Grbić, V.; Osborne, E.J.; Dermauw, W.; Ngoc, P.C.T.; Ortego, F.; et al. The Genome of *Tetranychus urticae* Reveals Herbivorous Pest Adaptations. *Nature* **2011**, *479*, 487–492.
18. Nachman, G.; Zemek, R. Interactions in a Tritrophic Acarine Predator-Prey Metapopulation System V: Within-Plant Dynamics of *Phytoseiulus persimilis* and *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae). *Exp. Appl. Acarol.* **2003**, *29*, 35–68.
19. Fakhour, S. L'acarien Jaune, *Tetranychus urticae* Koch. (Acari: Tetranychidae) Sur Maïs Fourrager Au Maroc: Impact et Stratégies de Lutte. In Proceedings of the Deuxième Colloque sur les Acariens des Cultures, Montpellier, France, 24–25 October 2005.
20. Sahraoui, H. Influence Des Pratiques Agro-Écologiques et de La Protection Phytosanitaire Sur Les Communautés d'acariens Phytoseiidae (Acari: Mesostigmata) Dans Les Vergers Agrumicoles Tunisiens. Available online: **https://www.supagro.fr/theses/extranet/12-0026_Sahraoui.pdf** (accessed on 17 June 2021).
21. Attia, S.; Gratia, E.; De Herde, A.; Hensen, J.L.M. Simulation-Based Decision Support Tool for Early Stages of Zero-Energy Building Design. *Energy Build.* **2012**, *49*, 2–15.
22. Lu, W.; Wang, M.; Xu, Z.; Shen, G.; Wei, P.; Li, M.; Reid, W.; He, L. Adaptation of Acaricide Stress Facilitates *Tetranychus urticae* Expanding against *Tetranychus cinnabarinus* in China. *Ecol. Evol.* **2017**, *7*, 1233–1249.
23. Qessaoui, R.; Bouharroud, R.; Amarraque, A.; Ajerrar, A.; El Hassan, M.; Chebli, B.; Dadi, M.; Elaini, R.; El Filali, F.; Walters, A.S. Ecological Applications of Pseudomonas as a Biopesticide to Control Two-Spotted Mite *Tetranychus urticae*: Chitinase and HCN Production. *J. Plant Prot. Res.* **2017**, *57*, 409–416.
24. Tsagkarakou, A.; Pasteur, N.; Cuany, A.; Chevillon, C.; Navajas, M. Mechanisms of Resistance to Organophosphates in *Tetranychus urticae* (Acari: Tetranychidae) from Greece. *Insect Biochem. Mol. Biol.* **2002**, *32*, 417–424.
25. Tehri, K. *A Review on Reproductive Strategies in Two Spotted Spider Mite*; AkiNik Publications: New Delhi, India, 2014; Volume 2, pp. 35–39.
26. Overmeer. Alternative Prey and Other Food Resources. *Spider Mites Biol. Nat. Enemies Control* **1985**, *1*, 131–139.
27. Sedaratian, A.; Fathipour, Y.; Moharramipour, S. Comparative Life Table Analysis of *Tetranychus urticae* (Acari: Tetranychidae) on 14 Soybean Genotypes. *Insect Sci.* **2011**, *18*, 541–553.

28. Jafari, S.; Fathipour, Y.; Faraji, F. Temperature-Dependent Development of *Neoseiulus barkeri* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae) at Seven Constant Temperatures. *Insect Sci.* **2012**, *19*, 220–228.
29. Golizadeh, A.; Ghavidel, S.; Razmjou, J.; Fathi, S.A.A.; Hassanpour, M. Comparative Life Table Analysis of *Tetranychus urticae* Koch (Acari: Tetranychidae) on Ten Rose Cultivars. *Acarologia* **2017**, *57*, 607–616.
30. Gutierrez, J. *Etude Biologique et Écologique de, Tetranychus neocaledonicus André (Acariens, Tetrmychidae)*; ORSTOM: Paris, France, 1976.
31. Luo, Z. Analysis of the effect of reasonable close planting on respiration characteristics of alfalfa (*Medicago sativa* l.) artificial grassland. *Turk. J. Agric. For.* **2021**, *45*, 533–540.
32. Allam, L.; Hmimina, M. Potentialités de Développement De *Tetranychus urticae* Koch (Tetranychidae, Acari) Sur Quelques Hôtes Sauvages et Cultivés. *Rev. Maroc. Des Sci. Agron. Et Vétérinaires* **2011**, *14*, 37–44.
33. Golan, K.; Jurado, I.G.; Kot, I.; Górska-Drabik, E.; Kmieć, K.; Łagowska, B.; Skwaryło-Bednarz, B.; Kopacki, M.; Jamiołkowska, A. Defense Responses in the Interactions between Medicinal Plants from Lamiaceae Family and the Two-Spotted Spider Mite *Tetranychus urticae* Koch (Acari: Tetranychidae). *Agronomy* **2021**, *11*, 438.
34. İçli, N.; Tahmas Kahyaoğlu, D. Investigation of pesticide residues in fresh sultani grapes and antioxidant properties of fresh/sun-dried/oven-dried grapes. *Turk. J. Agric. For.* **2020**, *44*, 350–360.
35. Farida, B. Usages Des Produits Phytosanitaires Dans Les Cultures Sous Serres Des Ziban (Algérie) et Évaluation Des Conséquences Environnementales Possibles. Ph.D. Thesis, Université Mohamed Kheider-Biskra, Biskra, Algeria, 2017; pp. 2016–2017.
36. Migeon, A.; Nouguier, E.; Dorkeld, F.; Cbgp, U.M.R.; Ird, I.; Montpellier, C.; Cedex, M. *Trends in Acarology. Trends in Acarology: Proceedings of the 12th International Congress*; Springer: Dordrecht, The Netherlands, 2010; pp. 557–560.
37. Hmimina, M.; Allam, L.; Ougass, Y.; Marmouche, A. Circonstances Des Pullulations de *Tetranychus urticae* Koch (Tetranychidae: Acarina) En Verger d'agrumes. *IOBC/Wprs Bull.* **1995**, *18*, 35.
38. Naher, N.; Islam, W.; Haque, M.M. Predation of Three Predators on Two-Spotted Spider Mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). *J. Life Earth Sci.* **2005**, *1*, 1–4.
39. FAO Strategie en Afrique FAO 2018–2021. 2018. Available online: **Https://www.fao.org/documents/card/fr/c/04da353a-9da5-407a-8401-b5a920390a9b/** (accessed on 2 January 2022).
40. Mohammed, K.; Karaca, İ.; Agarwal, M.; Newman, J.; Ren, Y. Age-specific life tables of *Aonidiella aurantii* (Maskell) (hemiptera: Diaspididae) and its parasitoid *Aphytis melinus* debach (hymenoptera: Aphelinidae). *Turk. J. Agric. For.* **2020**, *44*, 180–188.
41. Baiomy, F. Efficiency of Modern Methods for Controlling Some Vegetable Pests in Greenhouses in Egypt and Morocco. Ph.D Thesis, Cairo University, Caire, Egypt, Ins. African Res. Studies. 2008; pp. 154–157. Available online: **https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Baiomy%2C+Fatina%2C+A.+M.+2008.+Efficiency+of+modern+methods+for+controlling+some+vegetable+pests+in+greenhouses+in+Egypt+and+Morocco.PhD+.Thesis%2C+Ins.+African+Res.+Studies%2C+Cairo+Univ.+154pp.+7** (accessed on 28 June 2021).
42. Shalaby, F.F.; Ali, F.A.; Hafez, A.A.; Saad, H.M. Planting Date in Relation To Insect and Animal Pests Attacking Cucumber Plants Under Protected Cultivation At Giza Governorate. *Egypt. J. Agric. Res.* **2013**, *91*, 1347–1360.
43. Brandenburg, R.L.; Kennedy, G.G. Intercrop Relationships and Spider Mite Dispersal in a Corn/Peanut Agro-Ecosystem. *Entomol. Exp. Et Appl.* **1982**, *32*, 269–276.
44. Gerson, U.; Aronowitz, A. Feeding of the carmine spider mite on seven host plant species. *Entomol. Exp. Et Appl.* **1980**, *28*, 109–115.
45. Chandler, L.D.; Archer, T.L.; Ward, C.R.; Lyle, W.M. Influences of Irrigation Practices on Spider Mite Densities on Field Corn. *Environ. Entomol.* **1979**, *8*, 196–201.

46. Vicente, C.; Joutei, A.B.; Lebrun, P. What Strategies to Use against Mite Pests of Apple in Morocco? *Parasitica* **2004**, *59*, 25–41.
47. Farouk, S.; Osman, M. Alleviation of Oxidative Stress Induced by Spider Mite Invasion through Application of Elicitors in Bean Plants. *Egypt. J. Biol.* **2012**, *14*, 1–13.
48. Saba, F. (Chef du Laboratoire d'Entomologie, Phytiatlie, Direction de la Recherche Agronomique, Rabat, Maroc.). *Aux Plantes Cultiv. Au Maroc.* **1973**, *49*, 69–97.
49. Abo-Elmaged, T.M.; Ali, A.W.M.; Abdel-Rahman, M.A.A.; Abd-Allah, A.H.A. Activity of the Two Spotted Spider Mite, *Tetranychus urticae* (Koch) (Acari) Infesting Cucumber Plants in Upper Egypt. *Int. J. Trop. Insect Sci.* **2021**, *41*, 463–469.
50. Attia, S.; Grissa, K.L.; Lognay, G.; Bitume, E.; Hance, T.; Mailleux, A.C. A Review of the Major Biological Approaches to Control the Worldwide Pest *Tetranychus urticae* (Acari: Tetranychidae) with Special Reference to Natural Pesticides: Biological Approaches to Control *Tetranychus Urticae*. *J. Pest Sci.* **2013**, *86*, 361–386.
51. Vicente, C.; Boutaleb, A.; Lebrun, P.H. Quelles Stratégies de Lutte Contre Les Acariens Ravageurs Du Pommier Au Maroc. *Parasitica* **2003**, *59*, 25–41.
52. Van Leeuwen, T.; Vontas, J.; Tsagkarakou, A.; Dermauw, W.; Tirry, L. Acaricide Resistance Mechanisms in the Two-Spotted Spider Mite *Tetranychus urticae* and Other Important Acari: A Review. *Insect Biochem. Mol. Biol.* **2010**, *40*, 563–572.
53. Ball, J.C. Impact of Fungicides and Miticides on Predatory and Phytophagous Mites Associated with Pecan Foliage. *Environ. Èntomol.* **1982**, *11*, 1001–1004.
54. Roy, M. État Actuel De La Lutte Biologique Contre Les Acariens Phytophages Par Des Acariens Prédateurs. *Phytoprotection* **2005**, *74*, 41–49.
55. ONSSA Commission Des Pesticides à Usage Agricole. Available online: **http://eservice.onssa.gov.ma/CPUA.aspx** (accessed on 10 April 2021).
56. Active, M.; Agro, S.; Pro, M.; Moussem, E.L. Liste Des Pesticides Homologués En Tunisie. 2017. Available online: **http://www.agridata.tn/dataset/liste-des-pesticides-homologues-en-tunisie** (accessed on 22 April 2021).
57. Dar Rehab, A.A.; Hala, H.A. Field Comparison between Tow Natural Compounds and a Common Acaricide on Two-Spotted Spider Mite, *Tetranychus urticae* and Three of Its Natural Enemies by Using Certain Ground Spraying Equipment on Soybean Crop in Egypt. *Egypt. Acad. J. Biol. Sci.* **2020**, *434*, 138–142.
58. Sato, M.E.; da Silva, M.Z.; Raga, A.; De Souza Filho, M.F. Abamectin Resistance in *Tetranychus urticae* Koch (Acari: Tetranychidae): Selection, Cross-Resistance and Stability of Resistance. *Neotrop. Entomol.* **2005**, *34*, 991–998.
59. Castagnoli, M.; Liguori, M.; Simoni, S.; Duso, C. Toxicity of Some Insecticides to *Tetranychus urticae*, *Neoseiulus californicus* and *Tydeus californicus*. *BioControl* **2005**, *50*, 611–622. [**Google Scholar**] [**CrossRef**]
60. Abo-Elmaged, T.M. Cucumber Plant Mites: Survey and Capacity of Certain Pesticides against the amplest one, *Tetranychus urticae* Koch, in Assiut area, Upper Egypt. *Egypt. Acad. J. Biol. Sciences. A Entomol.* **2020**, *13*, 237–242.
61. IRAC Mode of Action Classification | Insecticide Resistance Action Committee (IRAC). Available online: **https://irac-online.org/mode-of-action/** (accessed on 5 October 2021).
62. Gashout, H.A.; Goodwin, P.H.; Guzman-Novoa, E. Lethality of Synthetic and Natural Acaricides to Worker Honey Bees (*Apis mellifera*) and Their Impact on the Expression of Health and Detoxification-Related Genes. *Environ. Sci. Pollut. Res.* **2018**, *25*, 34730–34739.
63. Mishra, J.; Arora, N.K. Secondary Metabolites of *Fluorescent pseudomonads* in Biocontrol of Phytopathogens for Sustainable Agriculture. *Appl. Soil Ecol.* **2018**, *125*, 35–45.
64. Hamza, A.; Mohamed, A.; Derbalah, A. Unconventional Alternatives for Control of Tomato Root Rot Caused by Rhizoctonia Solani under Greenhouse Conditions. *J. Plant Prot. Res.* **2016**, *56*, 298–305.
65. Ruiu, L. Insect Pathogenic Bacteria in Integrated Pest Management. *Insects* **2015**, *6*, 352–367.

66. Osman, M.E.; Abo Elnasr, A.A.; Nawar, M.A.; Hefnawy, G.A. Myco-Metabolites as Biological Control Agents against the Two-Spotted Spider Mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). *Egypt. J. Biol. Pest Control* **2019**, *29*, 64.
67. Mehdi, H.M.R. The Effect of Some Fungi in Biocontrol in Two Spotted Spider Mite *Tetranychus urticae* (Koch.) (Tetranychidae: Acari). *J. Basrah Res. (Sci.)* **2006**, *32*, 12–26.
68. Hanash, A.A.; Hanawi, M.J.; Hamad, B.S.H. Laboratory Based Bioefficacy of Selected Biopesticides Against the Adults and Nymphs of Two-Spotted Spider Mite *Tetranychus urticae* Koch (Acari: Tetranychidae). *Plant Arch.* **2020**, *20*, 3965–3971.
69. Saenz-De-Cabezon Irigaray, F.J.; Marco-Mancebón, V.; Pérez-Moreno, I. The Entomopathogenic Fungus Beauveria Bassiana and Its Compatibility with Triflumuron: Effects on the Twospotted Spider Mite *Tetranychus urticae*. *Biol. Control* **2003**, *26*, 168–173.
70. Roobakkumar, A.; Babu, A.; Kumar, D.V. Pseudomonas Fluorescens as an Efficient Entomopathogen against *Oligonychus coffeae* Nietner (Acari: Tetranychidae) Infesting Tea. *J. Entomol.* **2011**, *3*, 73–77.
71. Aksoy, H.M.; Ozman-Sullivan, S.K.; Ocal, H.; Celik, N.; Sullivan, G.T. The Effects of Pseudomonas Putida Biotype B on *Tetranychus urticae* (Acari: Tetranychidae). *Exp. Appl. Acarol.* **2008**, *46*, 223–230.
72. Shoda, M. Bacterial Control of Plant Diseases. *J. Biosci. Bioeng.* **2000**, *89*, 515–521.
73. Basaid, K.; Chebli, B.; Mayad, E.H.; Furze, J.N.; Bouharroud, R.; Krier, F.; Barakate, M.; Paulitz, T. Biological Activities of Essential Oils and Lipopeptides Applied to Control Plant Pests and Diseases: A Review. *Int. J. Pest Manag.* **2020**, *67*, 155–177. [**Google Scholar**] [**CrossRef**]
74. Isman, M.B.; Wan, A.J.; Passreiter, C.M. Insecticidal Activity of Essential Oils to the Tobacco Cutworm, *Spodoptera litura*. *Fitoterapia* **2001**, *72*, 65–68.
75. Hance, T.; Attia, S.; Grissa, K.; Ghrabi-Gammar, Z.; Mailleux, A.; Lognay, G.; Goff, G. Contrôle de *Tetranychus urticae* Par Les Extraits de Plantes En Vergers d'agrumes. *Entomol. Faun. Faun. Entomol.* **2010**, *63*, 229–235.
76. Daniel, C.; Wyss, E.C.L. Applications de Soufre En Automne: Une Nouvelle Manière de Lutter Contre Lériophyide à Galles Du Poirier. *Rev. Suisse Vitic. Arboric. Hortic.* **2004**, *36*, 199–203.
77. Boutaleb Joutei, A.; Bassy, F. Essais de Lutte Chimique et Biologique Contre Les Acariens (Tetranychus urticae Koch) et Les Pucerons (Myzus persicae Sulzer) Sur Cultures Maraîchères Dans La Région Du Saïs. Trav. L'institut Sci. Série Zool. 2009. Available online: **https://www.researchgate.net/profile/Abdelmalek_Boutaleb_Joutei/publication/321225400_Essais_de_lutte_chimique_et_biologique_contre_les_acariens_Tetranychus_urticae_Koch_et_les_pucerons_Myzus_persicae_Sulzer_sur_cultures_maraicheres_dans_la_region_du_Sais** (accessed on 28 April 2021).
78. Vacacela Ajila, H.E.; Oliveira, E.E.; Lemos, F.; Haddi, K.; Colares, F.; Marques Gonçalves, P.H.; Venzon, M.; Pallini, A. Effects of Lime Sulfur on *Neoseiulus californicus* and *Phytoseiulus macropilis*, Two Naturally Occurring Enemies of the Two-Spotted Spider Mite *Tetranychus urticae*. *Pest Manag. Sci.* **2020**, *76*, 996–1003.
79. Kreiter, S. Action Du Soufre Sur Les Acariens Phytophages et Prédateurs En Viticulture: Étude Bibliographique et Perspectives de Recherches. 1987. Available online: **https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=8311741** (accessed on 26 June 2021).
80. Guichou, S.; Auger, P.; Kreiter, S. The Acaricidal Effect of Sulfur on Tetranychus urticae (Acari: Tetranychidae) under Laboratory Conditions. *Int. Congr. Acarol.* 2002. Available online: **https://hal.archives-ouvertes.fr/hal-01231316** (accessed on 29 June 2021).
81. Ketoh, G.K.; Koumaglo, H.K.; Glitho, I.A.; Huignard, J. Comparative Effects of *Cymbopogon schoenanthus* Essential Oil and Piperitone on Callosobruchus Maculatus Development. *Fitoterapia* **2006**, *77*, 506–510.
82. Miresmailli, S.; Bradbury, R.; Isman, M.B. Comparative Toxicity of *Rosmarinus officinalis* L. Essential Oil and Blends of Its Major Constituents against *Tetranychus urticae* Koch (Acari: Tetranychidae) on Two Different Host Plants. *Pest Manag. Sci.* **2006**, *62*, 366–371.

83. Kordali, S.; Aslan, I.; Çalmaşur, O.; Cakir, A. Toxicity of Essential Oils Isolated from Three Artemisia Species and Some of Their Major Components to Granary Weevil, *Sitophilus granarius* L. (Coleoptera: Curculionidae). *Ind. Crops Prod.* **2006**, *23*, 162–170.
84. Roh, H.S.; Lee, B.H.; Park, C.G. Acaricidal and Repellent Effects of Myrtacean Essential Oils and Their Major Constituents against *Tetranychus urticae* (Tetranychidae). *J. Asia-Pac. Entomol.* **2013**, *16*, 245–249.
85. Cheng, S.S.; Chua, M.T.; Chang, E.H.; Huang, C.G.; Chen, W.J.; Chang, S.T. Variations in Insecticidal Activity and Chemical Compositions of Leaf Essential Oils from Cryptomeria Japonica at Different Ages. *Bioresour. Technol.* **2009**, *100*, 465–470.
86. Badawy, M.E.I.; El-Arami, S.A.A.; Abdelgaleil, S.A.M. Acaricidal and Quantitative Structure Activity Relationship of Monoterpenes against the Two-Spotted Spider Mite, *Tetranychus urticae*. *Exp. Appl. Acarol.* **2010**, *52*, 261–274.
87. Park, H.M.; Kim, J.; Chang, K.S.; Kim, B.S.; Yang, Y.J.; Kim, G.H.; Shin, S.C.; Park, I.K. Larvicidal Activity of Myrtaceae Essential Oils and Their Components against Aedes Aegypti, Acute Toxicity on Daphnia Magna, and Aqueous Residue. *J. Med. Entomol.* **2011**, *48*, 405–410.
88. Kordali, S.; Cakir, A.; Ozer, H.; Cakmakci, R.; Kesdek, M.; Mete, E. Antifungal, Phytotoxic and Insecticidal Properties of Essential Oil Isolated from Turkish Origanum Acutidens and Its Three Components, Carvacrol, Thymol and p-Cymene. *Bioresour. Technol.* **2008**, *99*, 8788–8795.
89. Roh, H.S.; Lim, E.G.; Kim, J.; Park, C.G. Acaricidal and Oviposition Deterring Effects of Santalol Identified in Sandalwood Oil against Two-Spotted Spider Mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). *J. Pest Sci.* **2011**, *84*, 495–501.
90. Ebadollahi, A.; Jalali-Sendi, J.; Razmjou, J. Toxicity and Phytochemical Profile of Essential Oil from Iranian *Achillea mellifolium* L. against *Tetranychus urticae* Koch (Acari: Tetranychidae). *Toxin Rev.* **2016**, *35*, 24–28.
91. Abdelgaleil, S.A.M.; Badawy, M.E.I.; Mahmoud, N.F.; Marei, A.E.S.M. Acaricidal Activity, Biochemical Effects and Molecular Docking of Some Monoterpenes against Two-Spotted Spider Mite (*Tetranychus urticae* Koch). *Pestic. Biochem. Physiol.* **2019**, *156*, 105–115.
92. Brahmi, F.; Adjaoud, A.; Marongiu, B.; Falconieri, D.; Yalaoui-Guellal, D.; Madani, K.; Chibane, M. Chemical and Biological Profiles of Essential Oils from *Mentha Spicata* L. Leaf from Bejaia in Algeria. *J. Essent. Oil Res.* **2016**, *28*, 211–220.
93. Benelli, G.; Pavela, R.; Canale, A.; Nicoletti, M.; Petrelli, R.; Cappellacci, L.; Galassi, R.; Maggi, F. Isofuranodiene and Germacrone from *Smyrnium olusatrum* Essential Oil as Acaricides and Oviposition Inhibitors against *Tetranychus urticae*: Impact of Chemical Stabilization of Isofuranodiene by Interaction with Silver Triflate. *J. Pest Sci.* **2017**, *90*, 693–699.
94. Attia, S.; Grissa, K.L.; Zeineb, G.G.; Mailleux, A.C.; Lognay, G.; Hance, T. Assessment of the Acaricidal Activity of Several Plant Extracts on the Phytophagous Mite *Tetranychus urticae* (Tetranychidae) in Tunisian Citrus Orchards. *Bull. Soc. R. Belg. D'entomologie* **2011**, *147*, 71–79.
95. Han, J.; Kim, S.I.; Choi, B.R.; Lee, S.G.; Ahn, Y.J. Fumigant Toxicity of Lemon Eucalyptus Oil Constituents to Acaricide-Susceptible and Acaricide-Resistant *Tetranychus Urticae*. *Pest Manag. Sci.* **2011**, *67*, 1583–1588.
96. Hamdi, S.H.; Hedjal-Chebheb, M.; Kellouche, A.; Khouja, M.L.; Boudabous, A.; Ben Jemâa, J.M. Management of Three Pests' Population Strains from Tunisia and Algeria Using Eucalyptus Essential Oils. *Ind. Crops Prod.* **2015**, *74*, 551–556.
97. Attia, S.; Grissa, K.L.; Lognay, G.; Heuskin, S.; Mailleux, A.C.; Hance, T. Chemical Composition and Acaricidal Properties of *Deverra scoparia* Essential Oil (Araliales: Apiaceae) and Blends of Its Major Constituents against *Tetranychus urticae* (Acari: Tetranychidae). *J. Econ. Entomol.* **2011**, *104*, 1220–1228.
98. Laborda, R.; Manzano, I.; Gamón, M.; Gavidia, I.; Pérez-Bermúdez, P.; Boluda, R. Effects of *Rosmarinus officinalis* and *Salvia officinalis* Essential Oils on *Tetranychus urticae* Koch (Acari: Tetranychidae). *Ind. Crops Prod.* **2013**, *48*, 106–110.
99. Ahmadi, Z.; Saber, M.; Bagheri, M.; Mahdavinia, G.R. Achillea Millefolium Essential Oil and Chitosan Nanocapsules with Enhanced Activity against *Tetranychus Urticae*. *J. Pest Sci.* **2018**, *91*, 837–848.

100. Smaili, M.C.; Abbassi, M.; Boutaleb, J.A.; Blenzar, A. Richesse Spécifique Des Ennemis Naturels Associés Aux Vergers d'agrumes Au Maroc: Intérêt et Implication Pour La Lutte Biologique. *EPPO Bull.* **2013**, *43*, 155–166.
101. Albendín, G.; García, M.D.C.; Molina, J.M. Multiple Natural Enemies Do Not Improve Two Spotted Spider Mite and Flower Western Thrips Control in Strawberry Tunnels. *Chil. J. Agric. Res.* **2015**, *75*, 63–70.
102. Kazak, C.; Karut, K.; Doker, I. Indigenous Populations of *Neoseiulus californicus* and *Phytoseiulus persimilis* (Acari: Phytoseiidae): Single and Combined Releases against *Tetranychus urticae* (Acari: Tetranychidae) on Greenhouse Eggplant. *Int. J. Acarol.* **2015**, *41*, 108–114.
103. Croft, B.A.; Monetti, L.N.; Pratt, P.D. Comparative Life Histories and Predation Types: Are *Neoseiulus californicus* and *N. fallacis* (Acari: Phytoseiidae) Similar Type II Selective Predators of Spider Mites? *Environ. Entomol.* **1998**, *27*, 531–538.
104. El Laithy, A.Y.M.; El Sawi, S.A. Biology and Life Table Parameters of the Predatory Mite Neoseiulus californicus Fed on Different Diet/Biologie Und Lebenstafel-Parameter Der Raubmilbe Neoseiulus californicus Bei Unterschiedlicher Ernährung. *Z. Pflanzenkrankh. Pflanzenschutz* **2016**, *105*, 532–537.
105. Bouharroud, R. Acariens Clés Des Agrumes Au Maroc, Agriculture Du Maghreb. Available online: **http://www.agri-mag.com/2017/06/acariens-cles-des-agrumes-au-maroc/** (accessed on 18 April 2021).
106. Kreiter, S.; Sahraoui, H.; Lebdi-Grissa, K.; Chermiti, B.; Khoualdia, O.; Ksantini, M. Phytoseiid Mites (Acari: Mesostigmata) from Tunisia: Catalogue, Biogeography and Key for Identification. *Tunis. J. Plant Prot.* **2008**, *5*, 151–178.
107. Cruz-Miralles, J.; Cabedo-López, M.; Guzzo, M.; Ibáñez-Gual, V.; Flors, V.; Jaques, J.A. Plant-Feeding May Explain Why the Generalist Predator *Euseius stipulatus* Does Better on Less Defended Citrus Plants but Tetranychus-Specialists *Neoseiulus californicus* and *Phytoseiulus persimilis* Do Not. *Exp. Appl. Acarol.* **2021**, *83*, 167–182.
108. Ferragut, F.; Garcia-Marí, F.; Costa-Comelles, J.; Laborda, R. Influence of Food and Temperature on Development and Oviposition of *Euseius stipulatus* and *Typhlodromus phialatus* (Acari: Phytoseiidae). *Exp. Appl. Acarol.* **1987**, *3*, 317–329.
109. McMurtry, J.A. Some Predaceous Mites [Phytoseiidae] on Citrus in the Mediterranean Region. *Entomophaga* **1977**, *22*, 19–30.
110. Adly, D. Use of Predators for Controlling the Whitefly, Bemisia Tabaci Genn. And the Two Spotted Spider Mite, *Tetranychus urticae* Koch., in Cucumber Greenhouses in Egypt. *Egypt. J. Biol. Pest Control* **2016**, *26*, 701–706.
111. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial Insect Community of Moroccan Citrus Groves: Assessment of Their Potential to Enhance Biocontrol Services. *Egypt. J. Biol. Pest Control* **2020**, *30*, 47.
112. Bouagga, S.; Urbaneja, A.; Pérez-Hedo, M. Combined Use of Predatory Mirids with *Amblyseius swirskii* (Acari: Phytoseiidae) to Enhance Pest Management in Sweet Pepper. *J. Econ. Entomol.* **2018**, *111*, 1112–1120.
113. Abad-Moyano, R.; Pina, T.; Dembilio, Ó.; Ferragut, F.; Urbaneja, A. Survey of Natural Enemies of Spider Mites (Acari: Tetranychidae) in Citrus Orchards in Eastern Spain. *Exp. Appl. Acarol.* **2009**, *47*, 49–61. [
114. Roy, M.; Brodeur, J.; Cloutier, C. Seasonal Activity of the Spider Mite Predators *Stethorus punctillum* (Coleoptera: Coccinellidae) and *Neoseiulus fallacis* (Acarina: Phytoseiidae) in Raspberry, Two Predators of *Tetranychus mcdanieli* (Acarina: Tetranychidae). *Biol. Control* **2005**, *34*, 47–57.
115. Guo, Y.Y.; Tian, J.C.; Shi, W.P.; Dong, X.H.; Romeis, J.; Naranjo, S.E.; Hellmich, R.L.; Shelton, A.M. The Interaction of Two-Spotted Spider Mites, *Tetranychus urticae* Koch, with Cry Protein Production and Predation by *Amblyseius andersoni* (Chant) in Cry1Ac/Cry2Ab Cotton and Cry1F Maize. *Transgenic Res.* **2016**, *25*, 33–44.
116. Kumar, V.; Mehra, L.; Mckenzie, C.L.; Osborne, L.S. "Predator-In-First": A Preemptive Biological Control Strategy for Sustainable Management of Pepper Pests in Florida. *Sustainability* **2020**, *12*, 7816.
117. Vincent, C.; Panneton, B. Les Méthodes de Lutte Physique Comme Alternatives Aux Pesticides 2001. Available online: **http://journals.openedition.org/vertigo/4093** (accessed on 16 April 2021).

118. Raza, M.F.; Yao, Z.; Dong, X.; Cai, Z.; Zhang, H. Citrus Insect Pests and Their Non Chemical Control in China. *Citrus Res. Technol.* **2017**, *38*, 122–138.
119. Unruh, T.R.; Knight, A.L.; Upton, J.; Glenn, D.M.; Puterka, G.J. Particle Films for Suppression of the *Codling moth* (Lepidoptera: Tortricidae) in Apple and Pear Orchards. *J. Econ. Entomol.* **2000**, *93*, 737–743.
120. Fields, P.; Korunic, Z.; Fleurat-Lessard, F. Control of Insects in Post-Harvest: Inert Dusts and Mechanical Means. In *Physical Control Methods in Plant Protection*; Springer: Berlin/Heidelberg, Germany, 2001; pp. 248–257.
121. Kim, Y.; Lounds-Singleton, A.J.; Talcott, S.T. Antioxidant Phytochemical and Quality Changes Associated with Hot Water Immersion Treatment of Mangoes (*Mangifera indica* L.). *Food Chem.* **2009**, *115*, 989–993.
122. Tanaka, M.; Yase, J.; Aoki, S.; Sakurai, T.; Kanto, T.; Osakabe, M. Physical Control of Spider Mites Using Ultraviolet-B with Light Reflection Sheets in Greenhouse Strawberries. *J. Econ. Entomol.* **2016**, *109*, 1758–1765.
123. Murata, Y.; Osakabe, M. The Bunsen-Roscoe Reciprocity Law in Ultraviolet-B-Induced Mortality of the Two-Spotted Spider Mite *Tetranychus urticae*. *J. Insect Physiol.* **2013**, *59*, 241–247.
124. Osakabe, M. Biological Impact of Ultraviolet-B Radiation on Spider Mites and Its Application in Integrated Pest Management. *Appl. Entomol. Zool.* **2020**, *56*, 139–155.
125. Capinera, J.L. Encyclopedia of Entomology-Google Livres. Available online: **https://books.google.co.ma/books?hl=fr&lr=&id=i9ITMiiohVQC&oi=fnd&pg=PR55&dq=The+Encyclopedia+of+Entomology&ots=VZzrSwiOOP&sig=DzVOD23SXJT2fxfFgmAx_dDFgdw&redir_esc=y#v=onepage&q=The-Encyclopedia-of-Entomology&f=false** (accessed on 16 April 2021).
126. Bouyer, J. Lutte Intégrée Contre Les Insectes Vecteurs de Maladies Humaines et animales. *Développer Lutte Génétique* **2014**, *34*, 4.
127. Estrella Santamaria, M.; Arnaiz, A.; Rosa-Diaz, I.; González-Melendi, P.; Romero-Hernandez, G.; Ojeda-Martinez, D.A.; Garcia, A.; Contreras, E.; Martinez, M.; Diaz, I. Plant Defenses against *Tetranychus urticae:* Mind the Gaps. *Plants* **2020**, *9*, 464.
128. Lilley, R.; Campbell, C.A.M. Biological, Chemical and Integrated Control of Two-Spotted Spider Mite *Tetranychus urticae* on Dwarf Hops. *Biocontrol Sci. Technol.* **2010**, *9*, 467–473.
129. Nicetic, O.; Watson, D.M.; Beattie, G.A.C.; Meats, A.; Zheng, J. Integrated Pest Management of Two-Spotted Mite *Tetranychus urticae* on Greenhouse Roses Using Petroleum Spray Oil and the Predatory Mite *Phytoseiulus Persimilis*. *Exp. Appl. Acarol.* **2001**, *25*, 37–53.
130. Iwassaki, L.A.; Sato, M.E.; Calegario, F.F.; Poletti, M.; Maia, A. de H.N. Comparison of Conventional and Integrated Programs for Control of *Tetranychus urticae* (Acari: Tetranychidae). *Exp. Appl. Acarol.* **2014**, *65*, 205–217.
131. Jones, G.; Campbell, C.A.M.; Hardie, J.; Pickett, J.A.; Pye, B.J.; Wadhams, L.J. Integrated Management of Two-Spotted Spider Mite *Tetranychus urticae* on Hops Using Hop β-Acids as an Antifeedant Together with the Predatory Mite *Phytoseiulus persimilis*. *Biocontrol Sci. Technol.* **2003**, *13*, 241–252.

Revue II

La mouche méditerranéenne *Ceratitis capitata* (Diptera : Tephritidae) dans les vergers d'agrumes marocains : méthodes de lutte chimique et durable et priorités pour les futures recherches

Cette étude a fait l'objet d'une publication dans Tropical Journal of Natural Product Research: (IF= 0.30).

Assouguem, A.; Kara, M.; Benmessaoud, S.; Mechchate, H.; Jabboury, Z. El; Farah, A.; Lazraq, A. Tropical Journal of Natural Product Research Ceratitis capitata Wiedemann (Diptera : Tephritidae) in Moroccan Citrus orchards : Chemical and Sustainable Control Methods and Priorities for Future Research. **2021**, *5*, 1703–1708.

Resumé

La mouche méditerranéenne (*Ceratitis capitata*) infecte les fruits de plus de 300 espèces végétales, causant des pertes économiques substantielles s'élevant à des millions de dollars par an. Bien qu'elle soit originaire du bassin méditerranéen, elle s'est répandue en Asie, en Europe, en Amérique centrale et du Sud, en Afrique, en Australie, etc. la lutte au Maroc contre ce ravageur a été principalement basée sur des pulvérisations chimiques. Cette revue vise à fournir des informations sur les méthodes de lutte contre *Ceratitis capitata*, principalement dans les vergers d'agrumes au Maroc. La littérature pertinente a été recherchée dans différents moteurs de recherche : Google scholar, science direct, PubMed, etc. Ce travail met en évidence les principaux résultats des études précédentes, discute les méthodes de contrôle actuelles et propose de nouvelles recherches innovantes et des approches durables pour contrôler les mouches méditerranéennes des fruits. La mise en place d'un programme intégré de surveillance écologique à long terme au Maroc et dans différents pays africains et l'incorporation de nouvelles technologies dans les programmes de surveillance sont des besoins urgents pour lutter contre ce ravageur. Ces programmes doivent tenir compte des conditions climatiques, de la phénologie, des taux d'infestation et de la vitesse de propagation des ravageurs. Parmi les autres méthodes, citons les nouvelles méthodes de lutte biologique et de piégeage, la technique de l'insecte stérile (SIT), les ennemis parasitoïdes comme *Diachasmimorpha longicaudata*, les agents pathogènes comme *Beauveria bassiana*, et l'introduction d'une méthode génétique auto-limitative. Ces éléments fondamentaux sont proposés pour contrôler les nuisibles, respecter l'environnement et la santé publique.

Review II
Ceratitis capitata Wiedemann (Diptera: Tephritidae) in Moroccan Citrus orchards: Chemical and Sustainable Control Methods and Priorities for Future Research

Amine Assouguem1*, Mohammed Kara2, Safaâ Benmessaoud 2, Hamza Mechchate 3, Zineb El Jabboury1, Abdellah Farah4, Abderrahim Lazraq1

1Laboratory of Functional Ecology and Genie of Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street,
Fez, P.O, Box 2202, Morocco
2Laboratory of Biotechnology, Conservation and Valorisation of Natural Resources (LBCVNR), Department of Biology, Sidi Mohamedd Ben Abdellah
University, Faculty of Science Dhar El Mahraz, Fez, Atlas, Morocco
3Laboratory of Biotechnology, Environment, Agri-Food, and Health (LBEAS), Faculty of Science Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez BP 1796, Morocco
4Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technology, , Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez, P.O, Box 2202, Morocco
*Correspondence: assougam@gmail.com, telephone number: 0691085832

Abstract

The Mediterranean fruit fly (*Ceratitis capitata*) infects fruits from over 300 plant species, causing substantial economic losses amounting to millions of dollars annually. Though it has its origin in the Mediterranean basin, it has spread to Asia, Europe, Central and South America, Africa, Australia, etc. Its control in Morocco has been principally based on chemical sprays. The review aims to provide information on control methods of *Ceratitis capitata*, mainly in citrus orchards in Morocco. Relevant literature was sourced from different search engines: Google scholar, science direct, PubMed, etc. The article highlighted the principal findings of previous studies, discussed current control methods, and proposed new innovative research and sustainable approaches to control medflies. Setting up an integrated long-term ecological monitoring program in Morocco and different African countries and incorporating new technologies into monitoring programs are urgently needed to fight this devastating pest. These programs must consider the climate conditions, phenology, infestation rates, and propagation speed of pests. Other methods include new organic pests and trapping, sterile insect technique (SIT), parasitoid enemies such as Diachasmimorpha longicaudata, pathogens like Beauveria bassiana, and introducing a self-limiting genetic method. These fundamental elements are suggested to control pests, respect the environment and public health.

Keywords: *Ceratitis capitata*, Citrus orchards, Diachasmimorpha longicaudata, Medflies, Morocco.

Introduction

In Morocco, the growing area of citrus lands has exceeded 130,000 ha with a total production of more than two million tons, thanks to strategies put in place by the Ministry of Agriculture.[1] Moreover, government policy has projected an estimated production output between 2.5 and 3.5 million tons before 2022. The extension of production to other areas is also targeted.[2]

The citrus fruit is mainly cultivated in Moulouya, Souss, Tadla, Haouz Loukkos, and Gharb regions.f Currently, there is an extraordinary change in the national citrus market, with a significant decrease in exports to the European Union from 70% to only 25-30%,[3]. In comparison, exports to Russia have increased enormously from 45 to 50% of all Moroccan exports.[4] Unfortunately, shortage of water and intense competition in the international citrus market constitutes the main constraints threatening the citrus sector in Morocco.[5,6]

Unlike recent climatic challenges, pest control management is a significant and old constraint for citrus exports due to the international market's demand for quality. The steady supply of quality fruits without pest infestation, damage, or pesticide residues, requires sustainable citrus pest approaches.[7] For citrus fruits, many pests cause an essential loss in quality and quantity: fruit fly *C. capitata* Wiedemann (Diptera: Tephritidae), red mite *Panonychus citri* McGregor (Acari: Tetranychidae), California red scale *Aonidiella aurantii* Maskell (Hemiptera: Diaspididae), and the citrus leaf miner *Phyllocnistis citrella Stainton* (Lepidoptera: Gracillariidae).[8–10] Currently, other pests, including the two-spotted mite *Tetranychus urticae* Koch (Acari: Tetranychidae) and the citrus brown mite *Eutetranychus orientalis* Klein (Acari: Tetranychidae), have also been recorded to impact citrus production considerably.[11] Among the citrus pests, the medfly is undoubtedly the most destructive pest, with indirect and direct economic effects.[12–14] Despite control measures, 10 to 20% of production is regularly infested.[15] Farmers are required to monitor medfly prevalence during the fruit-maturation phases, carefully and potentially apply several pesticide sprays to control this insect pest.[16] Furthermore, to export fruit to countries like the USA, UK, and Japan, exporting countries need cold treatment conditions as quarantine procedures for pests of medfly, which raises costs.[17]

Although enormous efforts were made to control Morocco's medfly, this pest is still a significant menace to the entire national citrus industry (exports and production).[18] For example, because of medfly infestation, the Department of Agriculture's Animal and Plant Health Inspection Service had to temporarily forbid importing some products, including clementines, tangerines, mandarins, and sweet oranges produced or shipped from the Berkane region during 2016.[19]

The review aimed at two objectives, namely: summarize existing literature on current approaches used to control the medfly population, prompt the employment of integrated medfly-management techniques based on environmentally-friendly practices, such as biological control, biopesticides, or the use of a self-limiting genetic process as well as discuss high-priority research guidelines to investigate new sustainable management strategies that have been tested in other countries with similar contexts.

1 Methodology

The authors collected the different information and control methods used on *C. capitata* from articles cited in indexed journals, from Google Scholar, Science Direct, PubMed, Web of Science, MDPI, etc., using different search criteria such as biopesticides, *C. Capitata,* medfly, pest control, and management.

2 Results and Discussions

2.1 Status of *C. capitata* in Morocco

In Morocco, as in other Mediterranean countries, the medfly (Mediterranean fruit fly) *C. capitata* is considered the most abundant tephritid pest and constitutes the most damaging fruit pests with a severe threat to fruit cultivation, production, and export.[20] It is closely related to suitable host plants, fruit availability, and habitats features, including environmental conditions.[21] Outside orchards, forest woodlands such as the Indian fig opuntia *(Opuntia ficus-indica)* and *Argania spinosa* offer huge and potential reservoirs of medflies for nearby citrus growing areas principally in the Souss region, where production accounts for 50% of the Moroccan production.[22,23] The medflies affect other fruit plantations like apples, pears, nectarines, peaches, and plums pomegranates, in different regions and environmental conditions.[24,25]

2.2 Control approaches in Morocco

In Morocco, pest management is profoundly dependent on chemical treatments.[26] Before 2010, the use of sustainable strategies was neglected and rudimentary. However, the application of eco-friendly methods has recently been slowly adopted due to public concerns (local and international markets) over chemical compounds, residues, and pest resistance to pesticides.[27] Several eco-friendly methods have revealed efficiency in the control of this pest. These methods could be utilized as control measures to meet the new international market requirements regarding fruit protection, quality, healthy environment, and human health.[28,29] Consequently,

sustainable approaches to chemical control like biopesticides,[30,31] the sterile insect technique (SIT),[19] cold treatment [32] and mass trapping [33] are used. Other methods, such as the continued release of self-limiting medfly strains, are also being studied.[3,4]

2.3 Unsustainable control

Generally, unsustainable methods are based on chemical and synthetic substances, including pesticides, insecticides, fungicides, nematicides, and herbicides.[35] In Morocco, chemical control is the most extensively used approach against medflies and other pests. Usually, treatments are used with a full-cover spray (with non-professional stuff) and a wide range of significant spectrum pesticides, which are incredibly destructive to natural pest enemies (beneficial insects, birds, bats, etc.).[36] Instead, the foliar spot's treatments using hydrolysed protein baits contain the other leading chemical application practice recently used.[37] Equally, baits are based on bio-ecology, diurnal and seasonal behaviour of medflies.[38] In reality, ingestion of proteins during the maturity (adult) phase improves male fitness via pheromone production, leks, the rate of sexual intercourse, and the rate of sperms transmission.[39,40]

Similarly, protein is also essential for egg production in medfly females.[41] Rotten fruit, bird droppings, fungi, and bacteria are natural sources of proteins.[42] Bait sprays consist of a protein source to attract adult medflies and an insecticide to kill them. By conjoining both methods in one invention, the bait is attractive as a nutrition source to both female and male medflies, which feed over the leaves for nutriments as approved currently.[43]

The "Spinosad" compound has become the favoured chemical treatment, particularly during the harvest phase, because of its short persistence in the ecosystem and its average pre-harvest interval of one day.[44] Infestation rate and adult pest prevalence fruit define the date and regularity of chemical sprays.[45] Therefore, the monitoring starting point that designates when spraying should start is three to five adult males per trap and day.[44] On the other hand, in small orchards, sprays are applied once every ten days, mainly during late summer and autumn periods for the precocious citrus varieties and between the end of winter and spring, for the tardive varieties, depending on the yield zone.[1] However, to conform with Russian quarantine protocols of imported crops, an arrangement has been engaged with Russia targeting to support medfly control by farmers interested in the Russian market, reducing the chemical spray threshold to 1 male or 0.5 females/(trap•day).

2.4 Sustainable approaches

2.4.1 Biological control

Generally, all citrus-growing regions have the following main pests; fruit flies, armoured scales, mealy bugs, mites, and thrips.[46,47] Most of these insect or mite pests are vulnerable to attack by natural enemies (entomopathogens). Then citrus pests must be seen as potential targets and explored.[48,49] Among the medfly's natural entomopathogens, we list parasitoids (mainly from the Braconidae family), the most regularly used in biological pest control.[50] However, recently, an enormous number of parasitoids such as the larval-pupal parasitoids *Fopius vandenboschi*, the egg-pupal parasitoid *Fopius arisanus*, *Aganaspis daci*, *Diachasmimorpha tryoni*, *Diachasmimorpha longicaudata* and *Psyttalia incisi* have been approved as significant enemies to the medfly inside citrus orchards.[51] Several pilot studies were performed in Spain to evaluate the capacity of *Diachasmimorpha longicaudata* and *Aganaspis daci* for the medfly's biological control. The results showed that the parasitoids could disperse and parasitize medfly larvae and eggs in both laboratory and greenhouse.[51] With the similarity in climate condition, agricultural practices between Morocco and Spain, these parasitoids are good biological enemies for Morocco testing.[25] However, research needs to investigate the new potential and indigenous parasitoids and natural enemies to control medfly and other destructive pests.

2.4.2 Use of biopesticides

The demand for biopesticides in agriculture is increasing due to the need to limit hazardous chemical pesticides.[52] In this context, the close alternative uses pesticide substances derived from biological materials with selective action against target pests and less persistence in ecosystems.

Although farmers may control medflies through chemical use in Morocco, awareness of their destructive impacts is rising.[25] Therefore, biopesticides like *Beauveria bassiana*, Azadirachtin and Spinosad have been listed for use.[53] These active substances are confirmed to have low persistence and limited side impacts on non-target insects. Besides, other natural materials can be extracted from Moroccan ecosystems. Currently, bacteria such as *Bacillus thuringiensis* and *Fusarium* as a biopesticide are essentially among the best alternatives to chemicals for controlling insect agricultural pests.[54]

Recent investigations proposed that the soil from the Argan forests (from the Souss region) may be a promoting reservoir for future and more comprehensive screening programs to identify microorganisms that can effectively control pests.[54] It was previously published that most autochthonous strains of *Beauveria bassiana* isolated from *Argania Spinosa* endemic species

to Morocco were highly infectious to medfly.[25] Therefore, these indigenous isolates might be a source of potential biological control for medfly.

2.4.3 Sterile insect technique

Sterile insect technique was developed during the last century as a promoting technology for pest control.[55] The technique has progressively been viewed as an appropriate method for integrated pest management (IPM) for certain agricultural pests due to the growth of restrictions on the use of chemicals and the increasing demand for organic products.[56] Similarly, SIT is used in Europe (Portugal, Spain), Asia (Israel, Jordan), Africa (South Africa, Tunisia), North (USA, Mexico), and South America (Chilie, Argentina) in several medfly programs as the primary control strategy.[57]

In Morocco, an agreement was signed by the citrus farmers and the Ministry of Agriculture to establish an area-wide sterile insect technique program to control the Mediterranean fruit fly in the Agadir region.[55,58] The pilot project was carried out to defeat medflies in approximately 5,000 ha in the Souss Valley, using an SIT component. Eight million sterile male flies were released weekly. In 2014, the Ministry of Agriculture ordered to build a medfly mass-rearing infrastructure and a sterile male-release station, with technical assistance from FAO/IAEA (Food and Agriculture Organisation /International Atomic Energy Agency), in partnership with Moroccan citrus. The constructions were enough to offer sterile males to cover the entire Souss area with an estimated surface of 40,000 ha of citrus-producing zones and the neighbouring regions. The facility is expected to produce between 130 to 200 million sterile males per week.[56] However, field evaluations' efficiency is still ongoing before the enlargement to cover all the Souss zone. The application of SIT as a nationwide program (All national zones producing citrus) is the targeted objective. As a first evaluation, after three years of release, despite encouraging environmental conditions for medflies between 2010 and 2011, the abundance of female medflies in the examined zone declined compared to previously recorded levels. Consequently, chemical sprays were decreased by 25-75% alongside this approach.[56] Generally, the SIT centres' achievement for rearing and release will guarantee highly cost-effective medfly control levels and cover all citrus-growing zones.

2.4.4 Mass trapping

Mass trapping is a sustainable and ecologically friendly insect control technique founded on the use of species-specific synthetic chemical traps, such as aggregation pheromones and sex or food/host attractants.[59]

Medfly mass trapping has been widely applied in Mediterranean countries by developing an artificial food-based female attractant: An extremely selective and potent combination of three chemical compounds produced for attracting female medflies.[19] It has proven to be very effective in managing *C. capitata, T. absoluta*, and its application in the Mediterranean zone has augmented remarkably.[59] In Morocco, various synthetic attractants, which are easy to handle and have a long life span, have been developed to substitute protein solutions. Putrescine, trimethylamine hydrochloride and ammonium acetate are the most excellent examples of such attractants. They are combined in one formula or used separately depending on the efficiency of each attractant. These materials are highly female selective and have a prolonged action period of at least 90 days.[44] In Moroccan farmlands, the application of attractant and killer technics implicates using the M3 bait station (blue plastic trap saturated with alpha-cypermethrin and protein hydrolysate, etc.) is abundant and very efficient, permitting the avoidance of spray treatments in stations where M3 was set.[1] However, the application of mass trapping in Morocco separately or as part of an integrated medfly pest control permits the decrease of chemical overuse.[19] Therefore, environmental pollution, pest proliferation, and chemical residues are minimized in the citrus production sector.

2.4.5 Cold treatment

The medfly *C. capitata* belongs to a list of pests with the maximum possibility of introducing pest-free provinces, countries, or areas.[60] Generally, to avoid the risk of disease and accidental introduction of invasive insect pests from imported fruit, many citrus fruit-importing countries request quarantine protocols, such as the case of Japan and the USA.[19] In Morocco and all Mediterranean basin countries, citrus farmers need to apply quarantine treatments before exportation dates.[61] The quarantine treatment is 16 days at temperatures between 0 to 2°C. However, this technique is expensive and has other disadvantages, mainly the vulnerability of some varieties (tangerines and clementines) to low temperatures[63] and the difficulty of reaching far markets due to long quarantine period.

Morocco's citrus exported to the US market increased from 7.800 t in 2006/2007 to 42,011 t in the marketing year 2013/2014. Morocco was required to send these cargos via Europe for cold treatments.[19,63] The shortest shipment to the US and the implementation of the Morocco-U.S Free Trade Arrangement were expected to increase citrus exports to the US in the near future.[25,64] Equally, exports to China involve quarantine treatment for various pests. Therefore, Moroccan citrus fruit destined for this vast Asian market must be exposed to a minimum temperature of 1°C for 16 days.[65]

However, to involve other international markets, new cold-treatment experimental protocols and technologies are required to open new windows for Moroccan products and increase revenues.[65] For example, Japan is a promising market for numerous Moroccan agricultural products. Morocco has signed an agreement between Maroc Citrus, Agronomic and Veterinary Institute (IAV) Hassan II, National Office of Food Safety (ONSSA), and the SAOAS Company to apply a cold-treatment experimental protocol delivered by Japanese consultants. The study's main goal was to verify the efficacy of cold treatment on infected fruit and fell within the overall strategic objective of eliminating the risk of the Mediterranean fruit fly introduction to Japan ecosystems.[19]

2.4.6 Sustained release of self-limiting medflies

Improved sterile pests are another possible technique to moderate the expensive costs of SIT-like programs and increase efficiency.[34,66] The SIT is a mating-based method whereby released sterile males (sterilized via irradiation) compete with their wild competitors for successful mating with wild females inside orchards.[66] Compared to wild males, the exposure of males to irradiation causes a complete loss of competitive mating aptitude.[67] In the field, treated insects (with irradiation) have reduced life cycles and are less competitive (mainly in mating).[68] Consequently, fitness is reduced by 4-10-fold for medflies.[69,70] To address the limitations of existing SIT approaches, the self-limiting technology is a novel and improved alternative, which aims specifically the expensive filter colony necessary for the stability of temperature-sensitive lethal mutation medfly strains caused by the use of irradiation and the uselessness of fluorescent powders. Indeed, sexing sterile males via genetics can be more effective than releases including mixed-sex populations.[71] In summary, the self-limiting method offers novel operational genetic sexing instead of the expensive and performance-reducing method of sterilization using irradiation. Similarly, fluorescent marking permits easy distinguishing between transgenic and wild insects in both laboratory and field, eliminating the use of fluorescent powders, which can damage specimens.

2.5 Future research directions

2.5.1 Investigations on medfly

Determining spatiotemporal variation of population size, details of the biological cycle, and ecological features of medflies in Moroccan orchards are paramount to improving our understanding of the population dynamics in each region and climate conditions. Similarly, micro-conditions should be addressed carefully to clarify the whole picture of medflies inside orchards. Understanding life-cycle details and surrounding conditions will help identify the

vulnerable stage that farmers could attack and the proper periods for treatment. Equally, the precise life cycle knowledge will help develop biopesticides and natural enemies that will disturb the normal medfly cycle with high effectiveness. Assessing the relationship between climatic variables (precipitation, temperature, humidity, and wind speed) and the medfly's presence, abundance, and reproductive success is essential to guiding control actions and adopting appropriate future management. Additional investigations on *C. capitata* feeding behaviour and population genetic structures are also crucial for any program's success.[25]

2.5.2 Investigations on new control methods

Research into new pest management programs is urgently needed. This program should incorporate new materials such as extracts from aromatic and medicinal plants. These materials have shown promising results in pest control, including medfly.[52] In parallel, natural enemies need to be investigated deeply because of their direct effect on pest insects. Remarkably, these entomopathogens are suggested to be well adapted inside orchards.

Conclusion

The study reviewed and highlighted the existing knowledge and future perspective of medfly control approaches used in Morocco. The prospective programs that can be used to manage the medfly population in Morocco include, in addition to mass trapping and chemical control, the development of new biopesticides, biological control, or the use of a self-limiting genetic approach. Further, setting up an integrated long-term ecological monitoring program and incorporating new technologies into monitoring programs is an urgent need to fight this devastating pest. This could be facilitated by natural resources that can support growth in this sector. Indeed, the African regions have the most incredible plant diversity on the planet. Genetic modifications of plants and medflies could be done to improve the molecular mechanisms that control the interplay between plants and medflies. An advanced understanding of the medflies–plant interaction will be an effective tool for protection. Finally, the current trend is to combine all these methods in an integrated *C. capitata* management strategy.

Acknowledgments

The authors are thankful to the Laboratory of Functional Ecology and Environment professors and professors of the Laboratory of Applied Organic Chemistry for their assistance.

Conflict of interest

The authors declare that there is no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that they will bear any liability for claims relating to the content of this article.

Reference

1. Mazih A. Status of citrus IPM in the southern Mediterranean basin Morocco, North Africa. Acta Hortic. 2015; 1065(1964): 1097-1104.

2. Afechtal M, Djelouah K, Cocuzza G, D'Onghia AM. Large Scale Survey of Citrus Tristeza Virus (CTV) and Its Aphid Vectors in Morocco. Acta Hortic. 2015; 1065(1963): 753-757.

3. Tudela-Marco L, Álvarez-Coque JMG, Martínez-Gómez V. Issues in Trade Liberalisation in Southern and Eastern Mediterranean Countries. Switzerland: Springer, Cham; 2015. 171-196 p.

4. Montaigne E, Hadad-Gauthier FE, Khefifi L. Challenges in Citrus Market Chains in Tunisia and Morocco. Sustain Agric Dev [online]. 2015 [cited 2021 sept 11];227-53. Available from: http://link.springer.com/chapter/10.1007/978-3-319-17813-4_9

5. Sraïri MT. New challenges for the moroccan agricultural sector to cope with local and global changes. Moroc Environ Soc Econ Issues 21st Century. 2017; 10(2): 165-188.

6. Oubelkacem A, Scardigno A, Choukr-Allah R. Treated Wastewater Reuse on Citrus in Morocco: Assessing the Economic Feasibility of Irrigation and Nutrient Management Strategies. Integr Environ Assess Manag. 2020; 16(6): 898-909.

7. Mac Loughlin TM, Peluso ML, Etchegoyen MA, Alonso LL, de Castro MC, Percudani MC, Marino Damián J. G. Pesticide residues in fruits and vegetables of the argentine domestic market: Occurrence and quality. Food Control. 2018; 93(24): 129-138.

8. Franco JC, Suma P, Da Silva EB, Blumberg D, Mendel Z. Management strategies of mealybug pests of citrus in Mediterranean countries. Phytoparasitica. 2004; 32(5): 507-522.

9. Masui S, Katayama H, Kaneko S. Status and use of biological control of insect pests in citrus IPM. Jpn J Appl Entomol Zool. 2018; 62(3): 137-148.

10. Urbaneja A, Grout TG, Gravena S, Wu F, Cen Y, Stansly PA. Citrus pests in a global world. The Genus Citrus. Amsterdam: Elsevier Inc. 2020. p 333-348.

11. Abad-Moyano R, Pina T, Dembilio Ó, Ferragut F, Urbaneja A. Survey of natural enemies of spider mites (Acari: Tetranychidae) in citrus orchards in eastern Spain. Exp Appl Acarol. 2009; 47(1): 49-61.

12. Jacas JA, Urbaneja A. Integrated Management of Arthropod Pests and Insect Borne Diseases. Integr Manag Arthropod Pests Insect Borne Dis. 2010; 2(5): 61-62.

13. Estrella Santamaria M, Arnaiz A, Rosa-Diaz I, González-Melendi P, Romero-Hernandez G, Ojeda-Martinez DA, Garcia A, Contreras E, Martinez M, and Diaz I. Plant defenses against tetranychus urticae: Mind the gaps. Plants. 2020;9(4):1-16.

14. Tena A, García-Marí F. Current situation of citrus pests and diseases in the Mediterranean Basin. IOBC-wprs Bull. 2011; 62(6): 365-378.

15. Krasnov H, Cohen Y, Goldshtein E, Mendelsohn O, Silberstein M, Gazit Y, and Blank L. The effect of local and landscape variables on Mediterranean fruit fly dynamics in citrus orchards utilizing the ecoinformatics approach. J Pest Sci. 2019; 92(2): 453-463.

16. Rather BA, Mir MM, Iqbal U, Mir SA. Integrated Pest Management of Stone Fruits. In: Production Technology of Stone Fruits. Singapore: Springer; 2021. p 397-422.

17. Japan Exports of Fruit & Vegetables | 1983-2021 Data | 2022-2023 Forecast | Historical [online]. 2021 [cited 6 April 2021]. Available on: https://tradingeconomics.com/japan/exports-of-fruit-vegetable

18. Boulahia-Kheder S. Review on major fruit flies (Diptera: Tephritidae) in North Africa: Bio-ecological traits and future trends. Crop Prot. 2021; 140(2): 1-10.

19. Rachid E, Ahmed M. Current status and future prospects of *Ceratitis capitata* wiedemann (Diptera: Tephritidae) control in Morocco. J Entomol. 2018; 15(1): 47-55.

20. Magaña C, Hernández-Crespo P, Ortego F, Castañera P. Resistance to malathion in field populations of *Ceratitis capitata.* J Econ Entomol. 2007;100(6): 1836-1843.

21. Hammouti N, Griebeler EM, Barr N, Mazih A, Seitz A. Extension of the pathway analysis for the medfly (*Ceratitis capitata*): mtDNA variation among Morocco populations. Ext Pathw Anal Medfly *Ceratitis capitata* MtDNA Var Moroc Popul. 2011; 62(3): 163-176.

22. Imoulan A, Alaoui A, Meziane A El. Natural occurrence of soil-borne entomopathogenic fungi in the Moroccan Endemic Forest of Argania spinosa and their pathogenicity to *Ceratitis capitata*. World J Microbiol Biotechnol. 2011; 27(11):2 619-2628.

23. Maatala N, Lebailly P, Benabdellah M, Dehhaoui M. The Mode of Management of Irrigation Water Service: A Technical Efficiency Determinant of Citrus Farms in the Souss-Massa Perimeter. Tropicultura. 2019; 37(3): 1-19.

24. Thomas MC, Heppner JB, Woodruff RE, Weems H V, Steck GJ, Fasulo TR. Mediterranean Fruit Fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). [online]. 2012 [cited 6 April 2021]. Available on: http://creatures.ifas.ufl.edu

25. Rachid E, Ahmed M. Current status and future prospects of *Ceratitis capitata* wiedemann (Diptera: Tephritidae) control in Morocco. J Entomol. 2018; 15(1): 47-55.

26. Mediouni Ben Jemâa J, Tersim N, Toudert KT, Khouja ML. Insecticidal activities of essential oils from leaves of *Laurus nobilis* L. from Tunisia, Algeria and Morocco, and comparative chemical composition. J Stored Prod Res. 2012; 48(1): 97-104.

27. Matzrafi M. Climate change exacerbates pest damage through reduced pesticide efficacy. Pest Manag Sci. 2019; 75(1): 9-13.

28. Reddy PP. Agro-ecological approaches to pest management for sustainable agriculture. (ed.). Switzerland AG: Springer; 2017. 1-339 p.

29. Rezaei R, Safa L, Ganjkhanloo MM. Understanding farmers' ecological conservation behavior regarding the use of integrated pest management- an application of the technology acceptance model. Glob Ecol Conserv. 2020; 22(2): 1-18.

30. Hallouti A, Zahidi A, Bouharroud R, El Mousadik R, Ait Ben Aoumar A, Boubaker H. Diversity of Entomopathogenic Fungi in Argane Forest Soil and Their Potential to Manage Mediterranean Fruit Fly (*Ceratitis capitata*). J Pharm Pharmacol. 2017; 5(10): 746-754.

31. Samri SE, Baz M, Ghalbane I, El Messoussi S, Zitouni A, El Meziane A, and Barakate M. Insecticidal activity of a Moroccan strain of Streptomyces phaeochromogenes LD-37 on larvae, pupae and adults of the Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). Bull Entomol Res. 1 avr 2017;107(2):217-224.

32. Insecticidal activity of a Moroccan strain of *Streptomyces phaeochromogenes* LD-37 on larvae, pupae and adults of the Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). [online]. 2017 [cited 2021 April 6]. Available on : https://pubmed.ncbi.nlm.nih.gov/28276307/

33. El-Sayed AM, Suckling DM, Wearing CH, Byers JA. Potential of Mass Trapping for Long-Term Pest Management and Eradication of Invasive Species. J Econ Entomol. 2009;99(5):1550–1564.

34. Asadi R, Elaini R, Lacroix R, Ant T, Collado A, Finnegan L, Siciliano P, Mazih A and Koukidou M. Preventative releases of self-limiting *Ceratitis capitata* provide pest suppression and protect fruit quality in outdoor netted cages. Int J Pest Manag. 2020; 66(2): 182-193.

35. de Bon H, Huat J, Parrot L, Sinzogan A, Martin T, Malézieux E, Deletre E, Bonafos R, Simon S, And Ngouajio M. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. Agron Sustain Dev. 2014; 34(4): 723-736.

36. Berni I, Menouni A, Ghazi El I, Duca RC, Kestemont MP, Godderis L, and El Jaafari S. Understanding farmers' safety behavior regarding pesticide use in Morocco. Sustain Prod Consum. 2021; 25(1): 471-483.

37. Hermoso de Mendoza A, Álvarez A, Michelena JM, González P, Cambra M. Working Group Integrated Control in Citrus Fruit Crops. International Conference on Integrated Control in Citrus Fruit Crops Proceedings of the meeting. Int Organ Biol Integr Control. 2008; 38(November 2007): 225-232.

38. Papanicolaou A, Schetelig MF, Arensburger P, Atkinson PW, Benoit JB, Bourtzis K, Castañera P, Cavanaugh JP, Chao H, Childers C, Curril I, Dinh H, Doddapaneni H, Dolan A, Dugan S, Friedrich M, Gasperi G, Geib S, Georgakilas G, Gibbs RA, Giers SD, Gomulski LM, M González-Guzmán, Guillem-Amat A, Han Y, Hatzigeorgiou AG, Hernández-Crespo P, Hughes DST, Jones JW, Karagkouni D, Koskinioti P, Lee SL, Malacrida AR, Manni M, Mathiopoulos K, Meccariello A, Murali SC, Murphy TD, Muzny DM, Oberhofer G, Ortego F, Paraskevopoulou MD, Poelchau M, Qu J, Reczko M, Robertson HM, Rosendale AJ, Rosselot AE, Saccone G, Salvemini M, Savini G, Schreiner P, Scolari F, Siciliano P, Sim SB, Tsiamis G, Ureña E, Vlachos IS, Werren JH, Wimmer EA, Worley KC, Zacharopoulou A, Richards S, and Handler AM. The whole genome sequence of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), reveals insights into the biology and adaptive evolution of a highly invasive pest species. Genome Biol. 2016; 17(1): 1-31.

39. Yuval B, Kaspi R, Shloush S, Warburg MS. Nutritional reserves regulate male participation in Mediterranean fruit fly leks. Ecol Entomol. 1998; 23(2): 211-215.

40. Medflies S. Breakfast of Champions or Kiss of Death? Survival and Sexual Performance of Protein-Fed, Sterile Mediterranean Fruit Flies (Diptera: Tephritidae). 2000; 90(1): 115-122.

41. Chapman T, Miyatake T, Smith HK, Partridge L. Interactions of mating, egg production and death rates in females of the Mediterranean fruit fly, *Ceratitis capitata*. Proc R Soc B Biol Sci. 1998; 265(1408): 1879-1894.

42. Gomulski LM, Dimopoulos G, Xi Z, Scolari F, Gabrieli P. Transcriptome Profiling of Sexual Maturation and Mating in the Mediterranean Fruit Fly, *Ceratitis capitata*. PLoS ONE. 2012; 7(1): 1-10.

43. Benelli G, Rizzo R, Zeni V, Govigli A, Samková A, Sinacori M, et al. Carlina acaulis and Trachyspermum ammi essential oils formulated in protein baits are highly toxic and reduce aggressiveness in the medfly, *Ceratitis capitata*. Ind Crops Prod. 2021; 161(3): 1-10.

44. Rachid E, Ahmed M. Current status and future prospects of *Ceratitis capitata* wiedemann (Diptera: Tephritidae) control in Morocco. J Entomol. 2018; 15(1): 47-55.

45. Yahia EM, Jones RW, Thomas DB. Quarantine pests of tropical and subtropical fruits and their control. In: Postharvest Biology and Technology of Tropical and Subtropical Fruits. (1st ed.). Sawston: Woodhead Publishing; 2011. 224-287 p.

46. Jacas JA, Karamaouna F, Zappalà L. Integrated Management of Arthropod Pests and Insect Borne Diseases. Integr Manag Arthropod Pests Insect Borne Dis. (1st ed.). Paris: Lavoisier 2010; 366 p.

47. Moore SD, Duncan LW. Microbial Control of Insect and Mite Pests of Citrus. Microbial Control of Insect and Mite Pests: From Theory to Practice. (2nd ed.). Amsterdam: Elsevier Inc. 2017. p 283-298.

48. Jaronski ST. Ecological factors in the inundative use of fungal entomopathogens. BioControl. 2010; 55(1): 159-185.

49. Peña JE, Hoddle MS, Aluja M, Palevsky E, Ripa R, Wysoki M. Insect and mite pests. The avocado: botany, production and uses. (2nd ed.). Florida: CABI. 2013. p 423-488.

50. Garcia FRM, Ovruski SM, Suárez L, Cancino J, Liburd OE. Biological control of tephritid fruit flies in the Americas and Hawaii: A review of the use of parasitoids and predators. Insects. 2020; 11(10): 1-32.

51. de Pedro L, Tormos J, Harbi A, Ferrara F, Sabater-Muñoz B, Asís JD, Beitia F. Combined use of the larvo-pupal parasitoids *Diachasmimorpha longicaudata* and *Aganaspis daci* for biological control of the medfly. Ann Appl Biol. 2019; 174(1): 40-50.

52. Di Ilio V, Cristofaro M. Polyphenolic extracts from the olive mill wastewater as a source of biopesticides and their effects on the life cycle of the Mediterranean fruit fly *Ceratitis capitata* (Diptera, Tephriditae). Int J Trop Insect Sci. 2021; 41(1): 359-366.

53. Mokrini F, Laasli SE, Benseddik Y, Joutei AB, Blenzar A, Lakhal H, Sbaghi M, Imren M, Özer G, Paulitz T, Lahlali R & Dababat AA. Potential of Moroccan entomopathogenic nematodes for the control of the Mediterranean fruit fly *Ceratitis capitata* Wiedemann (Diptera: Tephritidae). Sci Rep. 2020; 10(1): 1-11.

54. Hallouti A, Ait Hamza M, Zahidi A, Ait Hammou R, Bouharroud R, Ait Ben Aoumar A, and Boubaker H. Diversity of entomopathogenic fungi associated with Mediterranean fruit fly (*Ceratitis capitata* (Diptera: Tephritidae)) in Moroccan Argan forests and nearby area: impact of soil factors on their distribution. BMC Ecol. 2020; 20(1): 1-13.

55. García Reyes LE. The Influence of Entrepreneurial Orientation, Innovation and Characteristics of Entrepreneurs on Business Performance in Wid Area . J Chem Inf Model . 2013; 53(9): 1689-1699 .

56. Grogan KA, & Goodhue RE. Citrus growers vary in their adoption of biological control. California Agriculture. 2012; 66(1): 29–36.

57. Benedict MQ. Sterile Insect Technique: Lessons from the Past. J Med Entomol. 2021; 58(5): 1-6.

58. Mazih A, Debouzie D. Infestation rate of argan fruit (Argania spinosa) by the Mediterranean fruit fly (*Ceratitis capitata*) in relation to phenology and maturation of the fruit. Entomol Exp Appl. 1996; 81(1): 31-38.

59. Shahini S, Bërxolli A, Kokojka F. Effectiveness of bio-insecticides and mass trapping based on population fluctuations for controlling *Tuta absoluta* under greenhouse conditions in Albania. Heliyon. 2021; 7(1): 1-7.

60. De Meyer M, Copeland RS, Wharton RA, McPheron BA, Barnes BN. On the geographic origin of the Medfly *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). Proc 6th Int Symp Fruit Flies Econ Importance. 2004;(May 2002):45-53.

61. Morocco Sterilizes the Mediterranean Fruit Fly [online]. [cited 2021 April 6]. available on: https://www.moroccoworldnews.com/2019/06/275841/morocco-sterilizes-the-mediterranean-fruit-fly/

62. Egziabher TBG, Edwards S. technogie of irradiatin citrus marocan. Afr Potential Ecol Intensif Agric. 2013; 53(9): 1689-1699.

63. Harbouze R, Pellissier J-P, Rolland J-P, Khechimi W. Synthesis report on agriculture in Morocco [online]. 2019 [cited 2021 Sep 12] p. 104. Available from: https://hal.archives-ouvertes.fr/hal-02137637

64. Aloui O, Kenny L. The cost of compliance with SPS standards for Moroccan exports : a case study. undefined [online]. 2005 [cited 2021 Sep 12]; Available from: https://www.semanticscholar.org/paper/The-cost-of-compliance-with-SPS-standards-for-%3A-a-Aloui-Kenny/89fa138c8725c34f01f6448192a3d4aec94d8674

65. Assouguem, A., Kara, M., Mansouri, I., Imtara, H., Alzain, M. N., Mechchate, H., Conte, R., Squalli, W., Farah, A., & Lazraq, A. Evaluation of the effectiveness of spirotetramat on the diaspine scale parlatoria pergandii in citrus orchards. Agronomy, 2021;11(8), 1–11.

66. Elaini R, Asadi R, Naish N, Koukidou M, Ahmed M. Evaluation of rearing parameters of a self-limiting strain of the mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). Insects. 2020; 11(10): 1-11.

67. Pereira R, Yuval B, Liedo P, Teal PEA, Shelly TE, McInnis DO, Hendrichs J. Improving sterile male performance in support of programmes integrating the sterile insect technique against fruit flies. J Appl Entomol. 2013; 137(SUPPL.1): 178-190.

68. Yamada H, Vreysen MJ, Gilles JR, Munhenga G, Damiens DD. The effects of genetic manipulation, dieldrin treatment and irradiation on the mating competitiveness of male Anopheles arabiensis in field cages. Malar J. 2014; 13(1): 1-10.

69. Shelly TE, Whittier TS, Kaneshiro KY. Sterile insect release and the natural mating system of the Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). Ann Entomol Soc Am. 1994; 87(4): 470-481.

70. Lance DR, McInnis DO, Rendon P, Jackson CG. (Diptera: Tephritidae) in Field Cages in Hawaii and Guatemala. Ann Entomol Soc Am. 2000; 93(5): 1179-1185.

71. Rendón P, McInnis D, Lance D, Stewart J. Medfly (Diptera:Tephritidae) genetic sexing: Large-scale field comparison of males-only and bisexual sterile fly releases in Guatemala. J Econ Entomol. 2004; 97(5): 1547-1553.

Chapitre I

Évaluation de l'effet de différentes concentrations de spirotétramate sur la cochenille diaspine *Parlatoria pergandii*

Cette étude a fait l'objet d'une publication dans Agronomy Journal : (IF= 3,95)

Assouguem, A.; Kara, M.; Mansouri, I.; Imtara, H.; Alzain, M.N.; Mechchate, H.; Conte, R.; Squalli, W.; Farah, A.; Lazraq, A. Evaluation of the Effectiveness of Spirotetramat on the Diaspine Scale *Parlatoria pergandii* in Citrus Orchards. 2021, 1–12.

Résumé

La lutte chimique contre *Parlatoria pergandii* (Comstock, 1881) a été étudiée dans des vergers d'agrumes de la région du Gharb de la commune Mechraa Belksiri. Trois concentrations de Spirotétramate (T0 = 0 L/Ha, T1 = 0,625 L/Ha, T2 = 0,755 L/Ha, et T3 = 1 L/Ha) ont été appliquées sur 4 ha de verger de Valencia late (chaque dose pour 1 ha d'agrumes). L'insecticide à base de Spirotétramate a été évalué sur deux stades larvaires (L1 et L2) de *P. pergandii* et trois stades de femelles, F1, F2 et F3. De même, les taux de parasitisme par *Aphytis hispanicus* sur les femelles de trois stades ont été suivis pour évaluer l'impact du Spirotétramate sur cet ennemi naturel. Les résultats ont montré que le Spirotétramate était plus efficace sur les larves que sur les femelles. Parmi les femelles, 26,04 % ont été parasitées, 65,81 % ont été inhibées et seulement 8,15 % sont restées intactes après la période du traitement. Parmi les larves, 79,73% ont été inhibées, et seulement 20,27% ont survécu après la période de traitement. Enfin, notre étude met en évidence que toutes les concentrations testées de ce produit ont été efficaces sur la population de *P. pergandii*. Par ailleurs, ce produit a montré un impact moins négatif sur les femelles parasitées avec la faible concentration (0,625 L/Ha) par rapport aux fortes concentrations du pesticide (T2 = 0,755 L/Ha et T3 = 1 L/Ha), notamment pour les stades femelles F2 et F3.

Evaluation of the Effectiveness of Spirotetramat on the Diaspine Scale *Parlatoria pergandii* in Citrus Orchards

Amine Assouguem 1, Mohammed Kara 2, Ismail Mansouri 1, Hamada Imtara 3, Mashail N. AlZain 4, Hamza Mechchate 5, Raffaele Conte 6, Wafae Squalli 1, Abdellah Farah 7 and Abderrahim Lazraq 1

1 Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco
2 Laboratory of Biotechnology and Conservation and Valorization of Natural Resources (LBCVRN) (ex LBPRN), Sidi Mohamed Ben Abdellah University, Fez B.P. 1796, Morocco
3 Faculty of Arts and Sciences, Arab American University Palestine, Jenin P.O. Box 240, Palestine
4 Department of Biology, College of Sciences, Princess Nourah Bint Abdulrahman University, Riyadh 11451, Saudi Arabia
5 Laboratory of of Biotechnology, Environment, Agri-Food, and Health (LBEAS), Faculty of Science Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez B.P. 1796, Morocco
6 Research Institute on Terrestrial Ecosystems (IRET)—CNR, Via Pietro Castellino 111, 80131 Naples, Italy
7 Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco
Correspondence : Hamza Mechchate

Abstract

The control of *Parlatoria pergandii* (Comstock, 1881) was studied in citrus orchards at Belksiri (Gharb area), Morocco. Three concentrations of Spirotetramat (T0 = 0 L/Ha, T1 = 0.625 L/Ha, T2 = 0.755 L/Ha, and T3 = 1 L/Ha) were applied to 4 ha of Valencia late orchard (each dose for 1 ha of citrus). The insecticidal of Spirotetramat was evaluated on two stages of larvae (L1 and L2) of *P. pergandii* and three stages of females, F1, F2, and F3. Similarly, the rates of parasitism by *Aphytis hispanicus* on the females of three different stages were monitored to evaluate the impact of Spirotetramat on this natural enemy. Results showed that Spirotetramat was more effective on larvae than females. Of the females, 26.04% were parasitized, 65.81% were inhibited, and only 8.15% were intact after the treatment period. Of the larvae, 79.73% were inhibited, and only 20.27% survived after the treatment period. Finally, our study highlights that all the tested concentrations of this product were effective on the population of *P. pergandii*. On the other hand, this product showed a less negative impact on the parasitized females with the low concentration (0.625 L/Ha) compared to the high concentrations of the pesticide (T2 = 0.755 L/Ha and T3 = 1 L/Ha), especially for the female stages F2 and F3. Moreover, the impact on the water table will be less severe with a low concentration.

Keywords: Parlatoria pergandii; parasitoid; pest control; Spirotetramat; Valencia late, Morocco

Introduction

Citrus is one of the most essential fruit trees cultivated in the Mediterranean area [1,2]. In Morocco, the amount of land dedicated to citrus plantations is growing every year; the total annual production is ~3 million tons of citrus fruit. It is mainly produced in Souss, Berkane, Tadla and Haouz regions with a total surface area of 126.600 ha [3,4]. However, in addition to the complications of production and marketing, there are numerous pest species and diseases that are reducing the quantity and quality of citrus fruits [5,6].

To date, there are more than 155 weed species, 90 pest species, 34 diseases species, and 16 nematodes in citrus farming zones, mainly in the Mediterranean region from Turkey in the East to Morocco in the far West Nadine [7,8,9]. Among this diversity of nuisances, the polyphagous *Parlatoria pergandii* (Comstock, 1881) (Hemiptera: Diaspididae) is one of the most widely-dispersed citrus pest species invading citrus worldwide and in Morocco [10,11]. Infestations caused by this insect pest can be documented by the occurrence of the scale-armor on citrus tree parts, including the leaves, stems, and fruits [12]. However, symptoms are mostly related to the severity of the infestation (density of pest on the host) and host immunity [13].

Infestations on the citrus trees, mainly on the stems and leaves, principally cause wilting and decrease the photosynthetic pigments and surfaces of the plants, leading to reductions in yields and revenues [14]. Generally, *P. pergandii* reduces the quantity and quality of citrus fruits produced. The latter decreases marketing opportunities, particularly in big markets, such as the European Union the USA where the exportation standards are more complex [15].

To control *P. pergandii*, many approaches, including chemical and eco-friendly methods, are used [16,17,18]. While in northern countries, sustainable methods are encouraged, pest management is profoundly dependent on chemical treatments in other southern countries [19]. In Morocco, before 2010, sustainable approaches were neglected and rudimentary [20]. However, with the newly imposed standards, mainly in terms of the use of chemical compounds, pesticides have become a problem because of the remaining residues on fruits. Moreover, the development of resistance to pesticides has negatively impacted production, harvesting, and exportation of citrus fruits [21].

The development cycle of *P. pergandii*, including the duration of each larval (L1 and L2), female (F1, F2, and F3), and male (pre-pupa, pupa, and adult) stage; fecundity; oviposition rate; and sex ratio are largely influenced by the host plant and temperature [22,23,24]. The life cycle lasts, on average, 56.28 days for lemons and only 45.33 days for squash. The fecundity is

86 larvae per female for lemons and 109 for squash [24]. On the other hand, the number of generations per year varies with climatic conditions—three generations in Morocco and Spain and three to four in Israel [23,25].

Aphytis hispanicus (Mercet, 1912) (Hymenoptera: Aphelinidae) is an important parasite of *P. pergandii* in Morocco [22,23,24]. They develop exclusively as primary ectoparasitoids of diaspine scaled insects [26]. The adult female pierces the shield of the scale with the ovipositor and lays one or several eggs on the body of the scaled insect [27].

Spirotetramat is a systemic insecticide listed in Group 23 of the Insecticide Resistance Action Committee. It is a compound that belongs to the chemical class of ketoenols [28]. It is active against piercing-sucking insects, by acting as an acetyl-CoA carboxylase (ACC) inhibitor, interrupting lipid biosynthesis in the insects [29,30]. In this study, we used field monitoring to investigate the adequate dose of Spirotetramat to control *P. pergandii* without affecting natural enemies of the pest in citrus orchards. More specifically, we studied the lowest effective dose of Spirotetramat on larvae and females regarding its impact on the parasitoids of *P. pergandii* inside citrus orchards.

1 Materials and Methods

1.1 Study Area

Fieldwork was conducted in the Belksiri northeast of the Kenitra province, situated at the Gharb plain, North of Morocco (Figure 2). Geographically, the study zone was at low altitude ranging between 300 and 500 m above sea level. The Gharb region is the largest agricultural area (600 km2) in Morocco [31]. This region is well known for the production of fruits and vegetables, including citrus, cereals, and vegetables due to the appropriate climate and soil properties [32]. The Gharb zone is characterized by a Mediterranean climate; annual precipitation ranges between 480 and 600 mm, and the average temperature is 27 °C during summer and 13 °C during winter.



Figure 2. Location of the orchard used.

1.2 Sampling Design

To evaluate the effect of Spirotetramat on *P. pergandii*, an orchard of "Valencia Late" (Citrus sinensis) was selected and monitored because of its abundance in the area [32]. Spirotetramat was selected based on two reasons: (1) the pesticide is effective against a wide range of pests; (2) its low impacts on the environment and natural enemies. The orchard covers 4 ha with 25-year-old citrus trees. The orchard was divided into 4 × 1 ha small plots (Figure 2), and each plot was treated with a specific dose of the pesticide: (i) T0 = 0 L Spirotetramat (as a control experiment), (ii) T1 = 0.625 L, (iii) T2 = 0.755 L, and (iv) T3 = 1 L. In addition, the Teyme Eolo sprayer (Teyme Tecnologia Agricola, Girona, Spain), with its turbulent nozzle and exit diameter of 12 mm, delivered 1.55 L/min at a pressure of 20 bars. The towed sprayer delivers 2500 L of spray liquid per hectare, at a rate of 6 L of spray liquid for each tree, allowing us to wet all parts of the tree. (Figure 3). Concentrations were selected based mainly on the quantity of pesticide used regularly by local farmers.

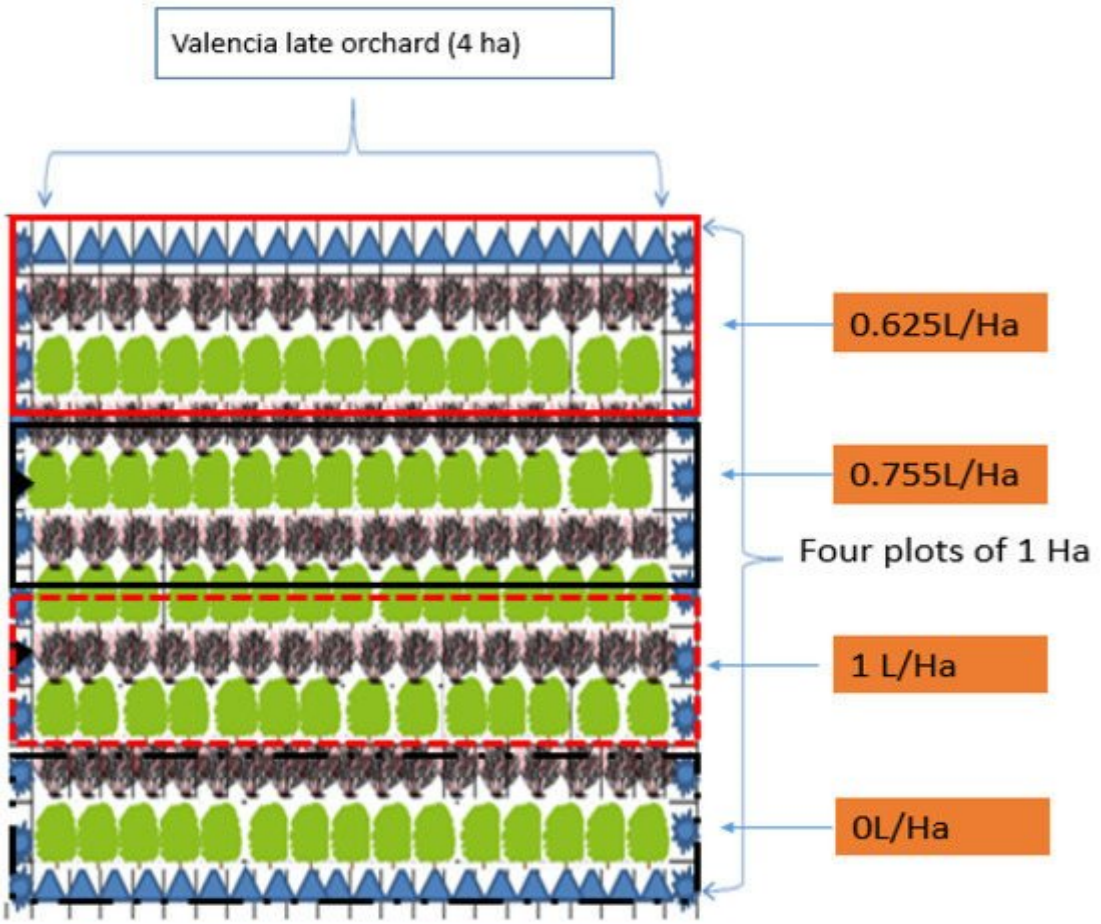


Figure 3. A model of the orchard we monitored (divided into four small plots of 1 ha) with the doses of Spirotetramat we used.

To evaluate the effect of each dose, after treatment (1 to 8 weeks) we sampled 200 leaves from late Valencia trees in each plot. Ten leaves/tree were collected randomly from the different directions (north, east, south, and west) of the tree, for a total of 20 trees/plot that belonged to a square block (3 repetitions were performed independently). We left 2 lines between the different plots treated with this systemic product. The collected leaves were transferred directly in polyethylene bags referenced to the laboratory for examination. The scaled insect stages on each leaf were determined and counted on both surfaces of the leaves by using a binocular microscope. Then, we counted the mortalities (M) and survivals (V) of *P. pergandii* at two larval stages (L1 and L2) and three female stages (F1, F2, and F3). In parallel, to evaluate the effect of Spirotetramat on natural enemies of *P. pergandii*, after each treatment, we counted the parasitism rates (P) by *Aphytis hispanicus* on the females at three different stages, F1, F2, and F3. *Aphytis hispanicus* is an important parasitoid of *P. pergandii* in the area and the Mediterranean in general.

1.3 Statistics

Statistics were done using the Statgraphics Centurion software, version XVI.I for windows (Statgraphics Technologies, The Plains, VA, USA), and the results are given as sample size and mean ± SD. Moreover, to evaluate the effectiveness of Spirotetramat, we calculated the survival (surviving specimens/total sampled specimens) and mortality (inhibited specimens/total sampled specimens) of *P. pergandii* for both larvae and females. In parallel, to evaluate the impact of the pesticide on natural enemies, we calculated the parasitism rate of A. hispanicus on females (parasitized females/total sampled females).

We checked for normality and homogeneity of variance for all variables via Kolmogorov–Smirnov test. To assess the mortality of larvae of *P. pergandii*, we used the independent t-test, considering the two stages as unrelated parameters [33]. The mortality among females (three stages) was tested by one-way ANOVA. We analyzed separately, for both larvae and females, the relationship between Spirotetramat inhibition effectiveness (mortalities of *P. pergandii*) and survival (surviving specimens of *P. pergandii*) by simple regression (linear model) [34], and all variables with P values greater than 0.05 were considered non-significant.

To investigate the effectiveness of Spirotetramat, treatment doses as predictors of pest and parasitoid mortalities (response variables: with 0 (no mortalities) and 1 (at least one victim recorded)), a model with a binomial error structure and a logit link function was applied [35]. The model was applied for the totality of *P. pergandii* pests (all recorded specimens) and A. hispanicus parasitoids (all recorded parasitoids). In the case of parasitoids, the impact was reversed (the mortalities were considered as losses of natural enemies).

2 Results

2.1 Impact on Larvae

Among the 5115 recorded larvae (Figure 3), 79.73% (n = 4078) were inhibited, and only 20.27% (n = 1037) survived after the treatment period. Equally, during stage 1 (larvae 1), 2441 larvae were dead and 841 survived. Similarly, during stage 2 (larvae 2), 1637 larvae were eliminated and 196 survived. Surviving larvae were more common during stage 1 (Table 2). Mortalities were higher during stage 1. Mortalities and survival rates were uncorrelated during both stages (Figure 5).

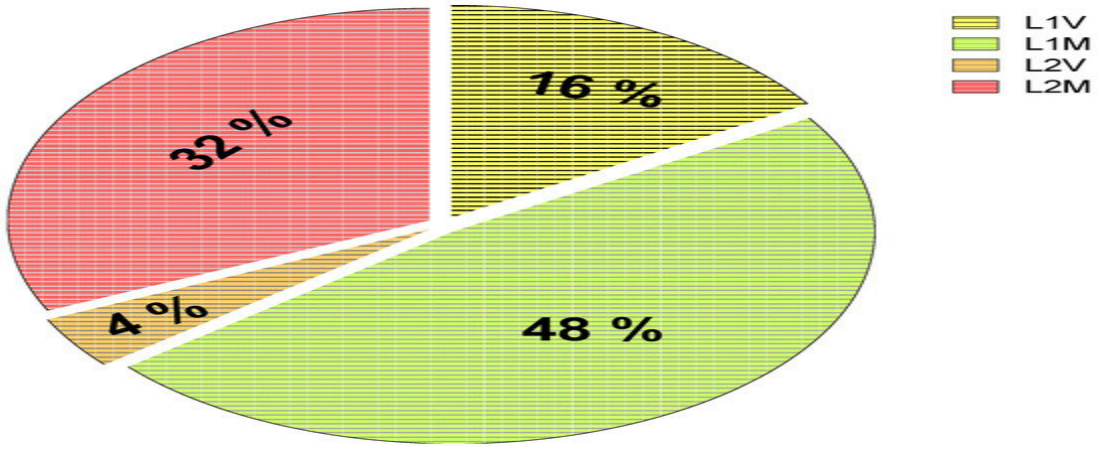


Figure 4. A comparison of mortalities (M) and survival rates (V) during two larvae stages (L1 and L2) of *Parlatoria pergandii* (L1V: surviving larvae of stage 1; L1M: dead larvae of stage 1; L2V: surviving larvae of stage 2; L2M: dead larvae of stage 2).

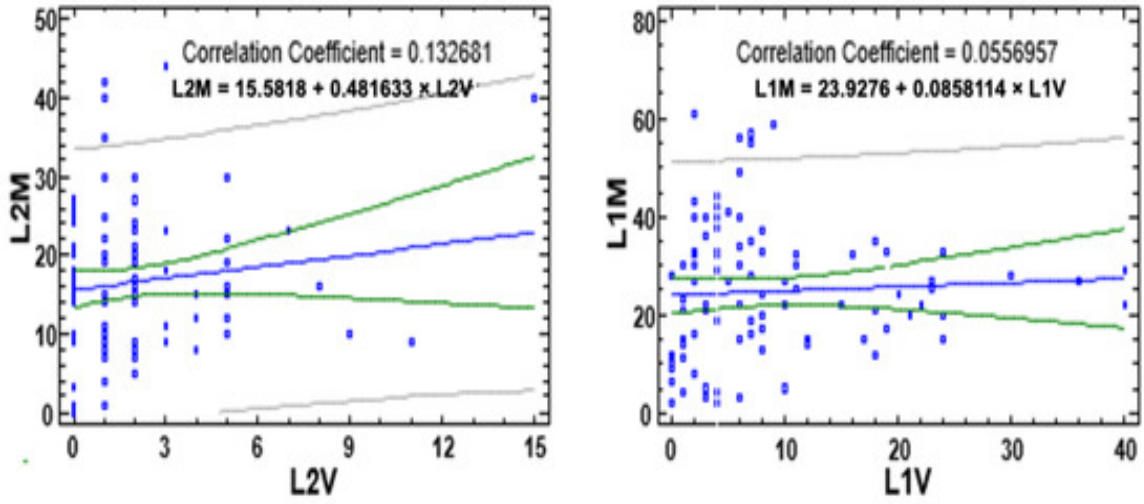


Figure 5. Analysis of the the survival rates of *Parlatoria pergandi*i during stages larvae 1 and larvae 2.

Table 2. A comparison of mortalities (M) and survival (V) rates among different larval stages of *Parlatoria pergandii* treated with Spirotetramat.

Compared Parameters	*T*	df	*p*-Value
L1V-L1M	−10.223	98	0.000
L2V-L2M	−16.183	98	0.000
L1V-L2V	7.948	98	0.000
L1M-L2M	5.263	98	0.000

Table 3. The survival (V) and mortality (M) of two larval stages (L1 and L2) of *Parlatoria pergandii* treated with different concentrations of Spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha).

	L1V	L1M	L2V	L2M
T0	16.08 ^{a} ± 2.32	17.70 ^{b} ± 1.73	3.95 ^{a} ± 0.53	11.75 ^{b} ± 1.19
T1	5.04 ^{b} ± 0.68	26.08 ^{ab} ± 2.89	0.91 ^{b} ± 0.17	14.95 ^{ab} ± 1.19
T2	6.12 ^{b} ± 1.46	29.37 ^{a} ± 2.94	0.79 ^{b} ± 0.15	17.33 ^{a} ± 2.17
T3	6.92 ^{b} ± 1.30	25.37 ^{ab} ± 2.68	2.22 ^{b} ± 0.61	21.48 ^{a} ± 1.82

Values in the same column with different superscripts are significantly different ($p < 0.05$)

Table 4. Comparison of mortality (M), parasitism rates (P), and survival rates (V) of three female stages (F1, F2, and F3) of *Parlatoria pergandii* by one-way ANOVA during treatment dates.

		Sum of Squares	df	Mean Square	F	*p*-Value
F1V	Between Groups	61.365	3	20.455	5.476	0.002
	Within Groups	343.625	92	3.735		
	Total	404.990	95			
F2V	Between Groups	158.531	3	52.844	4.687	0.004
	Within Groups	1037.208	92	11.274		
	Total	1195.740	95			
F3V	Between Groups	125.531	3	41.844	1.974	0.123
	Within Groups	1950.208	92	21.198		
	Total	2075.740	95			
F1M	Between Groups	1766.365	3	588.788	8.181	0.000
	Within Groups	6621.375	92	71.971		
	Total	8387.740	95			
F2M	Between Groups	3655.031	3	1218.344	6.511	0.000
	Within Groups	17,213.958	92	187.108		
	Total	20,868.990	95			
F3M	Between Groups	11,303.865	3	3767.955	13.589	0.000
	Within Groups	25,509.292	92	277.275		
	Total	36,813.156	95			
F1P	Between Groups	618.698	3	206.233	19.971	0.000
	Within Groups	950.042	92	10.327		
	Total	1568.740	95			
F2P	Between Groups	78.781	3	26.260	0.382	0.767
	Within Groups	6332.208	92	68.828		
	Total	6410.990	95			
F3P	Between Groups	279.750	3	93.250	0.516	0.672
	Within Groups	16,634.750	92	180.813		
	Total	16,914.500	95			

2.2 Impact on Females

Among the 14,657 recorded females (**Figure 6**), 26.04% (*n* = 3816) were parasitized, 65.81% (*n* = 9646) were inhibited, while only 8.15% (*n* = 1195) were intact after the treatment period. In detail, during stage F1, only 1% (*n* = 161) survived; 10% (*n* = 1526) and 3% (*n* = 421) were inhibited and colonized by parasites, respectively. In addition, during stage F2, 3% (*n* = 373) survived, 22% (*n* = 3167) were eliminated, and 9% (*n* = 1343) were parasitized. Equally, 4% (*n* = 661) survived, 34% (*n* = 4953) were inhibited, and 14% (*n* = 2052) were parasitized during stage F3.

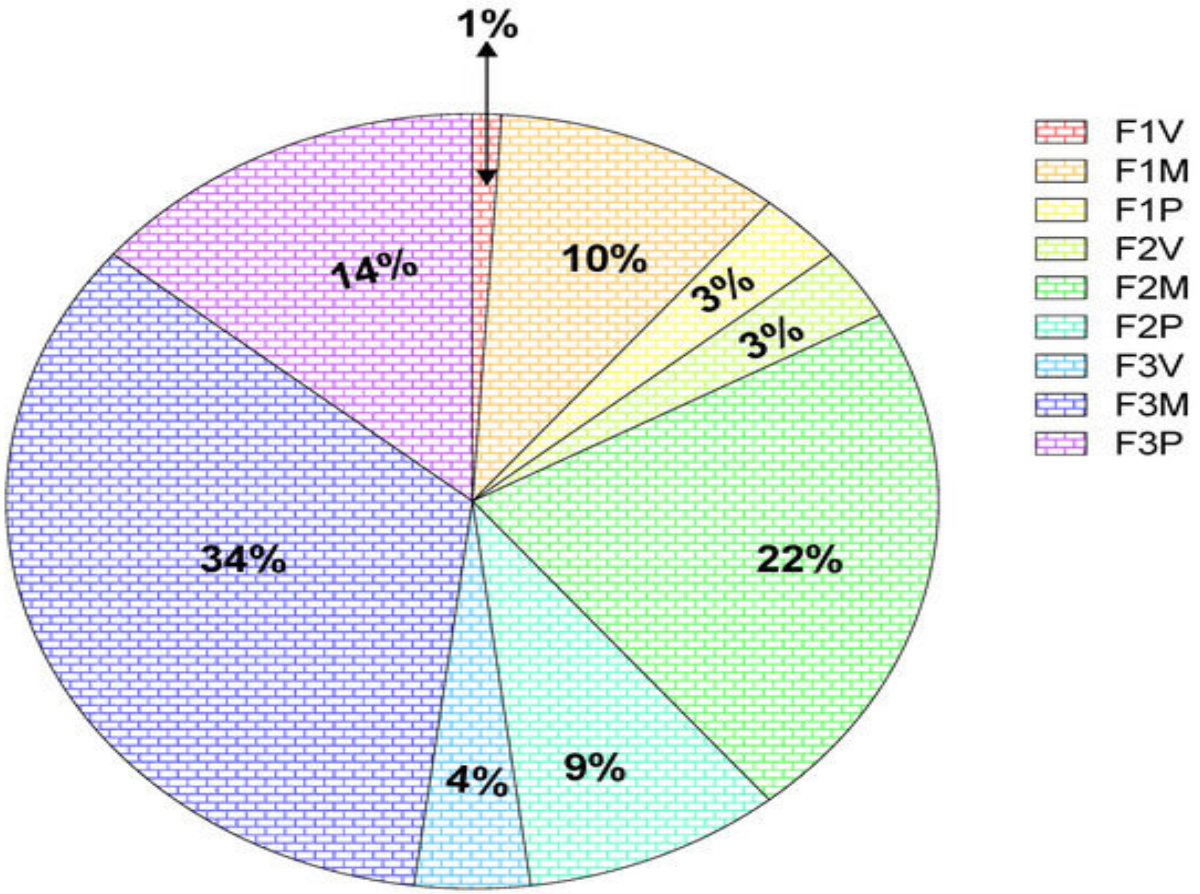


Figure 6. A comparison of mortalities (M), parasitism rates (P), and survival rates (V) during three female stages (F1V: survived females of stage 1; F1M: dead females of stage 1; F1P: parasitized females of stage 1; F2V: surviving females of stage 2; F2M: dead females of stage 2; F2P: parasitized females of stage 2; F3V: surviving females of stage 3; F3M: dead females of stage 3; F3P: parasitized females of stage 3.

In terms of a comparison among the stages, total surviving females and parasitism rates were higher during stage 3 (4% and 14%, respectively) (**Figure 6**). Inhibited females were higher in number during stages two and three. On the other hand, survival rates were variable

for all periods (**Table 4**). Similarly, eliminated females (F1M, F2M, and F3M) were different during monitoring dates. Parasitism rates were variable only during stage F1.

With respect to T0 (untreated plot), all three doses of the systemic product were effective on surviving females at stages two and three (F2V and F3V). The same effect was produced for dead females of stages 1 and 2 (F1M and F2M); however, for dead females of stage 3 (F3M), the concentration 0.755 (T2) was most effective, with an average of 57.25 ^{a} ± 5.07. In addition, T1 ensured the higher parasitism rate at all three female stages (**Table 5** and **Table 6**). The average was 4.75 ^{ab} ± 0.93 for females of stage 1, 14.5 ^{b} ± 0.99 for females of stage 2, and 20.45 ^{b} ± 1.22 for females of stage 3.

Table 5. Survival (V), mortality (M), and parasitism (P) of *Parlatoria pergandii* females (F1, F2, and F3) treated with different concentrations of Spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha).

	F1V	F1M	F1P	F2V	F2M	F2P	F3V	F3M	F3P
T0	2.83 ^{a} ±0.41	9.75 ^{b} ± 0.94	6.20 ^{a} ± 0.79	6.20 ^{a} ± 0.92	21.16 ^{b} ± 2.27	23.91 ^{a} ± 1.51	12.08 ^{a} ± 0.98	42.41 ^{b} ± 2.28	40.25 ^{a} ± 1.87
T1	1.95 ^{ab} ± 0.59	18.83 ^{a} ± 2.32	4.75 ^{ab} ± 0.93	3.66 ^{b} ± 0.77	37.16 ^{a} ± 2.21	14.5 ^{b} ± 0.99	4.5 ^{b} ± 0.50	52.25 ^{ab} ± 3.20	20.45 ^{b} ± 1.22
T2	1.16 ^{ab} ± 0.20	18.16 ^{a} ± 1.82	3.87 ^{ab} ± 0.87	2.58 ^{b} ± 0.31	40.20 ^{a} ± 3.49	8.79 ^{c} ± 0.69	4.58 ^{b} ± 0.53	57.25 ^{a} ± 5.07	13.45 ^{c} ± 1.23
T3	0.66 ^{b} ± 0.15	17.14 ^{a} ± 1.67	2.90 ^{b} ± 0.43	2.47 ^{b} ± 0.30	32.95 ^{a} ± 2.23	8.95 ^{c} ± 1.02	5.57 ^{b} ± 0.59	54.04 ^{ab} ± 4.41	11.57 ^{c} ± 1.11

Means that do not share a letter are significantly different.

Table 6.Effect of treatment doses (T0: 0 L/Ha Spirotetramat (as a witness experiment), T1 = 0.625 L/Ha, T2 = 0.755 L/Ha, and T3 = 1 L/Ha) on the mortalities of *Parlatoria pergandii*, and the parasitoid *Aphytis hispanicus*.

		Estimate	Standard Error	Wald Test	*p*-Value
Survival	Intercept	−1.073	0.530	4.101	0.043
	T0	−0.118	0.038	9.523	0.002
	T1	0.063	0.028	4.991	0.055
	T2	−0.001	0.002	0.525	0.539
	T3	−0.136	0.563	0.561	0.056
	Scale	1.000	0.000		
Mortalities	Intercept	−1.046	0.480	5.212	0.065
	T0	−0.161	0.073	8.431	0.042
	T1	0.058	0.033	9.047	0.002
	T2	−0.051	0.012	10.321	0.001
	T3	−0.456	0.451	0.621	<0.001
	Scale	1.000	0.000		
Parasitoid Survival	Intercept	−1.064	0.690	5.654	0.007
	T0	−0.543	0.053	10.632	0.001
	T1	0.454	0.032	7.431	0.05
	T2	−0.034	0.0453	0.565	0.789
	T3	−0.136	0.563	0.674	0.796
	Scale	1.000	0.000		

3 Discussion and Conclusions

To our knowledge, this is the first study on the use of chemical treatment to control *P. pergandii*. Our main aim was to provide detailed data on the effectiveness of Spirotetramat regarding the pest and the secondary effect on the parasitoid *A. hispanicus*. These findings provided the first set of data related to the control of *P. pergandii* in citrus in Morocco and the entire Northwest African zone, which should be of great interest for the undertaking of new comparative studies and the adoption of sustainable doses to control the pest and protect the natural enemies.

Our results showed that in the larval stage the inhibition was nearly 80%, whereas in the adult stage the inhibition rate was lower. These results are similar to the results reported for other pests, including the citriculus mealybug *Pseudococcus cryptus* (Hempel), the spherical mealybug *Nipaecoccus viridis* (Newstead), the longtailed mealybug *P. longispinus* (Targioni-Tozzetti), *Planococcus citri* (Risso), the citrophilus mealybug *P. calceolariae* (Maskell), and the obscure mealybug *P. viburni* (Signoret) treated by different control methods and substances

in the same area [**36**,**37**]. The lower mortality rates in females are mainly due to the vulnerability of larval stage [**38**]. Equally, females are characterized by their resistance toward chemicals, and this is considered among the issues of pesticide use in pest control [**38**,**39**].

In larval stages, the effectiveness of the concentrations was variable. T2 (0.755 L/Ha) was effective against larvae 1, and T3 (0.625 L/Ha) was effective on larvae 2. Increasing the amount of pesticide applied significantly increased the inhibition rate observed. However, the main goal was using the minimum pesticide concentration necessary to achieve effective control of *P. pergandii*. This approach will allow lower pesticide use and avoid the development of pesticide resistance. Consequently, less residues should remain on the fruits and in the soil [**40**,**41**].

Among the 14,657 recorded females, 26.04% were parasitized, 65.81% were inhibited, and only 8.15% were intact after the treatment period. In Algeria, similar results were mentioned for citrus: Spirotetramat controlled *P. pergandii* with encouraging results [**42**]. However, the effectiveness each concentration was variable depending on the insect stage. In fact, all three concentrations of the systemic product were effective on surviving females of stages two and three (F2V and F3V); the same was true for dead females of stages 1 and 2 (F1M and F2M); however, for dead females of stage 3 (F3M), the low concentration 0.625 (T1) was most effective. T1 ensured the highest parasitism rate for all three female stages. Therefore, 0.625 L/Ha is suggested to be less harmful to the environment and natural enemies. In Algeria, the same results were reported by [**43**]: all the doses used of Spirotetramat were effective on the population of *P. blanchardi* on date palms. Therefore, the choice of the right concentration remains a necessity in order to preserve the agroecosystem [**44**]. Generally, high quantities of pesticides allow one to control pests, but they negatively influence natural enemies of pests and the environment. On the other hand, the combination of natural enemies and low pesticide doses would allow effective and eco-friendly control of *P. pergandii.*

Our findings highlight four key messages: (1) data indicate that Spirotetramat was most effective on the larvae of *P. pergandii*; (2) the lowest dose was effective on different stages of female and had a low impact on the parasitoid *A. hispanicus;* (3) the combination of chemical measures and natural enemies will reduce the population of *P. pergandii* on citrus trees in the Gharb plain; (4) the use of small doses of the pesticide will reduce the impact on the environment and reduce the resistance of the insect. Given that Spirotetramat is an effective pesticide and is widely used, more studies on its effects on other populations of natural enemies and the residues remaining on fruits are needed to establish proper management strategies.

Author Contributions

Conceptualization, A.A. and A.L.; methodology, A.A. and I.M.; validation, W.S. and M.K.; data curation, H.M., H.I., R.C. and M.N.A.; writing—original draft preparation, A.A.; writing—review and editing, R.C. and M.N.A.; supervision, A.L. and A.F. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University through the Fast-track Research Funding Program.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Acknowledgments

The authors are thankful to the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University for the support of this research through the Fast-track Research Funding Program.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Dambier, D.; Benyahia, H.; Pensabene-Bellavia, G.; Kaçar, Y.A.; Froelicher, Y.; Belfalah, Z.; Lhou, B.; Handaji, N.; Printz, B.; Morillon, R. Somatic Hybridization for Citrus Rootstock Breeding: An Effective Tool to Solve Some Important Issues of the Mediterranean Citrus Industry. *Plant Cell Rep.* **2011**, *30*, 883–900. [**Google Scholar**] [**CrossRef**] [**PubMed**]
2. Klein, J.D. Citron cultivation, production and uses in the Mediterranean region. In *Medicinal and Aromatic Plants of the Middle-East*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 199–214. [**Google Scholar**]
3. El-Otmani, M.; Coggins, C.W.; Duymovic, A. Citrus Cultivars and Production in Morocco. *HortScience* **1990**, *25*, 1343–1346. [**Google Scholar**] [**CrossRef**]
4. Oubelkacem, A.; Scardigno, A.; Choukr-Allah, R. Treated Wastewater Reuse on Citrus in Morocco: Assessing the Economic Feasibility of Irrigation and Nutrient Management Strategies. *Integr. Environ. Assess. Manag.* **2020**, *16*, 898–909. [**Google Scholar**] [**CrossRef**]
5. Porat, R.; Weiss, B.; Cohen, L.; Daus, A.; Aharoni, N. Reduction of Postharvest Rind Disorders in Citrus Fruit by Modified Atmosphere Packaging. *Postharvest Biol. Technol.* **2004**, *33*, 35–43. [**Google Scholar**] [**CrossRef**]
6. Prusky, D. Reduction of the Incidence of Postharvest Quality Losses, and Future Prospects. *Food Secur.* **2011**, *3*, 463–474. [**Google Scholar**] [**CrossRef**]
7. Tena, A.; Garcia-Marí, F. Current Situation of Citrus Pests and Diseases in the Mediterranean Basin. *IOBC Bull.* **2011**, *62*, 365–368. [**Google Scholar**]
8. Gutierrez, A.P.; Ponti, L. Prospective Analysis of the Geographic Distribution and Relative Abundance of Asian Citrus Psyllid (Hemiptera: Liviidae) and Citrus Greening Disease in North America and the Mediterranean Basin. *Fla. Entomol.* **2013**, *96*, 1375–1391. [**Google Scholar**] [**CrossRef**]
9. Ali, N. Communautés de Nématodes Phytoparasites Associés à L'olivier: Réponse Aux Forçages Anthropiques et Environnementaux. Ph.D. Thesis, Montpellier SupAgro, Montpellier, France, 2015. [**Google Scholar**]
10. Mazih, A. Current Situation of Citrus Pests and the Control Methods in Use in Morocco. *IOBC WPRS Bull.* **2008**, *38*, 10–16. [**Google Scholar**]
11. Mazih, A. Status of Citrus IPM in the Southern Mediterranean Basin Morocco, North Africa. *Acta Hortic.* **2015**, *1065*, 1097–1103. [**Google Scholar**] [**CrossRef**]

12. Elekcioğlu, N.Z.; Ölçülü, M. Determination of Parasitoid and Predator Species of Chaff Scale [*Parlatoria Pergandii* Comstock (Hemiptera: Diaspididae)] in Citrus Orchards in Eastern Mediterranean Region of Turkey. *Bitki Koruma Bülteni* **2018**, *58*, 131–139. [**Google Scholar**]
13. Jendoubi, H.; Suma, P.; Russo, A. Response of the *Parlatoria* Citrus Scale Insects (Hemiptera, Coccoidea) to Coloured Sticky Traps. In Proceedings of the VII International Scientific Agriculture Symposium, "Agrosym 2016", Jahorina, Bosnia and Herzegovina, 6–9 October 2016; pp. 1529–1535. [**Google Scholar**]
14. Jaouad, M.; Moinina, A.; Ezrari, S.; Lahlali, R. Key Pests and Diseases of Citrus Trees with Emphasis on Root Rot Diseases: An Overview. *Moroc. J. Agric. Sci.* **2020**, *1*, 149–160. [**Google Scholar**]
15. Arenstein, Z.; Ausher, R.; Beicht, W.; Blair, B.D.; Blazquez, C.H.; Dinoor, A.; Dishon, I.; Edelbaum, G.; Elkana, J.; Eshel, J. *Advisory Work in Crop Pest and Disease Management*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2012. [**Google Scholar**]
16. Michael, G.; Ong'amo, G.O.; Nderitu, J.; Watson, G.W.; Kinuthia, W. Diversity of Scale Insects (Hemiptera: Coccomorpha) Attacking Citrus Trees in Machakos, Makueni, Kilifi and Kwale Counties, Kenya. *J. Agric. Sci. Pract.* **2021**, *6*, 79–85. [**Google Scholar**]
17. Damalas, C.A.; Eleftherohorinos, I.G. Pesticide Exposure, Safety Issues, and Risk Assessment Indicators. *Int. J. Environ. Res. Public Health* **2011**, *8*, 1402–1419. [**Google Scholar**] [**CrossRef**] [**PubMed**]
18. Weng, C.-Y.; Black, C. Taiwanese Farm Workers' Pesticide Knowledge, Attitudes, Behaviors and Clothing Practices. *Int. J. Environ. Health Res.* **2015**, *25*, 685–696. [**Google Scholar**] [**CrossRef**] [**PubMed**]
19. Soto, A.; Costa-Comelles, J.; Alonso, A.; Rodriguez, J.M. Efficacy of Some Citrus Pesticides on the Diaspidid Scales Lepidosaphes Beckii (Newman) and Parlatoria Pergandii Comstock (Homoptera, Diaspididae) and Impact on Nontarget Organisms. *Bol. Sanid. Veg. Plagas Esp.* **1994**, *20*, 357–369. [**Google Scholar**]
20. Berni, I.; Menouni, A.; El, I.G.; Duca, R.-C.; Kestemont, M.-P.; Godderis, L.; El, S.J. Understanding Farmers' Safety Behavior Regarding Pesticide Use in Morocco. *Sustain. Prod. Consum.* **2021**, *25*, 471–483. [**Google Scholar**] [**CrossRef**]
21. El Bakouri, H.; Aassiri, A.; Morillo, J.; Usero, J.; Khaddor, M.; Ouassini, A. Pesticides and Lipids Occurrence in Tangier Agricultural Soil (Northern Morocco). *Appl. Geochem.* **2008**, *23*, 3487–3497. [**Google Scholar**] [**CrossRef**]
22. Abbassi, M. Notes Bio-Écologiques Sur Parlatoria Pergandei COMSTOCK (Homopt. Coccidae) Au Maroc. *Fruits* **1975**, *30*, 179–184. [**Google Scholar**]
23. García-Marí, F.; Rodrigo, E. Life Cycle of the Diaspidids *Aonidiella Aurantii*, Lepidosaphes Beckii and Parlatoria Pergandii in an Orange Grove in Valencia (Spain). *IOBC WPRS Bull.* **1995**, *18*, 118. [**Google Scholar**]
24. Jebbour, Y.; Abbassi, M. Recrudescence Du Pou Violet *Parlatoria Pergandii* (Comstock). Homoptera Diaspi-Didae, Sur Agrumes Au Maroc: Biologie et Écologie de l'espèce. *Al Awamia* **2006**, *3*, 118–119. [**Google Scholar**]
25. Rodrigo, M.E.; Garcia-Mari, F.; Rodriguez-Reina, J.M.; Olmeda, T. Colonization of Growing Fruit by the Armored Scales Lepidosaphes Beckii, *Parlatoria Pergandii* and Aonidiella Aurantii (Hom., Diaspididae). *J. Appl. Entomol.* **2004**, *128*, 569–575. [**Google Scholar**] [**CrossRef**]
26. Rosen, D.; De Bach, P. *Species of Aphytis of the World (Hymenoptera: Aphelinidae)*; Series Entomologica; Junk, W., Ed.; The Hague: Boston, MA, USA; London, UK, 1979; Volume 17. [**Google Scholar**]
27. Rodrigo, E.; Troncho, P.; García-Marí, F. Parasitoeds (Hym.: Aphelinidae) of Three Scale Insects (Hom.: Diaspididae) in a Citrus Grove in Valencia, Spain. *Entomophaga* **1996**, *41*, 77–94. [**Google Scholar**] [**CrossRef**]
28. Planes, L.; Catalán, J.; Tena, A.; Porcuna, J.L.; Jacas, J.A.; Izquierdo, J.; Urbaneja, A. Lethal and Sublethal Effects of Spirotetramat on the Mealybug Destroyer, Cryptolaemus Montrouzieri. *J. Pest Sci.* **2013**, *86*, 321–327. [**Google Scholar**] [**CrossRef**]
29. Kühnhold, J.; Klueken, A.M.; De Maeyer, L.; Van Waetermeulen, X.; Brück, E.; Elbert, A. Movento®, an Innovative Solution for Sucking Insect Pest Control in Agriculture: Field Performance in Fruits and Vegetables. *Bayer Crop. J.* **2008**, *61*, 279–306. [**Google Scholar**]
30. Mohapatra, S.; Deepa, M.; Jagadish, G.K. An Efficient Analytical Method for Analysis of Spirotetramat and Its Metabolite Spirotetramat-Enol by HPLC. *Bull. Environ. Contam. Toxicol.* **2012**, *88*, 124–128. [**Google Scholar**] [**CrossRef**] [**PubMed**]
31. Hassouni, T.; Belghyti, D. Distribution of Gastrointestinal Helminths in Chicken Farms in the Gharb Region—Morocco. *Parasitol. Res.* **2006**, *99*, 181–183. [**Google Scholar**] [**CrossRef**]

32. Benyahia, H.; Talha, A.; Fadli, A.; Chetto, O.; Omari, F.E.; Beniken, L. Performance of 'Valencia Late'Sweet Orange (Citrus Sinensis) on Different Rootstocks in the Gharb Region (Northwestern Morocco). *Annu. Res. Rev. Biol.* **2017**, *20*, 1–11. [**Google Scholar**] [**CrossRef**]
33. Mansouri, I.; Squalli, W.; El Agy, A.; El-Hassani, A.; El Ghadraoui, L.; Dakki, M. Comparison of Nesting Features and Breeding Success of Turtle Dove Streptopelia Turtur between Orchards and Riparian Habitats. *Int. J. Zool.* **2021**, *2021*, 5566398. [**Google Scholar**] [**CrossRef**]
34. Cankaya, S. A Comparative Study of Some Estimation Methods for Parameters and Effects of Outliers in Simple Regression Model for Research on Small Ruminants. *Trop. Anim. Health Prod.* **2009**, *41*, 35–41. [**Google Scholar**] [**CrossRef**]
35. Abdel-Aty, M.; Abdalla, M.F. Modeling Drivers' Diversion from Normal Routes under ATIS Using Generalized Estimating Equations and Binomial Probit Link Function. *Transportation* **2004**, *31*, 327–348. [**Google Scholar**] [**CrossRef**]
36. Berlinger, M.J.; Gol'berg, A.M. The Effect of the Fruit Sepals on the Citrus Mealybug Population and on Its Parasite. *Entomol. Exp. Appl.* **1978**, *24*, 238–243. [**Google Scholar**] [**CrossRef**]
37. Franco, J.C.; Suma, P.; Da Silva, E.B.; Blumberg, D.; Mendel, Z. Management Strategies of Mealybug Pests of Citrus in Mediterranean Countries. *Phytoparasitica* **2004**, *32*, 507–522. [**Google Scholar**] [**CrossRef**]
38. Carrière, Y. Haplodiploidy, Sex, and the Evolution of Pesticide Resistance. *J. Econ. Entomol.* **2003**, *96*, 1626–1640. [**Google Scholar**] [**CrossRef**]
39. Kedia, A.; Prakash, B.; Mishra, P.K.; Singh, P.; Dubey, N.K. Botanicals as Eco Friendly Biorational Alternatives of Synthetic Pesticides against *Callosobruchus* Spp. (Coleoptera: Bruchidae)-A Review. *J. Food Sci. Technol.* **2015**, *52*, 1239–1257. [**Google Scholar**] [**CrossRef**]
40. Amirahmadi, M.; Shoeibi, S.; Abdollahi, M.; Rastegar, H.; Khosrokhavar, R.; Hamedani, M.P. Monitoring of Some Pesticides Residue in Consumed Tea in Tehran Market. *Iran. J. Environ. Health Sci. Eng.* **2013**, *10*, 1–6. [**Google Scholar**] [**CrossRef**][**Green Version**]
41. Bajwa, U.; Sandhu, K.S. Effect of Handling and Processing on Pesticide Residues in Food-A Review. *J. Food Sci. Technol.* **2014**, *51*, 201–220. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
42. Urbaneja, A.; Grout, T.G.; Gravena, S.; Wu, F.; Cen, Y.; Stansly, P.A. Citrus pests in a global world. In *The Genus Citrus*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 333–348. [**Google Scholar**]
43. Belkhiri, D.; Biche, M.; Mehaoua, M.S. Effet de Spirotetram Ate Surl' Evolution des Larves et des Adultes de Parlatoria Blanchardi du Palmier Dattier en Algerie *Parlatoria Blanchardi* of the Date Palm in Algeria. *Courr. Savoir* **2018**, *25*, 157–161. [**Google Scholar**]
44. Stanley, J.; Preetha, G. *Pesticide Toxicity to Non-Target Organisms: Exposure, Toxicity and Risk Assessment Methodologies*; Springer: Berlin/Heidelberg, Germany, 2016; ISBN 978-94-017-7752-0. [**Google Scholar**]

Chapitre II

Évaluation de l'effet de différentes concentrations de spirotétramate sur la cochenille diaspine *Parlatoria ziziphi*

Cette étude a fait l'objet d'une publication dans Agronomy Journal : (IF= 3,95)

Assouguem, A.; Kara, M.; Mechchate., H.; Alzain, M.N.; Noman, O.M.; Imtara, H.; Hano, C.; Ibrahim, M.N.; Benmessaoud, S.; Farah, A.; et al. Evaluation of the Effect of Different Concentrations of Spirotetramat on the Diaspine Scale *Parlatoria ziziphi* in Citrus Orchards. *Agronomy* **2021**, *11*, 1–11, doi:10.3390/agronomy11081562

Resumé

La lutte contre *Parlatoria ziziphi* (Lucas, 1853) a été étudiée dans des vergers d'agrumes à Mechraa Belksiri dans la région du Gharb au Maroc. Trois concentrations de Spirotétramate; T0 = 0 L/Ha traité seulement avec l'eau, T1 = 0,625 L/Ha de Spirotétramate, T2 = 0,755 L/Ha de Spirotétramate, et T3 = 1 L/Ha de Spirotétramate, ont été appliquées sur 4 ha de verger de Valencia taradif (*Citrus sinensis*). L'effet du produit systémique à base de Spirotétramate a été évalué sur les mortalités et les taux de survie de *P. ziziphi* pendant les stades des larves (premier et deuxième stade) et des femelles (F1, F2 et F3). Les résultats ont montré que le Spirotétramate était efficace sur les larves et les femelles de *P. ziziphi*. Parmi les 11 229 femelles enregistrées, 93% ont été inhibées, tandis que seulement 7% étaient intactes après la période de traitement. Enfin, les trois concentrations de ce produit testées ont été efficaces sur les larves et les femelles de *P. ziziphi*. En outre, la pulvérisation d'une faible concentration de ce produit (0,625 L/Ha) a permis un meilleur contrôle de ce ravageur et un impact moins nocif sur l'environnement.

Evaluation of the Effect of Different Concentrations of Spirotetramat on the Diaspine Scale *Parlatoria ziziphi* in Citrus Orchards

Amine Assouguem 1*, Mohammed Kara 2 , Hamza Mechchate 3* , Mashail N. AlZain 4 , Omar Mohammed Noman 5 , Hamada Imtara 6 , Christophe Hano 7 , Mansour N. Ibrahim 8 , Safaâ Benmessaoud 2 , Abdellah Farah 9 and Abderahim Lazraq 1

1 Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco; assougam@gmail.com (A.A.); lazraqab@gmail.com (A.L.)
2 Laboratory of Biotechnology and Conservation and Valorization of Natural Resources (LBCVRN) (ex LBPRN), Sidi Mohamed Ben Abdellah University, Fez P.O. Box 1796, Morocco; mohammed.kara@usmba.ac.ma (M.K.); Safaa.Benmessaoud@usmba.ac.ma (S.B.)
3 Laboratory of Biotechnology, Environment, Agri-Food, and Health (LBEAS), Faculty of Science Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez P.O. Box 1796, Morocco
4 Department of Biology, College of Sciences, Princess Nourah Bint Abdulrahman University, Riyadh 11451, Saudi Arabia; mnalzain@pnu.edu.sa
5 Department of Pharmacognosy, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia; Onoman20@gmail.com
6 Faculty of Arts and Sciences, Arab American University Palestine, Jenin P.O. Box 240, Palestine; hamada.tarayrah@gmail.com
7 Laboratoire de Biologie des Ligneux et des Grandes Cultures, INRAE USC1328, University of Orleans, CEDEX 2, 45067 Orléans, France; christophe.hano@univ-orleans.fr
8 Department of Agricultural Engineering, College of Food and Agriculture Sciences, King Saud University, Riyadh 11451, Saudi Arabia; malsamee@ksu.edu.sa
9 Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco; farah.abdellah1@gmail.com
* Correspondence: Hamza.mechchate@usmba.ac.ma (H.M) ,assougam@gmail.com (A.A)

Abstract

The control of *Parlatoria ziziphi* (Lucas, 1853) was studied in citrus orchards at Mechraa Belksiri in the Gharb area of Morocco. Three concentrations of spirotetramat T0 = 0 L/Ha as a control experiment, T1 = 0.625 L/Ha, T2 = 0.755 L/Ha, and T3 = 1 L/Ha, were applied on 4 ha of Valencia late orchard (each dose for 1 ha of Valencia late). The effect of spirotetramat was evaluated on the mortalities and survival rates of *P. ziziphi* during the stages of larvae (first instar and second instar) and females (F1, F2, and F3). Results showed that the spirotetramat was effective on larvae and females of *P. ziziphi*. Among the 11,229 females recorded, 93% were inhibited, while only 7% were intact after the treatment period. Finally, our study highlights that all concentrations tested were effective on the *P. ziziphi* population; besides, all three concentrations of this product tested were equally effective on larvae and females of *P. ziziphi*. Thus, during the spread period, spraying a low concentration of this product (0.625 L/Ha) will better control this pest and reduce the environmental impact.

Introduction

In Morocco, the citrus sector is of great importance to socio-economic development, with an estimated production of 2.2 million tons per year [**1**]. It is mainly produced in Souss, Berkane, Tadla, and Haouz regions, with a total surface area of 126.600 ha [**2**]. Despite the importance of the citrus sector in the national economy and its particular interest, this sector has been seriously affected in recent years by biotic and abiotic factors [**3**]. In addition to the complications of production and marketing, numerous pest species and diseases reduce the quantity and quality of citrus fruits [**4**,**5**,**6**].

Among all, the black scale *Parlatoria ziziphi* (Lucas 1853) (Hemiptera: Diaspididae) is the most destructive pests to citrus. It is a cosmopolitan species and very abundant in citrus orchards in several countries. It originated from Europe and, later, from tropical and subtropical parts of the world on numerous hosts, especially on citrus [**7**,**8**,**9**].

The black parlatoria scale is one of the most significant pests attacking citrus trees in Morocco [**10**,**11**,**12**]. This pest causes considerable damage to citrus fruits in the Mediterranean basin and has a negative economic impact that translates into a loss of production in the Maghreb countries, including Morocco [**13**]. The damage caused by *P. ziziphi* consists of the weakening and drying of aerial parts of the tree, discoloration of the leaves and fruits, and, most importantly, a commercial loss in the fruits due to the scales fixed on it. Its specific resistance to fruit cleaning aggravates this cosmetic damage. Further, it is one of the most difficult armored scales to control with insecticides [**14**].

The life cycle of *P. ziziphi* including the duration of each larval (L1: Mobile larvae on the leaf; L2: Larvae fixed on the leaf), female (F1: Young female of small size with small black scale cover; F2: Female of medium size and medium scale cover; and F3: Adult female with a large scale cover, often carrying eggs), and male (pre-pupa, pupa, and adult) stage is influenced by the host plant, climatic conditions, and interaction with parasitoids [**15**,**16**]. *P. ziziphi* lays 10 to 20 eggs. There are two to five generations per year, sometimes six in countries where conditions are more favorable [**17**].

Spirotetramat (Movento 100 SC, BAYER SA) is a systemic insecticide that contains an active ingredient with a mode of action classified as Group 23 of the Insecticide Resistance

Action Committee. It is a compound that belongs to the chemical class of ketoenols, and it is a lipid biosynthesis inhibitor (LBI) [**18**]. It is active against piercing–sucking insects by acting as an acetyl-CoA carboxylase (ACC) inhibitor, interrupting lipid biosynthesis in the insects [**19**,**20**].

In this study, we used field monitoring to investigate the appropriate dose of spirotetramat to control *P. ziziphi* without disturbing the natural functioning of the agroecosystem. More specifically, we investigated the low effective concentration of spirotetramat on *P. ziziphi* larvae and females inside citrus orchards.

1 Materials and Methods

1.1 Study Area

This work was carried in Bel Ksiri, Northeast of the Kenitra province, situated on the Gharb plain, North of Morocco (**Figure 7**). The study area was geographically located at a low altitude ranging from 300 to 500 m above sea level. The Gharb region is Morocco's largest agricultural area (600 Km^2) [**21**]. This region is well known for the production of citrus, cereals, and vegetable cultures due to the appropriate climate and soil properties [**22**]. The Gharb zone is characterized by the Mediterranean climate with annual precipitations ranging between 480 and 600 mm, and an average temperature of 27 °C during summer and 13 °C during winter.



Figure 7. Location of studied orchards [23].

1.2 Sampling Design

To investigate the impact of spirotetramat on *P. ziziphi*, an orchard of 'Valencia Late' (*Citrus sinensis*) was selected and followed [**22**]. This product systemic (spirotetramat) has been used because of its effectiveness against a wide range of pests, including the diaspine scale insects, and its reduced damage to the environment and natural enemies. The orchard covers 4 ha on Valencia Late trees. The orchard was divided into 4 plots of 1 ha (**Figure 8**), and each plot was treated by a specific dose of the pesticide: (i) T0 treated only by water (as a control experiment), (ii) T1 = 0.625 L/ha, (iii) T2 = 0.755 L/ha, and (iv) T3 = 1 L/ha. In addition, the Teyme Eolo sprayer (Teyme Tecnologia Agricola, Girona, Spain), with its turbulent nozzle and exit diameter of 12 mm, delivered 1.55 L/min at a pressure of 20 bars. In addition, 2500 L of spray liquid were sprayed by a towed atomizer on each plot (1 ha), at a rate of 6 L of spray for each tree (**Figure 8**). These 3 concentrations were used based mainly on the quantities of pesticides used by local farmers.

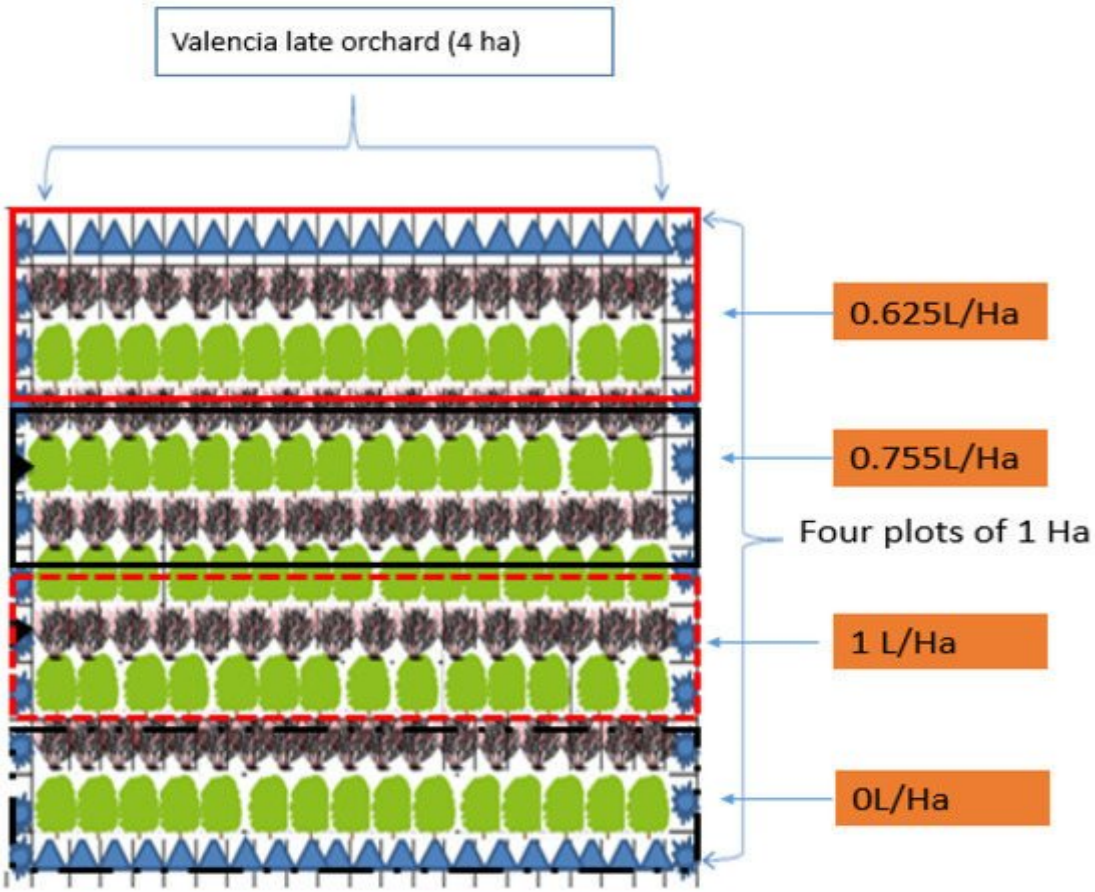


Figure 8. Model of the monitored orchard (divided into four small plots of 1 ha) and used doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha).

To evaluate the effect of each concentration after treatment (1 to 8 weeks), 200 leaves of Valencia late trees in each plot were collected weekly and randomly from the different directions of the tree (North, East, South, and West), for a total of 20 trees by the plot that belonged to a square block (3 repetitions were performed independently). We left 2 lines between the different plots treated with spirotetramat. Then, we count the mortalities (M) and survival rates (V) of *P. ziziphi* at two stages: Larvae (L1 and L2) and females (F1, F2, and F3) on each leaf surface.

In the laboratory, the different stages of *P. ziziphi* on each leaf were determined and counted on both leaf surfaces; we counted the survival rates (V) and mortalities (M) of *P. ziziphi* at two larval stages (L1 and L2) and three generations of female (F1, F2, and F3) using a binocular microscope.

1.3 Statistics

Statistics of data were done in Minitab software, version 1.1.19, LLC, USA. The results were given as mean ± SD. Moreover, to evaluate the effectiveness of spirotetramat, we calculated the survival (survived specimens/total sampled specimens) and mortality (inhibited specimens/total sampled specimens) of *P. ziziphi* for both larvae and females [**23**]. We checked for normality and homogeneity of variance for all variables with the Kolmogorov–Smirnov test. To assess the difference between the survival rates and mortalities between different stages of *P. ziziphi*, we used the independent t-test, considering the two stages as unrelated variables, while the effect of different doses of the systemic product was tested by the ANOVA One-way test followed by a post hoc Tukey test at $p < 0.05$. The linear correlation between different larvae and female stages was obtained by the Pearson correlation coefficient at $p < 0.05$. Principal component analyses were accomplished to elucidate the relationship between the treatment and different stages of *P. ziziphi*.

2 Results

2.1 Impact on Larvae

Out of 3965 larvae, 83% were inhibited, and only 17% survived after the treatment period. Specifically, during the first instar larval (L1) stage, 620 survived (16%), while 2234 were suppressed (56%). Moreover, in the second instar larval (L2) stage, 53 larvae survived (1%) and 1058 larvae were inhibited (27%). On the other hand, survival and mortality rates were very high during larval stage 1 (**Figure 9**), while these two parameters were low during larval stage 2. Mortalities and survival rates were uncorrelated during both stages (**Table 7**).

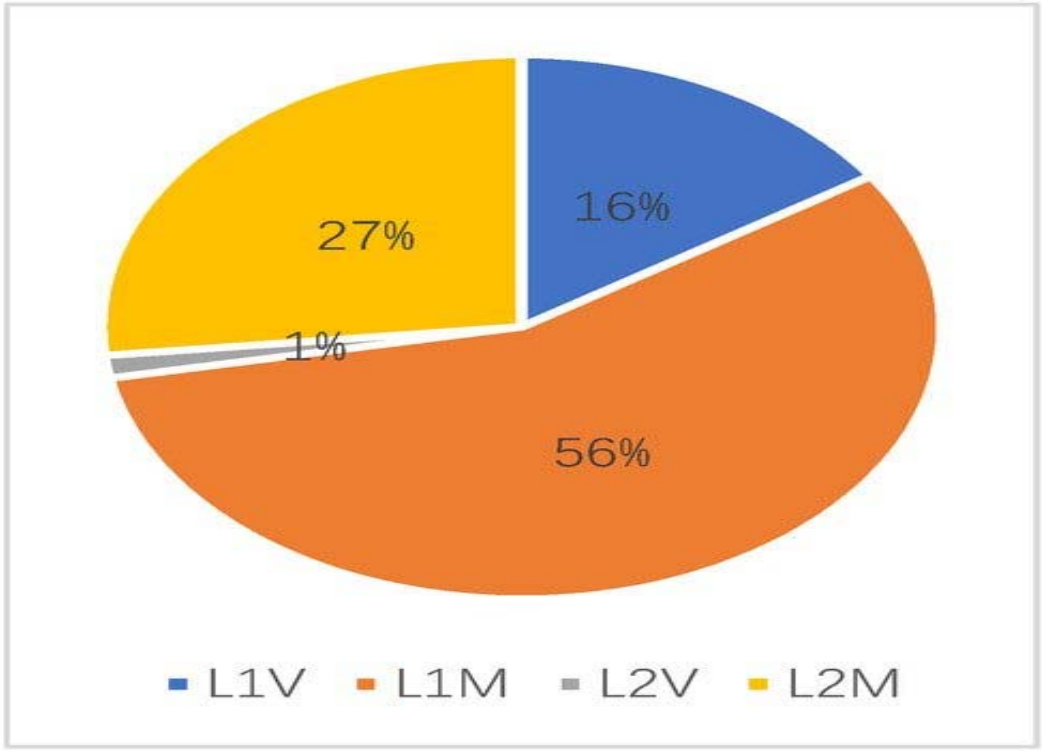


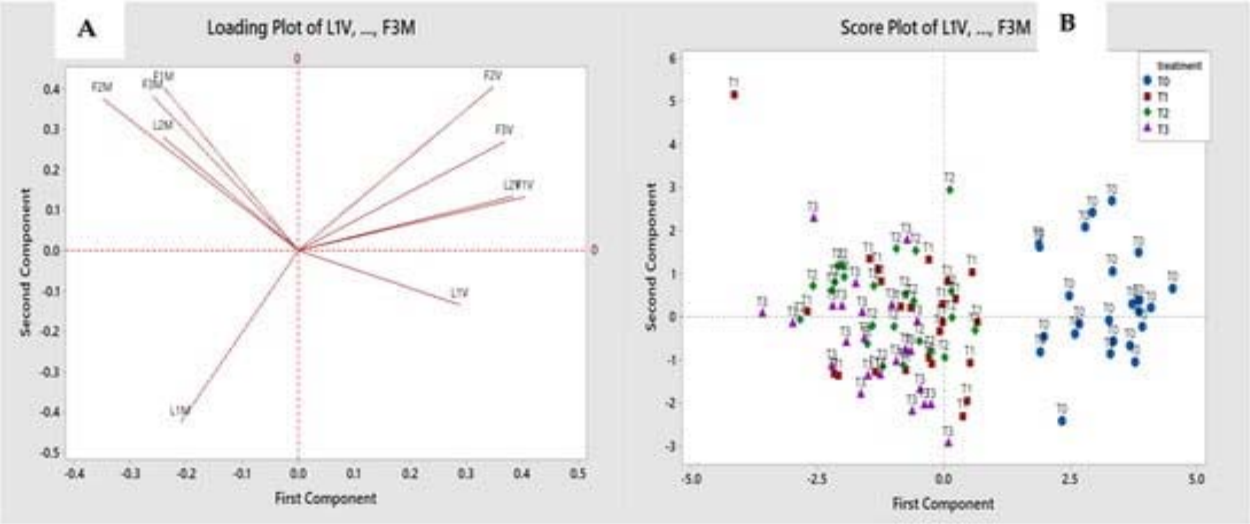
Figure 9. Comparison of mortalities (M) and survival rates (V) during two larvae stages of *P. ziziphi* (L1V: Surviving larvae of stage 1; L1M: Dead larvae of stage 1; L2V: Surviving larvae of stage 2; L2M: Dead larvae of stage 2).

Table 7. Relationship between the different stages of *P. ziziphi*.

	L1V	L1M	L2V	L2M	F1V	F1M	F2V	F2M	F3V
L1M	−0.197								
L2V	0.344	−0.390							
L2M	−0.396	0.036	−0.178						
F1V	0.445	−0.406	0.779	−0.352					
F1M	−0.244	−0.122	−0.323	0.256	−0.268				
F2V	0.269	−0.462	0.550	−0.204	0.580	−0.170			
F2M	−0.389	0.117	−0.451	0.440	−0.452	0.599	−0.269		
F3V	0.348	−0.296	0.542	−0.275	0.589	−0.283	0.860	−0.429	
F3M	−0.336	0.126	−0.390	0.296	−0.374	0.312	−0.099	0.617	−0.103

Regarding the efficacy of the doses on the different larval stages, all concentrations of spirotetramat tested were effective on stage 1 larvae survivors (L1V) with the means of T1 = 10.00 ^{B} ± 3.30, T2 = 7.75 ^{B} ± 3.17, and 8.08 ^{B} ± 2.49, while the T3 dose was very effective on stage 1 dead larvae (L1M) with an average of 41.13 ^{B} ± 10.82. Further, all the tested doses (T1, T2, and T3) were effective against stage 2 larvae (**Table 8**). Furthermore, all doses of this systemic product were positively correlated with second instar larval Inhibited (L2M)

specimens. The T3 concentration was positively correlated with first instar larval Inhibited (L1M) specimens. In contrast, all doses tested were negatively correlated with surviving larvae of the first instar and second instar (L1V and L2V) (**Figure 10**).



10. Principal component analysis (PCA) of the different stages of *P. ziziphi* according to the different treatment rates (A); double projection diagram for the two components (B).

Table 8. Survival (V) and mortality (M) of *Parlatoria ziziphi* larvae (L1,L2) treated with different doses of spirotetramat T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha.

	L1V	L1M	L2V	L2M
T0	14.13 ^{A} ± 4.79	21.13 ^{A} ± 7.96	3.42 ^{A} ± 1.67	9.13 ^{A} ± 5.90
T1	10.00 ^{B} ± 3.30	27.92 ^{A} ± 10.60	1.00 ^{B} ± 1.38	14.42 ^{B} ± 5.24
T2	7.75 ^{B} ± 3.17	24.04 ^{A} ± 7.32	0.67 ^{B} ± 0.87	13.71 ^{B} ± 4.51
T3	8.08 ^{B} ± 2.49	41.13 ^{B} ± 10.82	0.54 ^{B} ± 0.59	15.96 ^{B} ± 4.43

Means in the same column with different superscripts are significantly different ($p < 0.05$).

Figure 11 shows that the survival means of the larval stage in the untreated plot increased significantly from week 1 (15.67 ^{AB} ± 2.06) to week 8 (22.67 ^{A} ± 1.15). On the other hand, the average for surviving larvae remained low for all weeks after treatment with all concentrations of spirotetramat (**Table 9**).

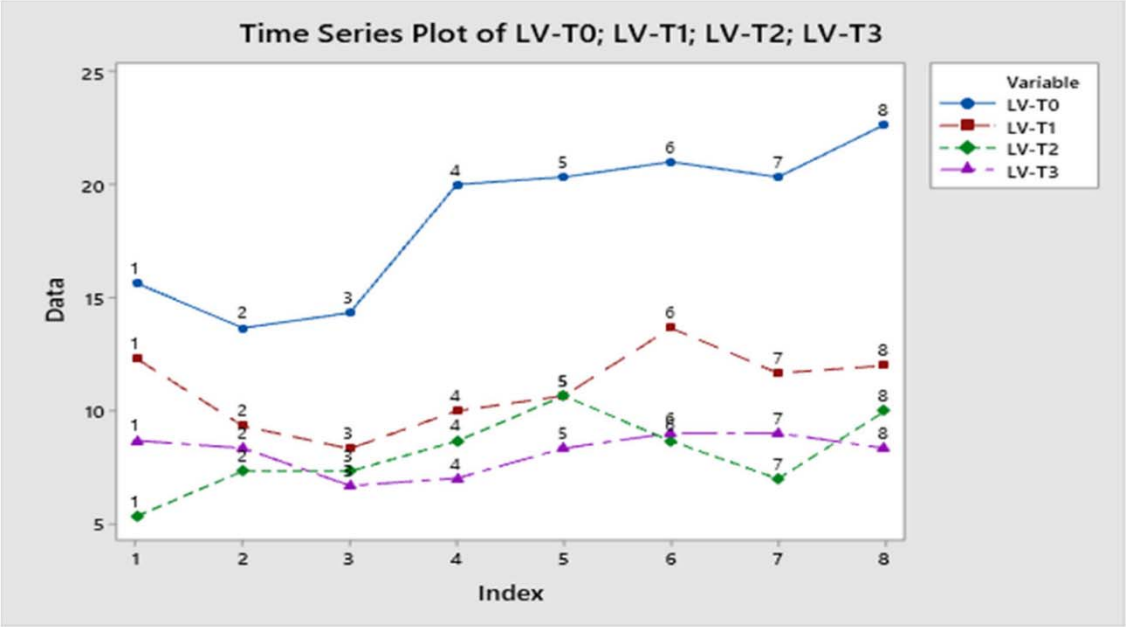


Figure 11. Evolution of the larvae survival of *Parlatoria ziziphi* according to different follow-up dates after treatment.

Table 9. Survival (V) of *Parlatoria ziziphi* larvae treated with different doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha) according to different follow-up dates after treatment.

	LV-TO	LV-T1	LV-T2	LV-T3
Week 1 BT	15.67 ^{AB} ± 2.06	12.33 ^{A} ± 2.31	5.33 ^{A} ± 1.31	8.66 ^{A} ± 0.57
Week 2 BT	13.67 ^{B} ± 0.57	9.33 ^{A} ± 1.53	7.33 ^{A} ± 1.52	8.33 ^{A} ± 0.57
Week 3 BT	14.33 ^{B} ± 2.62	8.33 ^{A} ± 2.51	7.33 ^{A} ± 1.15	6.67 ^{A} ± 4.51
Week 4 BT	20.00 ^{AB} ± 2.65	10.00 ^{A} ± 2.57	8.67 ^{A} ± 2.52	7.00 ^{A} ± 1.00
Week 5 BT	20.33 ^{AB} ± 2.31	10.68 ^{A} ± 1.52	10.67 ^{A} ± 2.50	12.00 ^{A} ± 3.00
Week 6 BT	21.00 ^{AB} ± 2.65	13.67 ^{A} ± 2.21	8.67 ^{A} ± 1.16	9.00 ^{A} ± 1.73
Week 7 BT	20.33 ^{AB} ± 2.08	11.67 ^{A} ± 1.04	7.00 ^{A} ± 1.73	9.00 ^{A} ± 2.00
Week 8BT	22.67 ^{A} ± 1.15	12.00 ^{A} ± 2.45	8.33 ^{A} ± 1.15	8.33 ^{A} ± 1.55

Means in the same column with different superscripts are significantly different ($p < 0.05$).

2.2 Impact on Females

Among the 11,229 females recorded (**Figure 12**), 93% (n = 10,473) were inhibited, while only 7% (n = 756) were intact after the treatment period. Specifically, during the F1 generation, only 1% (n = 76) survived, while 14% (n = 1574) were inhibited. Furthermore, during the F2 generation, 2% (n = 225) survived and 30% (n = 3377) were eliminated. Similarly, 4% (n = 455) survived and 49% (n = 5522) were inhibited during the F3 generation.

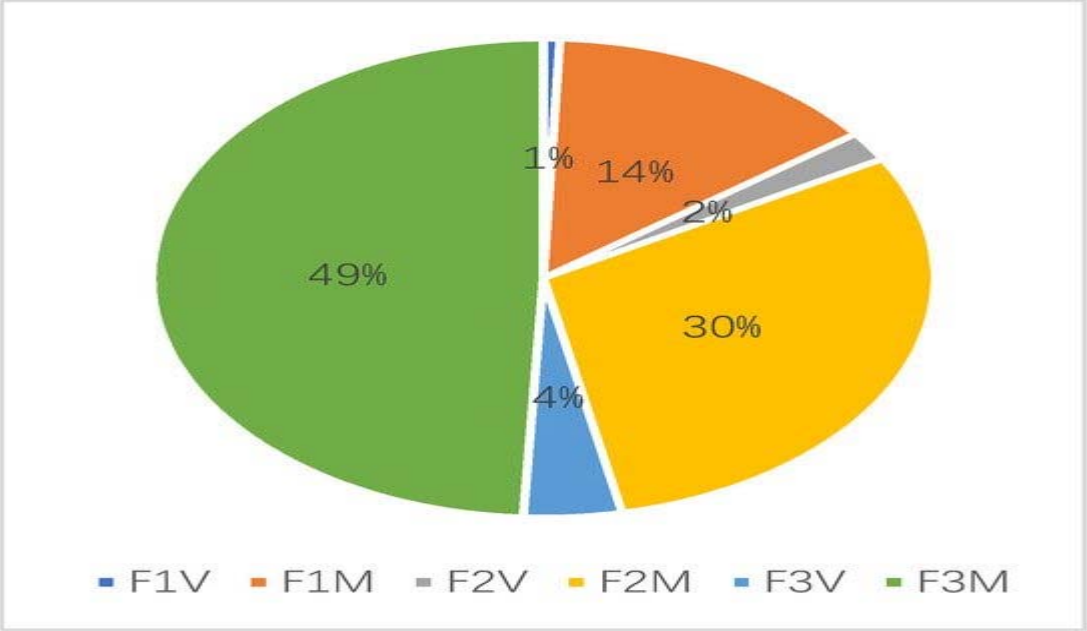


Figure 12. Comparison of mortalities (M) and survival rates (V) during three female stages of *P. ziziphi*. (F1V: Survived females of stage 1; F1M: Dead females of stage 1; F2V: Surviving females of stage 2; F2M: Dead females of stage 2; F3V: Surviving females of stage 3; F3M: Dead females of stage 3.

In terms of comparisons between stages, the means of surviving females were higher in F3, followed by F2 and then F1. Similarly, inhibited females were more numerous in F3, followed by F2 and F1. On the other hand, survival averages were variable for all periods. Similarly, the means of females eliminated from the three stages were significantly different during the entire follow-up period (**Table 10**).

Table 10. Survival (V) and mortality (M) of *Parlatoria ziziphi* females (F1, F2, and F3) treated with different doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha).

	F1V	F1M	F2V	F2M	F3V	F3M
T0	6.08 ^{A} ± 2.59	13.38 ^{B} ± 4.86	9.43 ^{A} ± 3.51	27.88 ^{A} ± 6.40	16.88 ^{A} ± 5.71	64.50 ^{A} ± 15.71
T1	1.38 ^{B} ± 1.17	23.21 ^{A} ± 11.33	3.29 ^{B} ± 2.45	43.42 ^{B} ± 14.27	6.67 ^{B} ± 3.10	76.54 ^{A} ± 22.41
T2	1.13 ^{B} ± 0.99	24.00 ^{A} ± 6.08	3.50 ^{B} ± 2.41	49.92 ^{B} ± 11.55	5.92 ^{B} ± 3.41	77.04 ^{A} ± 22.01
T3	0.67 ^{B} ± 0.90	18.38 ^{AB} ± 7.57	2.58 ^{B} ± 2.55	47.38 ^{B} ± 16.05	6.83 ^{B} ± 2.20	76.50 ^{A} ± 23.29

Means that do not share a letter are significantly different.

The three doses were all effective on the survival rates of females in all three stages (F1V, F2V, and F3V) with averages of T1 = 1.38 ^{B} ± 1.17, T2 = 1.13 ^{B} ± 0.99, and T3 = 0.67 ^{B} ± 0.90. The concentrations T1 = 23.21 ^{A} ± 11.33 and T2 = 24.00 ^{A} ± 6.08 were effective on stage 1 dead females (F1M). What is more, all doses of this systemic product tested were effective on

dead females of stage 2 (F2M) with the averages T1 = 43.42 ^{B} ± 14.27, T2 = 49.92 ^{B} ± 11.55, and T3 = 47.38 ^{B} ± 16.05, while spirotetramat showed no effect on stage 3 females (F3M) (**Table 10**). In addition, the doses of this systemic product were positively correlated with inhibited females of all stages (F1M, F2M, and F3M), while all doses tested were negatively correlated with surviving females (F1V, F2V, and F3V) (**Figure 13**).

Figure 13 shows that female survival in the untreated plot decreased significantly from week 1 (46.00 ^{A} ± 5.56) to week 8 (28.00 ^{B} ± 2.00 14.33 ^{AB} ± 2.45). While the mean survival of females in the 0.625 L/ha treated plot was very high in the first week after treatment (21.00 ^{A} ± 2.31), the means then decreased significantly over the last 7 weeks after treatment to (14.33 ^{AB} ± 2.45) in week 8. The survival averages of the females remained low for all 8 weeks after treatment with the concentrations 0.755 L/he and 1 L/he (**Table 11**).

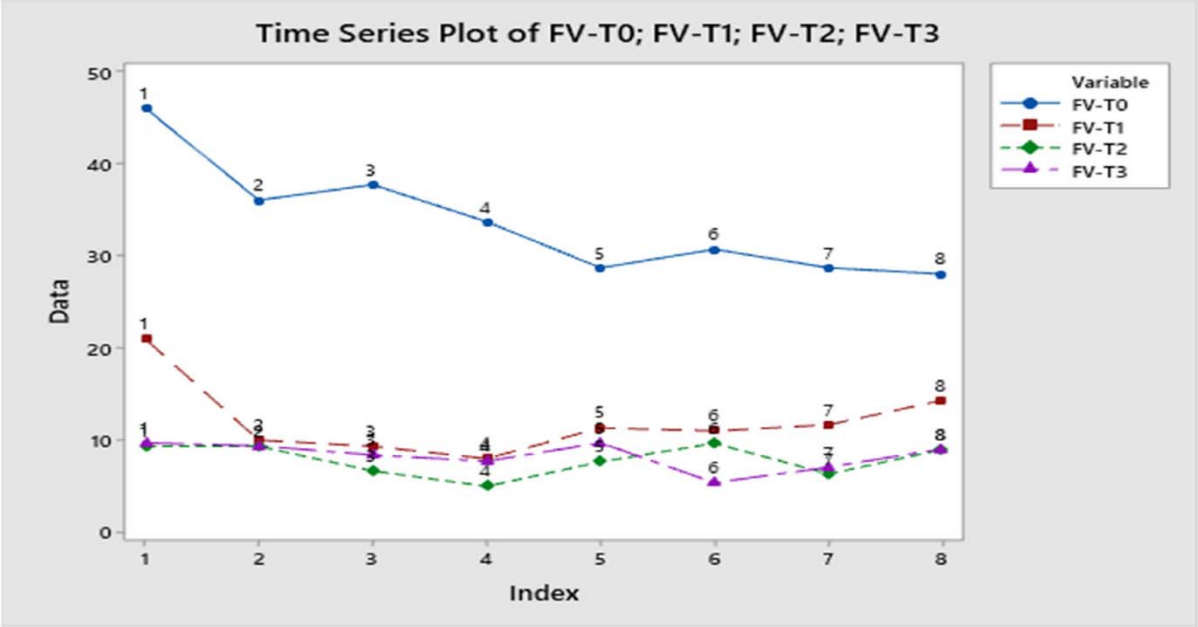


Figure 13. Evolution of females' survival of *Parlatoria ziziphi* according to the different follow-up dates after treatment.

Table 11. Survival (V) of *Parlatoria ziziphi* females treated with different doses of spirotetramat (T0 = 0 L/ha, T1 = 0.625 L/ha, T2 = 0.755 L/ha, and T3 = 1 L/ha) according to different follow-up dates after treatment.

	FV-TO	FV-T1	FV-T2	FV-T3
Week 1 BT	46.00 ^{A} ± 5.56	21.00 ^{A} ± 2.31	9.33 ^{A} ± 0.58	9.68 ^{A} ± 0.57
Week 2 BT	36.00 ^{AB} ± 5.33	10.00 ^{B} ± 1.53	9.33 ^{A} ± 1.53	9.33 ^{A} ± 0.57
Week 3 BT	37.67 ^{AB} ± 3.21	9.33 ^{B} ± 2.51	6.67 ^{A} ± 1.53	8.33 ^{A} ± 4.51
Week 4 BT	33.67 ^{AB} ± 2.52	8.00 ^{B} ± 0.57	5.00 ^{A} ± 1.73	7.67 ^{A} ± 1.00
Week 5 BT	28.67 ^{B} ± 2.08	11.33 ^{B} ± 1.52	7.67 ^{A} ± 1.52	9.66 ^{A} ± 3.00
Week 6 BT	30.67 ^{B} ± 2.89	11.00 ^{B} ± 2.21	9.67 ^{A} ± 2.31	5.33 ^{A} ± 1.73
Week 7 BT	28.67 ^{B} ± 4.04	11.67 ^{B} ± 1.04	6.33 ^{A} ± 1.15	7.00 ^{A} ± 2.00
Week 8 BT	28.00 ^{B} ± 2.00	14.33 ^{AB} ± 2.45	9.00 ^{A} ± 2.65	9.00 ^{A} ± 1.55

Means that do not share a letter are significantly different.

3 Discussion

Based on our nationwide survey, this is the first research on the control of *P. ziziphi* using a systemic product, spirotetramat. Our main objective was to provide detailed and extensive data on the efficacy of this systemic product in controlling this pest. These results are the first and only data supplied in the control of *P. ziziphi* in citrus in North Africa, which is of great importance for further comparative research and the adoption of less environmentally damaging and more effective doses to control the pest.

Our results showed that in the larval stage, inhibition was nearly 83%, while in females, the inhibition rate was more than 92%. All three doses tested were effective on the survival rates of females in all three stages (F1V, F2V, and F3V) during the whole follow-up period, and the same results were reported by [**24**], where spraying spirotetramat on citrus fruit reduced the survival rate and fecundity of the mealybug (*Lepidosaphes beckii*) to 100% 172 days after treatment. In addition, spirotetramat showed no effect on the mortality rates of stage 3 females (F3M). This may be due to other unknown factors that contributed to the increased mortality in the untreated plot. In Egypt, the same results were reported on navel orange trees, *Citrus sinensis*, which reported high mortality due to unknown factors [**7**]. All doses of spirotetramat tested were effective on stage 1 larvae, while the T3 concentration was very effective on stage 2 larvae. According to the findings of Nauen [**25**], spirotetramat causes death in larvae deposited by adult female aphids after 24 h of its application. At the larval stages, the efficacy of the doses used was variable. Regarding the mortality rate, the T3 concentration (1 L/he) was effective against larva 1, while all three doses tested were effective on the survival rate of larva 1, while

on larva stage 2, all concentrations showed the same efficacy. Our objective was to search for lower concentrations of pesticides that have effective control against *P. ziziphi*. This will reduce pesticide use and avoid pesticide resistance [**26**,**27**,**28**]. Therefore, for easy marketing, the remaining residues are suggested to be less on treated fruits [**29**,**30**].

Among the total population of 15,194 treated with this systemic product, 90.59% were inhibited, and only 9.41% were intact after treatment. Similar results were reported in Morocco and Algeria where spirotetramat controlled *Parlatoria pergandii* with encouraging results in the citrus orchard [**23**,**31**]. All doses of spirotetramat used showed a significant effect on larvae and females of *P. ziziphi*. All the concentrations of spirotetramat used were effective on the population of *Parlatoria blanchardi* of date palm. Among all concentrations tested, we noticed that the survival rate remained low for 8 weeks after the application of the treatment. According to [**24**], spirotetramat spraying on citrus fruit resulted in 100% lower survival and fecundity of Lepidosaphes beckii for 172 days after treatment. Therefore, the choice of the right concentration remains a necessity in order to preserve the agroecosystem. In general, large amounts of pesticides control pests but negatively influence natural enemies and the environment [**32**]. In contrast, the combination of the effect of parasitism (natural enemies) and low doses of pesticides would provide effective and environmentally friendly pest control [**23**].

Conclusions

Our findings highlight two key messages: (1) The data indicated that spirotetramat was effective on larvae and females of *P. ziziphi* and (2) all doses tested were effective on the *P. ziziphi* population. Since spirotetramat is an effective and widely used pesticide, further studies on its effect on other natural enemy populations and the residues remaining on fruits are needed to establish appropriate management strategies.

Author Contributions

Conceptualization, A.A. and A.L.; methodology, A.A., M.K., and H.M.; validation, H.I. and A.F.; investigation, A.A.; data curation, M.N.A., O.M.N., and C.H.; writing—original draft preparation, A.A. and H.M.; review and editing, M.N.I. and S.B.; supervision, A.L. and A.F. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University through the Fast-track Research Funding Program.

Acknowledgments

The authors are thankful to the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University for the support of this research through the Fast-track Research Funding Program.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. ASPAM Campagne Agrumicole 2020–2021: Les Professionnels Tablent Sur Des Exportations de 630,000 Tonnes—La Vie Éco. 2021. Available online: **https://www.lavieeco.com/** (accessed on 6 June 2021).
2. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial Insect Community of Moroccan Citrus Groves: Assessment of Their Potential to Enhance Biocontrol Services. *Egypt J. Biol. Pest Control* **2020**, *30*, 1–15. [**Google Scholar**] [**CrossRef**]
3. Smaili, M.C.; Blenzar, A.; Boutaleb, J.A. Facteurs de Mortalité Du Puceron Noir de l'oranger Toxoptera Aurantii Boyer de Fonscolombe (Hemiptera: Aphididae) Sur Agrumes Dans La Région Nord Du Gharb. Du Symposium Méditerranéen Sur La Protection Phytosanitaire Des Agrumes Rabat, Maroc. Available online: **https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili%2C+M.+C.%2C+Blenzar%2C+A.%2C+%26+Boutaleb%2C+J.+A.+%282008%29.+Facteurs+de+mortalité+du+puceron+noir+de+l'oranger+Toxoptera+aurantii+Boyer+de+Fonscolombe+%28Hemiptera%3A+Aphididae%29+sur+agrum** (accessed on 10 July 2021).
4. Mazih, A. Status of Citrus IPM in the Southern Mediterranean Basin Morocco, North Africa. *Acta Hortic.* **2015**, *1065*, 1097–1104. [**Google Scholar**] [**CrossRef**]
5. Smaili, M.C. Current Pest Status and the Integrated. Available online: **https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili+MC+%282017%29+Current+pest+status+and+the+integrated+pest+management+strategy+in+the+citrus+groves+in+Morocco.+In%3A+Abstracts+of+the+IOBC+citrus+working+group+meeting+on+citrus+pests%2C+disea** (accessed on 10 July 2021).
6. Smaili, M.C.; Afellah, M.; Zrida, L. Contribution à La Mise En Place d'un Système de Lute Intégrée Sur Clémentinier Dans La Région Du Gharb. Available online: **https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili+MC%2C+Afellah+M%2C+Aarab+A+%282001%29+Biologie%2C+écologie+et+lutte+biologique+contre+Phyllocnistis+citrella+Stain.+sur+clémentinier+dans+la+région+du+Gharb.+In+%3A+Abstracts+of+the+"I+Coll+de** (accessed on 10 July 2021).
7. Awadalla, S.; Bayoumy, M.H.; El-Metwally, M.; Alhussieny, R. Population and Mortality Studies on the Black Scale Insect, *Parlatoria ziziphi* (Lucas) (Hemiptera: Diaspididae) in an Egyptian Citrus Orchard. *J. Plant Prot. Pathol.* **2021**, *12*, 197–202. [**Google Scholar**] [**CrossRef**]
8. Tawfeek, M.E.; Abu-shall, A.M.H. Seasonal Population Dynamics of *Parlatoria ziziphus* (Lucas) (Homoptera: Diaspididae) in Menoufia Gavernorate, Egypt. *Alex. Sci. Exch. J. Int. Q. J. Sci. Agric. Environ.* **2010**, *31*, 331–338. [**Google Scholar**] [**CrossRef**]
9. Ferris, G.F. Atlas of the Scale Insects of North America. *Nature* **1937**, *151*, 657. [**Google Scholar**] [**CrossRef**]
10. Abbassi, M.I. Notes Bio-Écologiques Sur *Parlatoria pergandii* Au Maroc. *Fruits* **1975**, *30*, 179–184. [**Google Scholar**]
11. Smirnoff, W. The Citrus Black Scale in Morocco. *Terre Maroc.* **1950**, *24*, 457–460. [**Google Scholar**]
12. Smaili, M.C.; Abbassi, M.; Boutaleb, J.A.; Blenzar, A. Richesse Spécifique Des Ennemis Naturels Associés Aux Vergers d'agrumes Au Maroc: Intérêt et Implication Pour La Lutte Biologique. *EPPO Bull.* **2013**, *43*, 155–166. [**Google Scholar**] [**CrossRef**]
13. Tena, A.; García-Marí, F. Current Situation of Citrus Pests and Diseases in the Mediterranean Basin. *IOBCwprs Bull* **2011**, *62*, 365–378. [**Google Scholar**]
14. Haddad, D.N.; Sadoudi, F.G.-M. Management of a main citrus pest black parlatoria scale *Parlatoria ziziphi* (lucas) (hemiptera: Diaspididae) in the mediterranean basin. *SciFed Virol. Res. J.* **2018**, *1*, 184–199. [**Google Scholar**] [**CrossRef**]
15. Kemayou, C.M.; Nono, C.T.; Audrey, V.V. Bio-Ecology of Black Scale Insects *Parlatoria ziziphi* Lucas (Homoptera: Bio-Ecology of Black Scale Insects *Parlatoria ziziphi* Lucas (Homoptera: Diaspididae) on

Three Varieties of Mandarin Trees in a Foumbot Orchard (West Cameroon) 2020. Available online: **https://entomoljournal.com** (accessed on 8 June 2021).
16. Polaszek, A. The Egyptian Species of Encarsia (Hymenoptera: Aphelinidae): A Preliminary Review. *Zool. Meded.* **1999**, *73*, 131–163. [**Google Scholar**]
17. Sweilem, S.M.; El-Bolok, M.M.; Abdel-Aleem, R.Y. Biological Studies on *Parlatoria zizyphus* (Lucas) (Homoptera—Diaspididae). Available online: **http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=orton.xis&method=post&formato=2&cantidad=1&expresion=mfn=073700** (accessed on 23 August 2021).
18. Planes, L.; Catalán, J.; Tena, A.; Porcuna, J.L.; Jacas, J.A.; Izquierdo, J.; Urbaneja, A. Lethal and Sublethal Effects of Spirotetramat on the Mealybug Destroyer, Cryptolaemus Montrouzieri. *J. Pest Sci.* **2012**, *86*, 321–327. [**Google Scholar**] [**CrossRef**]
19. Kühnhold, A.M.J.; Klueken, L.D.M. Movento®, an Innovative Solution for Sucking Insect Pest Control in Agriculture: Field Performance in Fruits and Vegetables. Available online: **https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Kuhnhold+et+al.%2C+2008&btnG=** (accessed on 24 July 2021).
20. Mohapatra, S.; Deepa, M.; Jagadish, G.K. An Efficient Analytical Method for Analysis of Spirotetramat and Its Metabolite Spirotetramat-Enol by HPLC. *Bull. Environ. Contam. Toxicol.* **2011**, *88*, 124–128. [**Google Scholar**] [**CrossRef**] [**PubMed**]
21. Hassouni, T.; Belghyti, D. Distribution of Gastrointestinal Helminths in Chicken Farms in the Gharb Region—Morocco. *Parasitol. Res.* **2006**, *99*, 181–183. [**Google Scholar**] [**CrossRef**] [**PubMed**]
22. Benyahia, H.; Talha, A.; Fadli, A.; Chetto, O.; Omari, F.E.; Beniken, L. Performance of 'Valencia Late' Sweet Orange (*Citrus sinensis*) on Different Rootstocks in the Gharb Region (Northwestern Morocco). *Annu. Res. Rev. Biol.* **2017**, *20*, 1–11. [**Google Scholar**] [**CrossRef**]
23. Assouguem, A.; Kara, M.; Mansouri, I.; Imtara, H.; AlZain, M.N.; Mechchate, H.; Conte, R.; Squalli, W.; Farah, A.; Lazraq, A. Evaluation of the Effectiveness of Spirotetramat on the Diaspine Scale *Parlatoria pergandii* in Citrus Orchards. *Agronomy* **2021**, *11*, 1562. [**Google Scholar**] [**CrossRef**]
24. Biche, M.; Siafa, A.; Adda, R.; Agagna, Y. Evaluation of Spirotetramat (Insecticide) on Scale Insects on Citrus in Algeria. *Eval. Spirotetramat Insectic. Scale Insects Citrus Alger.* **2011**, *62*, 123–131. [**Google Scholar**]
25. Nauen, R.; Reckmann, U.; Thomzik, J.; Thielert, W. Biological Profile of Spirotetramat (Movento)—A New Two Way Systemic (Amimobile) Insecticide against Sucking Pests Studies on the Susceptibility of Tuta Absoluta to Novel and Diamide Insecticides View Project Biological Profile of Spirotetramat (Movento ®). *Bayer Crop. J.* **2007**, *61*, 245–278. [**Google Scholar**]
26. Carrière, Y. Haplodiploidy, Sex, and the Evolution of Pesticide Resistance. *J. Econ. Entomol.* **2003**, *96*, 1626–1640. [**Google Scholar**] [**CrossRef**]
27. Kedia, A.; Prakash, B.; Kumar Mishra, P.; Singh, P.; Kishore Dubey, N. Botanicals as Eco Friendly Biorational Alternatives of Synthetic Pesticides against *Callosobruchus* spp. (Coleoptera: Bruchidae)—A Review. *J. Food Sci. Technol.* **2015**, *52*, 1239–1257. [**Google Scholar**] [**CrossRef**]
28. Pan, D.; Dou, W.; Yuan, G.R.; Zhou, Q.H.; Wang, J.J.; Anderson, T. Monitoring the Resistance of the Citrus Red Mite (Acari: Tetranychidae) to Four Acaricides in Different Citrus Orchards in China. *J. Econ. Entomol.* **2020**, *113*, 918–923. [**Google Scholar**] [**CrossRef**] [**PubMed**]
29. Amirahmadi, M.; Shoeibi, S.; Abdollahi, M.; Rastegar, H.; Khosrokhavar, R.; Hamedani, M.P. Monitoring of Some Pesticides Residue in Consumed Tea in Tehran Market. *J. Environ. Health Sci. Eng.* **2013**, *10*, 2–7. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
30. Bajwa, U.; Singh Sandhu, K. Effect of Handling and Processing on Pesticide Residues in Food—A Review. *J. Food Sci. Technol.* **2014**, *51*, 201–220. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
31. Urbaneja, A.; Grout, T.G.; Gravena, S.; Wu, F.; Cen, Y.; Stansly, P.A. *Citrus Pests in a Global World*; Elsevier Inc.: Amsterdam, The Netherlands, 2020; ISBN 9780128122174. [**Google Scholar**]
32. Stanley, J.; Preetha, G. *Pesticide Toxicity to Microorganisms: Exposure, Toxicity and Risk Assessment Methodologies*; Springer Nature: Dordrecht, The Netherlands, 2016; ISBN 9789401777506. [**Google Scholar**] [**CrossRef**]

Chapitre III:

Évaluation de l'impact de différentes méthodes de lutte sur *Tetranychus urticae* (Acari : Tetranychidae) et sur ses prédateurs

Cette étude a fait l'objet d'une publication dans Plants journal Research: (IF= 4.656)

Assouguem, A.; Kara, M.; Mechchate, H.; Al-Mekhlafi, F.A.; Nasr, F.; Farah, A.; Lazraq, A. Evaluation of the Impact of Different Management Methods on *Tetranychus urticae* (Acari: Tetranychidae) and Their Predators in Citrus Orchards. *Plants* **2022**, *11*, 623, doi:10.3390/PLANTS11050623.

Resumé

Pour évaluer l'efficacité des traitements écologiques à base de détergents classés non dangereux et de savon noir sur le ravageur *Tetranychus urticae* Koch 1836, et ses prédateurs (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromus* sp, *Phytoseiulus persimilis* Athias-Henriot, 1957), différents traitements ont été appliqués dans des vergers d'agrumes plantés en Valencia tardif (*Citrus sinensis*) dans la région de Mechraa Belksiri au Maroc (T0 = expérience témoin ; T1 = spirodiclofen 0,5 L/Ha ; T2 = 125 L/Ha (5%) de savon noir ; T3 = détergent ; 4 L/Ha de produit "Oni" + 2 L/Ha de produit "Tide"). Les résultats obtenus pendant toute la période de surveillance ont indiqué que les trois traitements utilisés, à savoir le spirodiclofen, le savon noir et les détergents, ont assuré une réduction du taux de population du ravageur *T. urticae* par rapport à la parcelle non traitée. Dans la parcelle non traitée, la moyenne était de 45,01 A± 4,90 formes mobiles, tandis que dans la parcelle traitée au spirodiclofen, elle n'était que de 21,10 C ± 2,71, le savon noir de 31,49 B ± 3,35, et dans la parcelle traitée aux détergents, la moyenne était quasi-similaire à celle obtenue par le spirodiclofen (22,90 C ± 2,18). Sur les prédateurs (*E. stipulatus, P. persimilis*, et *Typhlodropmus* sp.), le savon noir et le traitement avec des détergents ont été moins nocifs par rapport au produit chimique à base de spirodiclofen.

Evaluation of the Impact of Different Management Methods on *Tetranychus urticae* (Acari: Tetranychidae) and Their Predators in Citrus Orchards

Amine Assouguem1,2,*, Mohammed Kara3, Hamza Mechchate4,*, Fahd A. Al-Mekhlafi5, Fahd Nasr6,Abdellah Farah2and Abderahim Lazraq1

1Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology,Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco; lazraqab@gmail.com
2Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technology,Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco; farah.abdellah1@gmail.com
3Laboratory of Biotechnology and Conservation and Valorization of Natural Resources(LBCVRN) (Ex LBPRN), Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco;mohammed.kara@usmba.ac.ma
4Laboratory of Inorganic Chemistry, Department of Chemistry, University of Helsinki, P.O. Box 55,FI-00014 Helsinki, Finland
5Department of Zoology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia; falmekhlafi@ksu.edu.sa
6Department of Pharmacognosy, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia;fahdnasr74@gmail.com
*Correspondence: assougam@gmail.com (A.A.); hamza.mechchate@helsinki.fi (H.M.)

Abstract

To evaluate the effectiveness of eco-friendly treatments based on detergents classified as non-hazardous and black soap on the pest *Tetranychus urticae* Koch 1836, and their predators (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromus* sp., *Phytoseiulus persimilis* Athias-Henriot, 1957), different treatments were applied to citrus orchards planted with Valencia late (Orange) in the Mechraa Belksiri region of Morocco (T0 = control experiment; T1 = spirodiclofen 0.5 L/Ha; T2 = 125 L/Ha (5%) of black soap; T3 = detergent; 4 L/Ha of Oni product + 2 L/Ha of Tide product). The results obtained during the whole monitoring period indicated that the three treatments used, namely spirodiclofen, black soap, and detergents, ensured a reduction in the rate of population of the pest *T. urticae* compared to the untreated plot. In the untreated plot, the average was 45.01 A± 4.90 mobile forms, while the plot treated with spirodiclofen it was only 21.10 C ± 2.71, the black soap 31.49 B ± 3.35, and in the plot treated with detergents, the average was similar to that obtained by spirodiclofen (22.90 C ± 2.18). On the predators (*E. stipulatus*, *P. persimilis*, and *Typhlodropmus* sp.), the black soap and the treatment with detergents were less harmful compared to the chemical spirodiclofen.

Keywords: *Tetranychus urticae; Euseius stipulatus;Typhlodromus* sp.; *Phytoseiulus persimilis*; citrusorchard; monitoring; predators; pest; treatment

Introduction

Citrus is one of the world's major fruit crops and is grown in over 100 countries [**1**]. It belongs to the Rutaceae family, with 140 genera and 1300 species, including fundamental groups like orange, lemons, mandarin, and pummelos. They are cultivated in tropical and subtropical areas [**2**]. The total worldwide production of citrus is 139.80 million tons [**3**].

In Morocco, thanks to the Ministry of Agriculture, citrus orchards have reached 130,000 ha with a total annual production of over 2.2 million tons [**4**]. However, the yield at the national level is still low compared to that achieved by other European and American countries [**5**]. The Ministry of Agriculture is currently trying to remedy constraints that are hampering the increase of citrus production, including lack of manpower, maturity of orchards, and biotic and abiotic constraints [**6**,**7**]. The negative impact caused by pests reduces the quantity and quality of production. Indeed, spider mites, aphids, medflies, and diaspine scales are pests of primary economic importance [**8**,**9**]. When conditions are favorable and in the absence of adequate methods of control, significant damage is often observed on the fruits, twigs, leaves, and young shoots of citrus [**10**]. *Tetranychus urticae* Koch, 1836 is an economically major pest to agricultural crops and ornamental plants throughout the world [**11**], being found in Europe, Asia, Africa, the Caribbean islands, and North America [**12**]. It is known for developing a resistance to pesticides [**13**], and causes significant damage to agricultural crops, such as defoliation, leaf yellowing, and leaf burning [**14**,**15**]. *Euseius stipulatus* Athias-Henriot, 1960 (Acari: Phytoseiidae), *Phytoseiulus persimilis* Athias-Henriot, 1957 (Acari: Phytoseiidae), and *Typhlodromus* sp. (Acari: Phytoseiidae) are the main predators of *T. urticae* in many regions of the world [**16**,**17**]. Spirodiclofen (Envidor 240 SC, Bayer, SA) is an acaricide of the keto-enol family. It acts by contact and ingestion as an inhibitor of lipid biosynthesis (LBI) [**18**]. It has a powerful ovicidal action, controls all juvenile stages, and significantly reduces fertility in females [**19**].

Black soap, brown in color, is biodegradable, non-polluting, and an excellent insecticide [**20**]. This product is effective against insects like mealy bugs, aphids, whiteflies, thrips, and spider mites. Through simple contact, it blocks the respiratory pores [**2**,**21**]. It does not produce toxic residues and does not affect natural predators. These products are approved by organic agriculture (EEC regulation 2092/91). To minimize the negative impact of these pests on citrus

production, the use of chemical applications is often the solution adopted by growers [**22**,**23**]. Spirodiclofen often gives good results in the control of spider mites, namely, the biological parameters, including developmental time, survival rate, and in particular, the fecundity of *T. urticae* [**24**,**25**]. The misuse of this active ingredient often has harmful impacts on the agroecosystems [**26**,**27**]. The development of new eco-friendly approaches is a necessity. In this context, our study aims to evaluate the impact of spirodiclofen, black soap, and a mixture of two detergents (Oni and Tide products) on the pest *T. urticae* and its predators (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*).

1 Materials and Methods

1.1 Study Area

This study was performed in Mechra Bel Ksiri, located north of Oued Sebou in the Gharb region, at an altitude of 300–500 m above sea level (**Figure 14**) [**28**]. The climate is temperate to hot. This region is well known for the production of citrus fruits, cereals, and vegetable crops due to the suitable properties of the climate and soil [**29**]. The Gharb region is characterized by a Mediterranean climate with annual precipitation ranging between 480 and 600 mm/year, and an average temperature of 27 °C in summer and 13 °C in winter [**30**].

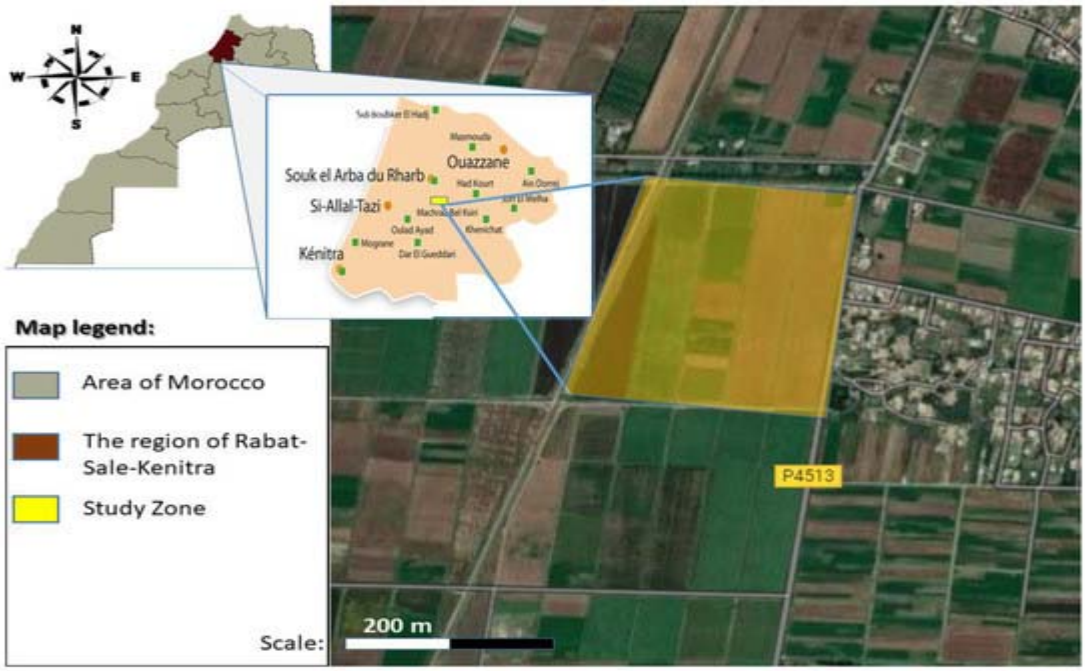


Figure 14. Location of experimental orchards.

1.2 Sampling Design

A Valencia late (*Citrus sinensis*) orchard with a high spider mite infestation was selected to study the impact of spirodiclofen, black soap, and a mixture of two detergents (Oni product

and Tide product) on *Tetranychus urticae* populations and their predators. Spirodiclofen was used because of its effectiveness against a wide range of biting/sucking pests, including spider mites. The orchard covers 4 ha of Valencia late trees. The orchard was divided into 4 plots of 1 ha (**Figure 15**), and each plot was treated with a specific dose of the treatment: (i) T0 treated with water only (as a control experiment), (ii) T1 = spirodiclofen 0.5 L/Ha, which is the recommended dose for treating citrus mites, (iii) T2 = 125 L/Ha (5%) of black soap, and (iv) T3 = detergent 4 L/Ha of Oni product (sodium C14–17 alkyl sec sulfonate, sodium C12–13 pareth sulfate) and 2 L/Ha of Tide product (sodium C10–16 alkylbenzene sulfonate, sodium borate, and propylene glycol). These two detergents are often used by local farmers to control pests and minimize the use of pesticides. They are not classified as hazardous, according to the European directive 99/45/EC on dangerous preparations [**31**]. The treatments were applied with the Teyme Eolo sprayer (Teyme Tecnologia Agricola, Girona, Spain), with turbulent nozzles 12 mm in diameter, delivering 1.55 L/min at 20 bar pressure. The towed sprayer delivers 2500 L of spray liquid per hectare, at a rate of 6 L of spray solution for each tree (**Figure 15**). To evaluate the effect of each product used, a block of 10 trees was selected and monitored weekly. Ten leaves were collected from each tree, from different directions (north, east, south, and west) and at different heights of the tree (10 replicates were performed independently) [**32**,**33**,**34**]. We left two untreated lines (12 m) between the different treated plots to avoid overlapping treatments. The total number of predators (*P. persimilis, Typhlodromus* sp., and *E. stipulatus*) and phytophagous mite (*T. urticae*) found on the 10 leaves of each plot was recorded [**35**]. All mites, except eggs and mites in quiescence, were counted on both sides of each leaf with a professional eye loop 10×. Then, to confirm the number of mites on each leaf, the collected leaves were transferred directly into polyethylene bags referenced to the laboratory for observation under a binocular microscope. Inspections were conducted 3 days after the treatment: 12 April (week 1), 19 April (week 2), 26 April (week 3), 3 May (week 4), 10 May (week 5), 17 May (week 6), 24 May (week 7), and 1 June (week 8).

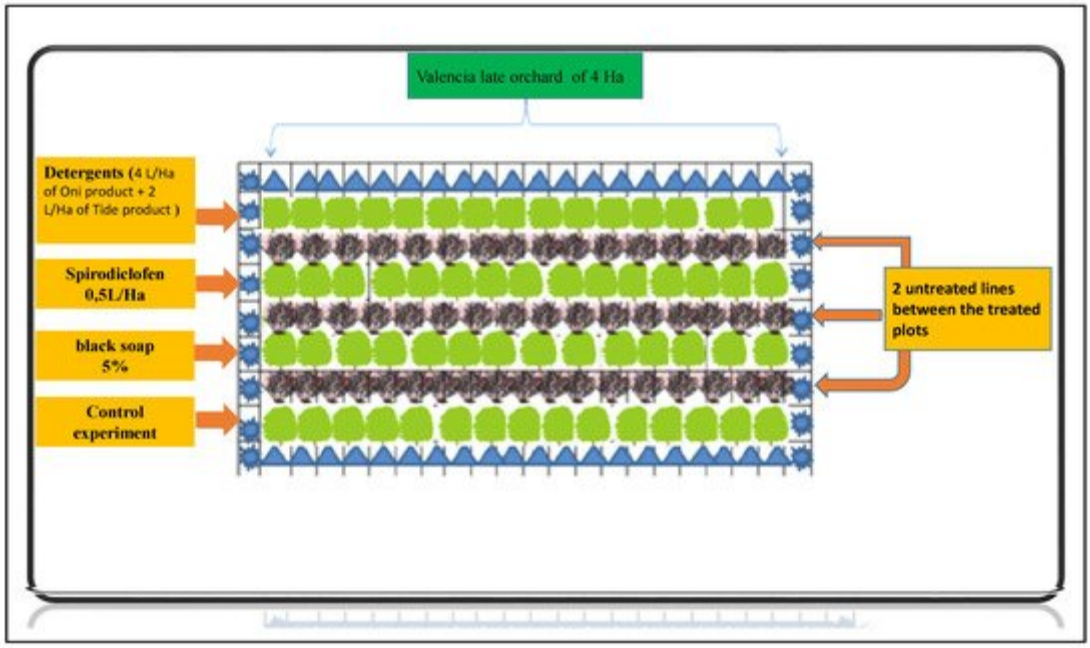


Figure 15. The different types of treatments used in the citrus orchard.

1.3 Statistics

Statistics of the data were performed using Minitab software, version 1.1.19, Minitab, Sydney, NSW, Australia. The results were given as percentage and mean ± SD. In order to evaluate the effectiveness of the treatments used on the pests and predators, we calculated the average of mobile forms found of *T. urticae* in (T0 = control experiment; T1 = plot treated with spirodiclofen; T2 = plot treated with black soap; T3 = plot treated with a mixture of two detergents). In parallel, we evaluated the impact of the treatments on natural enemies. We calculated the averages of each predator (*P. persimilis*, *Typhlodromus* sp. and *E. stipulatus*) in T0, T1, T2, and T3 [**36**]. We tested for normality and homogeneity of variance for all variables with the Kolmogorov–Smirnov test. The impact of treatments, monitoring dates, and their interactions was compared using the general linear model (GLM) univariate, followed by a post hoc Tukey test at $p < 0.05$. The principal component analyses (PCA) were accomplished using Minitab 19.1 software (Minitab, State College, PA, USA) to elucidate the relationship between the different mites studied and the treatments tested.

2 Results

2.1 Leaf Occupancy Rate by Mites in the Different Plots

During the whole monitoring period, on the untreated plot, the occupancy of the inspected leaves by the pest *Tetranychus urticae* was $n = 3601$ mobile forms (54%); moreover, the

predator *Typhlodromus* sp. presented the most important proportion with 18% (*n* = 1212), followed by *P. persimilis* with 15% (*n* = 1032) and *E. stipulatus* with 13% (*n* = 838).

In the plot treated with spirodiclofen, the abundance of these mites was low compared to the untreated plot. The pest *T. urticae* presented 46% with 1688 mobile forms. The predator *P. persimilis* presented 22% (*n* = 805), while *E. stipulatus* and *Typhlodromus* sp. presented the same proportion of 16% (*n* = 595 and *n* = 571, respectively).

In the plot managed with black soap, we recorded 2519 mobile forms (50%) for the pest *T. urticae*, 19% (*n* = 948) for the predator *P. persimilis*, 17% (*n* = 832) for *Typhlodromus* sp., and only 14% (*n* = 728) for *E. stipulatus*.

In the plot treated with detergents, we recorded 42% (*n* = 1832) of *T. urticae*, 23% (*n* = 1022) of *P. persimilis*, 18% (*n* = 809) of *Typhlodromus* sp., and 17% (*n* = 766) of *E. stipulatus* (**Figure 16**).

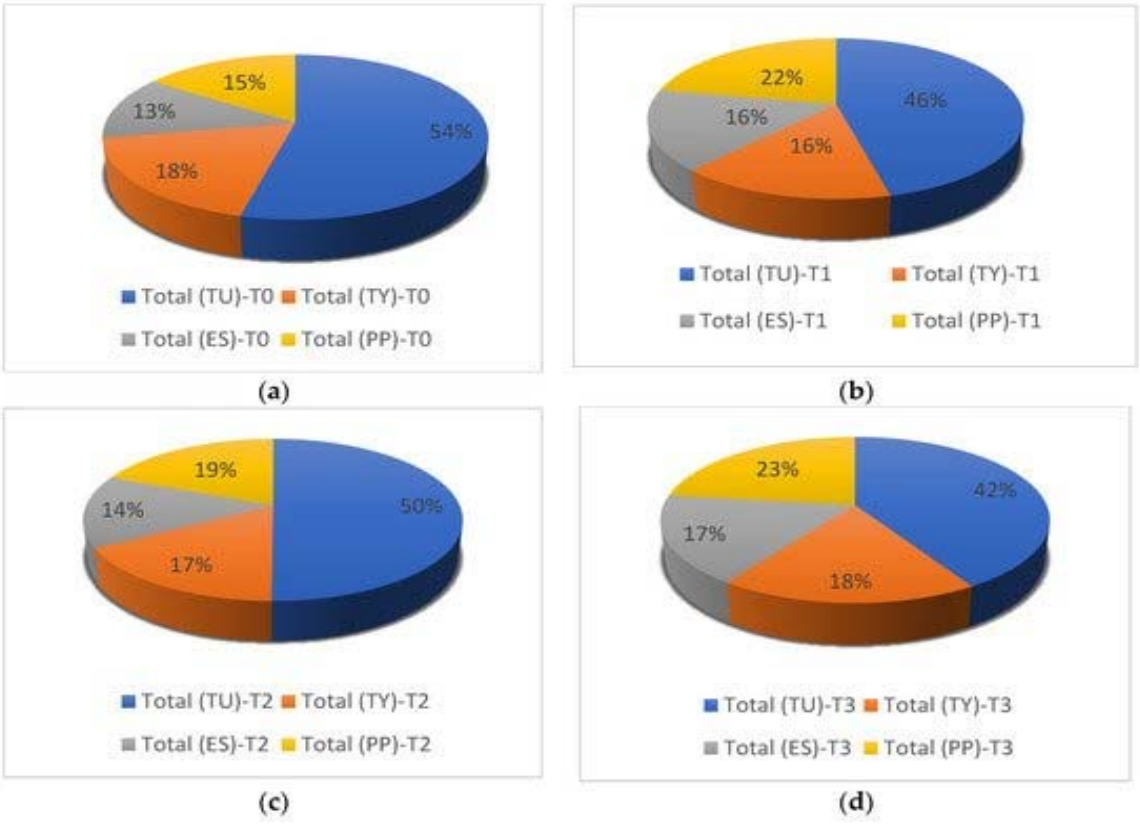


Figure 16. The proportion of the different mites studied (the phytophagous mite *Tetranychus urticae* (TU) and their predators *Euseius stipulatus* (ES), *Typhlodromus* sp. (TY), and *Pytoseiulus persimilis* (PP)) according to the treatments used.

2.2 The Influence of Treatments on the Different Mites Studied

Regarding the effect of the different treatments used on the mites studied, the treatment with detergents and spirodiclofen showed the highest efficiency on the populations of the pest *T. urticae* (**Figure 17**), while on the predators (*E. stipulatus*, *P. persimilis*, and *Typhlodropmus* sp.), the black soap and the treatment with detergents were less harmful compared to the chemical product (spirodiclofen). **Table 12** confirms these results; spirodiclofen treatment significantly reduced *T. urticae* populations with a mean of 21.10 C ± 2.71 compared to the control (45.01 A ± 4.90). The same result was observed with the detergent treatment, which reduced the *T. urticae* levels to an average of 22.90 C ± 2.18. Black soap provided a significant reduction for the mean of this pest (31.49 B ± 3.35) compared to the control; however, this treatment was less effective on *T. urticae* compared to the treatment with spirodiclofen and detergents.

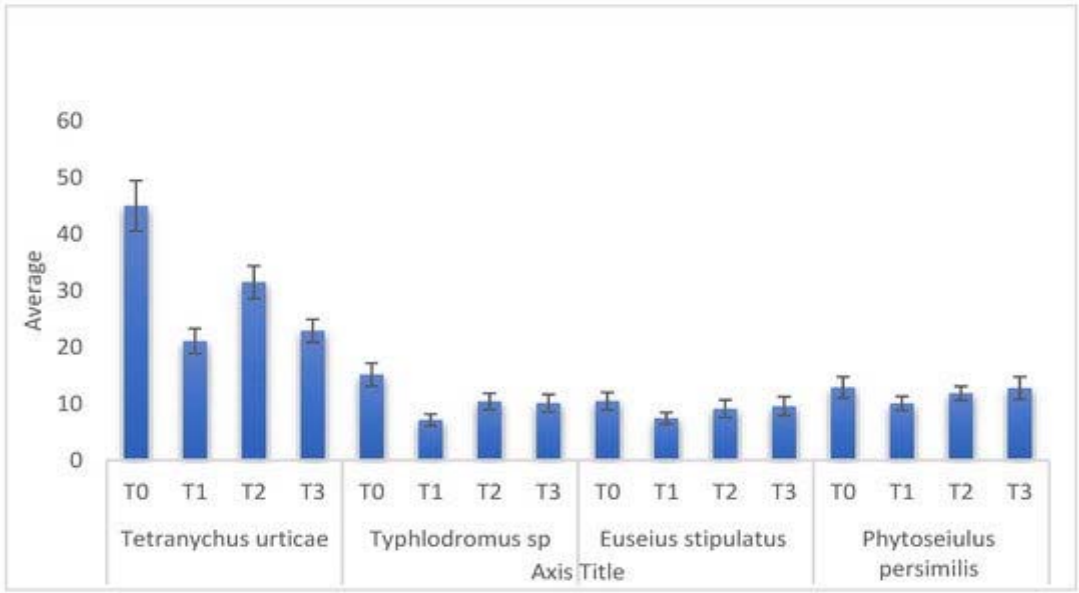


Figure 17. Comparison between the means of different mites according to the treatments (T0 = control experiment; T1 = spirodiclofen 0.5 L/Ha; T2 = 125 L/Ha (5%) of black soap; T3 = detergents; 4 L/Ha of Oni product + 2 L/Ha of Tide product).

Table 12. The impact of different treatments used on the mites studied (TU: *T. urticae*; ES: *E. stipulatus*; TY: *Typhlodromus* sp.; PP: *P. persimilis*) in citrus orchards. Values in the same column with different superscripts are significantly different ($p < 0.05$).

	TU	TY	ES	PP
Control experiment (T0)	45.01 ^{A} ± 4.90	15.15 ^{A} ± 1.83	10.47 ^{A} ± 1.63	16.02 ^{A} ± 2.12
Spirodiclofen 0.5 L/Ha (T1)	21.10 ^{C} ± 2.71	7.13 ^{C} ± 1.28	7.44 ^{B} ± 1.37	10.06 ^{B} ± 1.15
Black soap 5% (T2)	31.49 ^{B} ± 3.35	10.40 ^{B} ± 2.05	9.10 ^{AB} ± 1.25	11.85 ^{AB} ± 1.11
Detergent (T3)	22.90 ^{C} ± 2.18	10.11 ^{B} ± 2.14	9.57 ^{AB} ± 1.47	14.68 ^{A} ± 1.87

The highest average of *Typhlodromus* sp. was in the water treatment, with an average of 15.15 A ± 1.83 and the treatment with black soap (T3) and detergents (T4) were less harmful on the predator *Typhlodromus* sp. with the means of 10.40 B ± 2.05 for the plot treated with black soap and 10.11 B ± 2.14 for the one sprayed with detergents, while the treatment with spirodiclofen (T2) had the most harmful impact on the population of *Typhlodromus* sp., with an average of 7.13 C ± 1.28. For the predator *E. stipulatus,* the average was 10.47 A ± 1.63 in the plot treated with water (T0), while it was 9.10 AB ± 1.25 in the plot treated with black soap (T3), and 9.57 AB ± 1.47 in the plot treated with detergents (T4). The average of this population was low in the plot treated with the chemical product spirodiclofen, with a mean of 7.44 B ± 1.37. On *P. persimilis* populations, the treatment with detergents was the least harmful, with an average (14.68 A ± 1.87) nearly similar to that for the plot treated only with water (16.02 A ± 2.12). With black soap, the average was 11.85 AB ± 1.11, whereas the plot treated with spirodiclofen was 10.06 B ± 1.15.

In **Figure 18**, the eigenvalues of the first two principal components explain 92.7 % of the variation in the data. The first principal component explains 86.5% of the total variance. The variables with the highest association with the first principal component (CP1) are *T. urticae* (0.50), *E. stipulatus* (0.50), and *P. persimilis* (0.50), while the variable *Typhlodromus* sp. (−0.75) is negatively associated with the second principal component (CP2). However, the projection of the scoring and the contribution diagram can visually show a positive contribution of the four mites studied (*T. urticae, P. persimilis, Typhlodromus* sp. and *E. stipulatus*) on the first main axis in positive correlation with T0 water treatment, while spirodiclofen (T2), detergents (T4), and black soap (T3) treatment were correlated negatively.

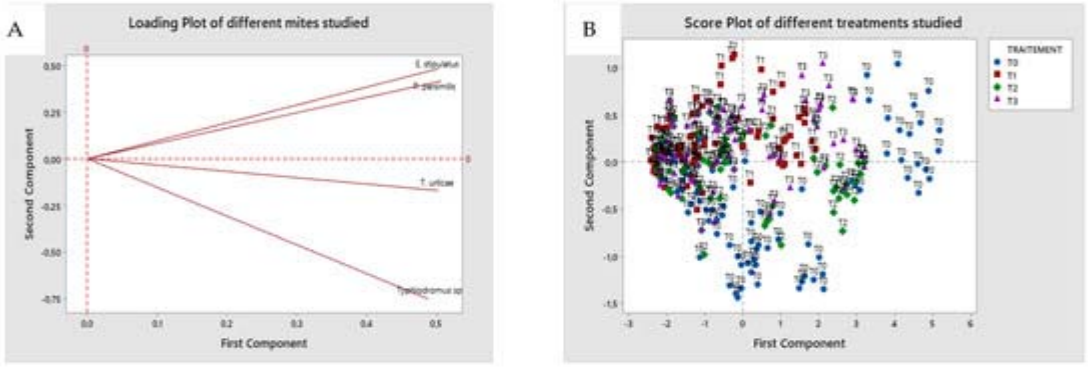


Figure 18. Principal component analysis (PCA) of the different mites studied (*T. urticae*; *E. stipulatus*; *Typhlodromus* sp.; *P. persimilis*) according to the different treatments (A); double projection diagram for the two components (B).

2.3 Fluctuation of Mites According to Treatments and Follow-Up Dates

According to the results in **Table 13**, we can conclude that the interaction between the treatment used and the monitoring dates has a significant effect on the variation of the means of the different mites studied. During the first week, three days after the spraying of the treatments, we observed a significant decrease in the rate of *T. urticae*; we had an average of 6.30 F ± 1.16 for the spirodiclofen, 8.20 E ± 1.69 for the black soap (**Table 14**), and 07.00 F ± 1.49 for the detergent treatment. In contrast, in the untreated plot T0, and during the same week (W1), this average almost doubled 14.30 E ± 2.00. Despite the increase in temperature from 27 to 34 °C from week 1 to week 5 (**Table 14**), the rate of *T. urticae* had a slight increase during the first five weeks after treatment with spirodiclofen compared to the average reached in the untreated plot (**Figure 19**). In week 5, these averages were 16.30 D ± 1.41 in the plot treated with spirodiclofen and 36.00 C ± 2.35 in the untreated plot. Beyond that, this pest had a significant increase during the last three weeks to reach an average of 53.60 A ± 4.77 in the plot treated with spirodiclofen (T1), and 86.60 A ± 7.06 in the untreated plot during week 8, where the temperature reached 39 °C.

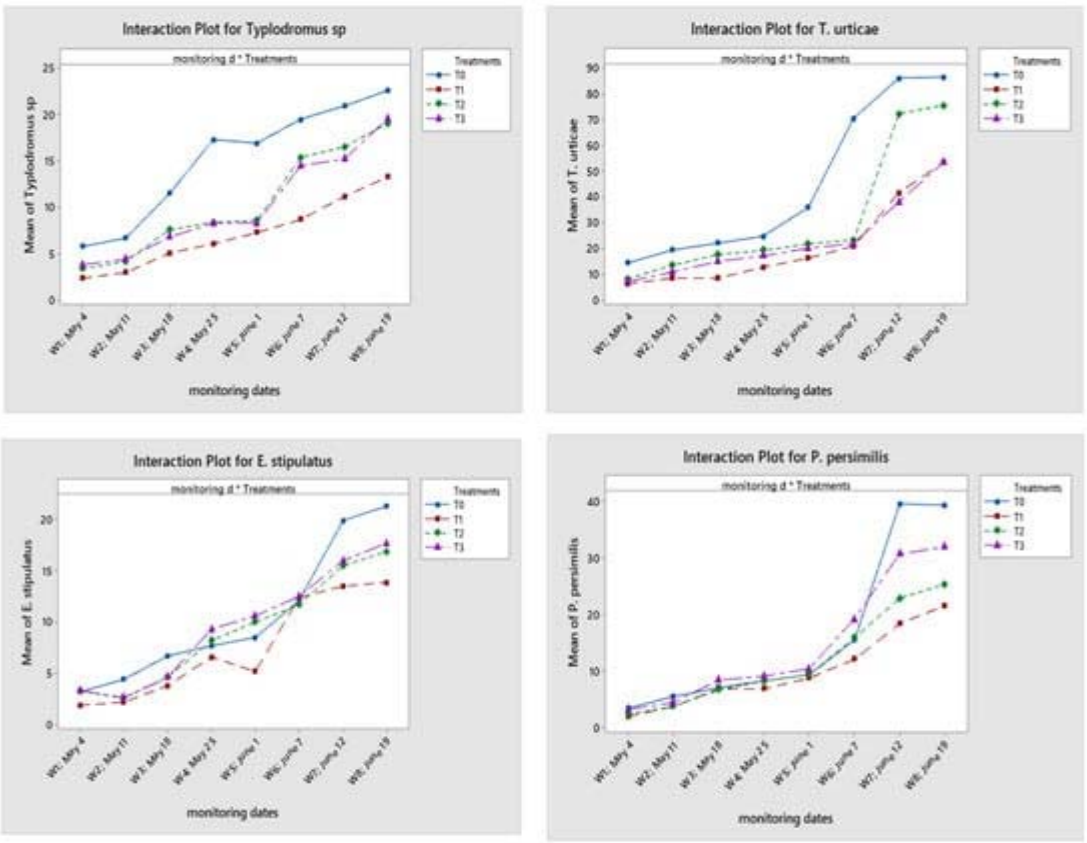


Figure 19. Variation of the means of *T. urticae* and their predators (ES: *E. stipulatus*; TY: *Typhlodromus* sp.; PP: *P. persimilis*) in the four plots according to the interaction between different monitoring dates and treatments (d = dates)

Table 13. General linear model (GLM) of analysis of variance for the mean density of *T. urticae* (a), *Typhlodromus* sp. (b), *P. persimilis* (c), and *E. stipulatus* (d) according to the treatments, monitoring dates, and their interactions

(a) *T. urticae*					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	***p*-Value**
Monitoring dates	7	135.717	19,388.1	1579.57	0.000 *
Treatments	3	28.572	9523.9	775.92	0.000 *
M. dates * Treatments	21	18.865	898.4	73.19	0.000 *
Error	288	3535	12.3		
Total	319	186.689			
(b) *Typhlodromus* sp.					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	***p*-Value**
Monitoring dates	7	7966.9	1138.13	211.42	0.000 *
Treatments	3	2634.3	878.11	163.12	0.000 *
M. dates * Treatments	21	579.6	27.60	5.13	0.000 *
Error	288	1550.4	5.38		
Total	319	12,731.2			
(c) *P. persimilis*					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	***p*-Value**
Monitoring dates	7	30,048	4292.56	473.97	0.000 *
Treatments	3	1745	581.70	64.23	0.000 *
M. dates * Treatments		3012	143.44	15.84	0.000 *
Error	288	2608	9.06		
Total	319	37,413			
(d) *E. stipulatus*					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	***p*-Value**
Monitoring dates	7	8996.3	1285.19	304.76	0.000 *
Treatments	3	389.7	129.90	30.80	0.000 *
M. dates * Treatments		409.6	19.50	4.62	0.000 *
Error	288	1214.5	4.22		
Total	319	11,010.1			

* Statistically significant *p*-values ($p < 0.05$).

Table 14. Fluctuation of the different species studied (TU: *T. urticae*; ES: *E. stipulatus*; TY: *Typhlodromus* sp.; PP: P. persimilis) in the four treated plots (T0 = control experiment; T1 = spirodiclofen 0.5 L/Ha; T2 = 125 L/Ha (5%) of black soap; T3 = detergents 4 L/Ha of Oni product + 2 L/Ha of Tide product) according to the different monitoring dates (W: week).

	TU-TO	TU-T1	TU-T2	TU-T3	TY-T0	TY-T1	TY-T2	TY-T3	ES-T0	ES-T1	ES-T2	ES-T3	PP-T0	PP-T1	PP-T2	Pp-T3
W1	14.30 ^{E} ± 2.00	6.30 ^{F} ± 1.16	8.20 ^{E} ± 1.69	07.00 ^{F} ± 1.49	5.80 ^{D} ± 1.33	2.40 ^{F} ± 0.63	3.40 ^{D} ± 1.57	3.80 ^{D} ± 1.39	3.20 ^{D} ± 1.81	1.90 ^{D} ± 0.94	3.30 ^{D} ± 1.25	3.30 ^{D} ± 1.25	3.50 ^{D} ± 1.90	2.00 ^{D} ± 1.16	2.40 ^{E} ± 1.02	3.20 ^{D} ± 1.41
W2	19.50 ^{DE} ± 1.51	8.60 ^{F} ± 1.71	13.50 ^{D} ± 2.17	10.80 ^{F} ± 2.39	6.70 ^{D} ± 1.14	3.00 ^{EF} ± 1.04	4.20 ^{D} ± 1.24	4.40 ^{D} ± 1.24	4.40 ^{CD} ± 1.64	2.20 ^{D} ± 1.31	2.60 ^{D} ± 1.07	2.60 ^{D} ± 1.07	5.50 ^{CD} ± 1.44	3.80 ^{D} ± 1.16	3.80 ^{DE} ± 1.34	4.40 ^{D} ± 1.22
W3	22.10 ^{D} ± 2.13	8.50 ^{F} ± 1.35	17.70 ^{CD} ± 4.08	14.90 ^{E} ± 4.33	11.50 ^{C} ± 1.43	5.10 ^{DE} ± 1.37	7.60 ^{C} ± 1.53	6.80 ^{CD} ± 1.56	6.70 ^{CD} ± 1.54	3.80 ^{CD} ± 1.44	4.60 ^{D} ± 1.95	4.60 ^{D} ± 1.53	7.10 ^{CD} ± 1.93	6.90 ^{C} ± 1.53	6.70 ^{CD} ± 1.37	8.40 ^{C} ± 1.43
W4	24.80 ^{D} ± 1.47	12.80 ^{E} ± 1.22	19.30 ^{BC} ± 2.22	17.0 ^{DE} ± 2.87	17.30 ^{B} ± 1.87	6.10 ^{CD} ± 1.10	8.40 ^{C} ± 1.43	8.30 ^{C} ± 1.47	7.70 ^{C} ± 1.70	6.60 ^{BC} ± 1.67	8.20 ^{C} ± 1.22	9.30 ^{C} ± 1.82	8.30 ^{C} ± 1.40	6.90 ^{B} ± 1.89	8.30 ^{C} ± 1.35	9.10 ^{C} ± 1.33
W5	36.00 ^{C} ± 2.35	16.30 ^{D} ± 1.41	21.80 ^{BC} ± 3.15	20.0 ^{CD} ± 2.44	16.90 ^{B} ± 1.79	7.30 ^{CD} ± 1.41	8.60 ^{C} ± 1.49	8.30 ^{C} ± 1.30	8.50 ^{BC} ± 1.87	5.20 ^{B} ± 1.41	10.00 ^{BC} ± 1.29	10.60 ^{BC} ± 1.71	9.40 ^{C} ± 1.59	8.80 ^{B} ± 1.91	9.40 ^{C} ± 1.67	10.40 ^{C} ± 1.4
W6	70.60 ^{B} ± 4.09	21.00 ^{C} ± 1.33	23.40 ^{B} ± 1.43	21.90 ^{C} ± 1.79	19.50 ^{A} ± 1.84	8.70 ^{BC} ± 1.45	15.40 ^{B} ± 2.14	14.50 ^{B} ± 1.94	12.10 ^{B} ± 1.54	12.40 ^{A} ± 1.26	11.70 ^{B} ± 1.82	12.50 ^{B} ± 1.78	15.50 ^{B} ± 2.04	12.10 ^{A} ± 2.01	15.90 ^{B} ± 2.04	19.20 ^{B} ± 1.7
W7	86.20 ^{A} ± 6.42	41.70 ^{B} ± 3.71	72.30 ^{A} ± 5.29	38.00 ^{B} ± 1.29	20.90 ^{A} ± 2.84	11.20 ^{AB} ± 2.44	16.50 ^{AB} ± 2.84	15.20 ^{B} ± 2.35	19.90 ^{A} ± 2.19	13.50 ^{A} ± 1.78	15.50 ^{A} ± 1.54	16.00 ^{A} ± 1.24	39.60 ^{A} ± 2.94	18.40 ^{A} ± 2.56	22.90 ^{A} ± 2.91	30.70 ^{A} ± 2.4
W8	86.60 ^{A} ± 7.06	53.60 ^{A} ± 4.77	75.70 ^{A} ± 4.69	53.60 ^{A} ± 3.77	22.60 ^{A} ± 2.77	13.30 ^{A} ± 1.17	19.10 ^{A} ± 1.27	19.60 ^{A} ± 2.55	21.30 ^{A} ± 2.75	13.90 ^{A} ± 1.83	16.90 ^{A} ± 1.96	17.70 ^{A} ± 1.57	39.30 ^{A} ± 2.87	21.60 ^{A} ± 2.04	25.90 ^{A} ± 2.87	32.0 ^{A} ± 2.97

Values in the same column with different superscripts are significantly different ($p < 0.05$).

For the treatment based on detergents, we obtained similar results to those achieved with spirodiclofen. These products ensured a significant reduction of the pest *T. urticae* during the eight-week monitoring period. Despite the increase in temperature from 27 °C to 38 °C (**Table 15**), the treatment with black soap ensured a significant decrease in the rates of *T. urticae* during the first six weeks after application compared to the untreated plot (**Figure 19**). During the sixth week, these averages were 23.40 B ± 1.43 on the plot sprayed with black soap and 70.60 B ± 4.09 on the untreated plot. The number of this pest increased during the last 2 weeks of monitoring (weeks 7 and 8) to reach 75.70 A ± 4.69 in week 8, almost the same as the average reached on the untreated plot (86.60 A ± 7.06).

Table 15. Temperatures recorded during the monitoring period.

Follow-Up Date	4 May	11 May	18 May	25 May	1 June	7 June	12 June	19 June
Temperature	27	28	30	32	34	38	37	39

During the whole monitoring period, **Figure 19** indicates that the three treatments used caused a decrease in the means of *T. urticae* from 12 April (week 1) to 19 May (week 8) compared to the untreated plot; the effectiveness of spirodiclofen was important compared to the control by black soap and detergents.

Regarding the interaction between treatments and monitoring dates (**Figure 19**), all three treatments used had a significant impact on the abundance of *Typhlodromus* sp. over time. This influence was greater in the spirodiclofen than the detergent and black soap treatments.

For *Typhlodromus* sp., this difference was less important during the first five weeks after spraying the treatments. On the date of 18 May, these averages were 7.30 CD ± 1.41 in T1 (spirodiclofen), 8.60 C ± 1.49 in T2 (black soap), and 8.30 C ± 1. 30 in T3 (detergents). Then, there was a significant difference between the treatment with spirodiclofen and the treatments with black soap and detergents from the sixth week until the last week. The averages were 8.70 BC ± 1.45 in T1, 15.40 B ± 2.14 in T2, and 14.50 B ± 1.94 in T3.

During the first five weeks, the detergent and black soap treatments showed less harmful impacts compared to spirodiclofen on the *E. stipulatus* population. The averages at this time (1 June) were 5.20 B ± 1.41 in T1 (spirodiclofen), 10.00 BC ± 1.29 in T2 (black soap), and 10.60 BC ± 1.71 in T3 (detergents).

For *P. persimilis,* the detergent treatment showed almost similar results as in the control, and showed the least harmful impact, in the last three weeks of the follow-up (from 7 to 19 June). In the plot treated with detergents, we had an average of 32.0 A ± 2.97 for this species; in the untreated plot, we had 39.30 A ± 2.87; in the plot treated with black soap, the average was 25.90 A ± 2.87; and the average was 21.60 A ± 2.04 in the one treated with spirodiclofen.

3 Discussion

The biodiversity of phytoseiid mites nationally and internationally has started to decline catastrophically, as well as the increase in resistance developed by the pests against acaricides, allowing unusual increases in the population of the latter. This work aims to compare the impact of detergents, black soap, and spirodiclofen on the pest *T. urticae* on the one hand and on phytoseiid mites on the other hand.

The results collected during the study period showed that the three treatments used, namely, spirodiclofen, black soap, and detergents, ensured a decrease in the population rate of the pest *T. urticae* compared to the untreated plot. In the untreated plot, the average was 45.01 A ± 4. 90 mobile forms, while the plot treated with spirodiclofen was only 21.10 C ± 2.71, the black soap gave 31.49 B ± 3.35, and average of the plot treated with detergents was similar to that obtained by spirodiclofen at 22.90 C ± 2.18. The same results were reported by [**26**,**37**]: the application of spirodiclofen ensured the decrease of the survival rate and fecundity of *T. urticae.* In another study, the efficacy of spirodiclofen and other acaricides against *T. urticae* on greenhouse strawberries was tested at different times after application. At seven days, spirodiclofen showed significant efficacy at 86.6%. This efficacy reached 90% on day 10 and started to decrease slightly after that period [**38**]. In addition, black soap also showed significant efficacy against several insects such as *Bemisia tabaci* Gennadius, 1889, *Aphis craccivora* Koch, 1854 and *parlatoria ziziphi* Lucas, 1853 [**39**,**40**]. The pesticidal activity of the agricultural detergents SU-120 and Tecsa® Fruta was evaluated on *T. urticae* and *Myzus persicae* Sulzer, 1776. Several concentrations of SU-120 were applied to nymphs and adults of *T. urticae*. Mortality was measured in both cases at 24 h. On *T. urticae*, both detergents caused mortality greater than 70% [**41**,**42**,**43**].

This study revealed that all three treatments used had an impact on the predators studied compared to the control, with the influence of spirodiclofen being greater than that of the detergents and black soap treatments. The effect of spirodiclofen was studied on *Neoseiulus californicus* McGregor, 1954, a potential predator of *T. urticae*, and the results indicated that the adverse consequences on the population growth parameters were significant [**44**]. In a small field plot test on spirodiclofen-treated apple trees, its use in a conventional chemical control program affected populations of *Forficula auricularia* Linnaeus, 1758 (Dermaptera), which is an important generalist predator in orchards, regulating populations of several damaging pest species, while the number of earwigs increased in the orchards with the compatible spray program (Integrated Pest Management) [**45**]. Many studies confirm that black soap and detergents can replace conventional chemical treatments and constitute an important tool in integrated pest management because of their low phytotoxicity [**43**,**46**].

The results revealed that there was an impact of the treatments used on the three predators compared to the control, and this influence was greater with the spirodiclofen than with the detergents and black soap treatments. Despite the benefits of pesticides, such as the rapidity of action in the reduction of number of pests and their easy use when compared to natural extracts from plants [**16**], chemical control has many limitations; the examination of the action spectrum of the active components used throughout the world reveals that 46% of acaricides and 72% of insecticides are globally toxic towards auxiliary arthropods and public health [**47**]. Concerning the impact of the treatments according to the dates on *T. urticae*, we noticed that the three treatments ensured a decrease in the abundance of this pest. On the other hand, the efficacy of spirodiclofen was superior to the black soap and detergents; this can be explained by the high toxicity of the pesticide [**22**], as it can be remedied by monthly repetitive spraying with black soap or/and detergents, which remain less toxic for the plant, the predators, and the agroecosystem in general [**39**]. Botanical pesticides from the Lamiaceae, the Asteraceae, the Myrtaceae, and the Apiaceae taxons can also be used as a complementary alternative in the control of *T. urticae* [**48**]. We can explain the increase of the number of pests during the last two weeks of follow-up by the increase in the temperature, which remains a paramount parameter for population fluctuation [**49**,**50**].

Conclusions

The following conclusions can be drawn from this work: the black soap and detergent products can replace conventional chemical treatments and are an important tool in integrated

pest management, provided they are used correctly. The repetitive spraying of eco-friendly products can ensure the reduction of the pest rates in the long term. Finally, the release of natural enemies can be ensured after four weeks of the treatment with these products, since their persistence does not exceed five weeks, according to our results.

Author Contributions

Conceptualization, A.A. and A.L.; methodology, A.A.; investigation, M.K.; data curation, H.M.; writing—original draft preparation, A.A.; writing, review and editing, F.A.A.-M. and F.N.; supervision, A.L. and A.F. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by Researchers Supporting Project number (RSP-2021/112), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data available upon request.

Acknowledgments

The authors are grateful for Researchers Supporting Project number (RSP-2021/112), King Saud University, Riyadh, Saudi Arabia. Open access funding provided by University of Helsinki.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Citrus Fruit Fresh and Processed Statistical Bulletin 2020|Policy Support and Governance|Food and Agriculture Organization of the United Nations. Available online: **https://www.fao.org/policy-support/tools-and-publications/resources-details/fr/c/1439010/** (accessed on 28 January 2022).
2. Bora, H.; Kamle, M.; Mahato, D.K.; Tiwari, P.; Kumar, P. Citrus essential oils (CEOs) and their applications in food: An overview. *Plants* **2020**, *9*, 357. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
3. Tahir, R. Impact of Foliar Application of Zn on Growth Yield and Quality Production of Citrus: A Review. *Indian J. Pure Appl. Biosci.* **2020**, *8*, 529–534. [**Google Scholar**] [**CrossRef**]
4. Afechtal, M.; Djelouah, K.; Cocuzza, G.; D'Onghia, A.M. Large Scale Survey of Citrus Tristeza Virus (CTV) and Its Aphid Vectors in Morocco. *Acta Hortic.* **2015**, *1065*, 753–757. [**Google Scholar**] [**CrossRef**]
5. Mazih, A. Status of citrus IPM in the southern mediterranean basin Morocco, North Africa. *Acta Hortic.* **2015**, *1065*, 1097–1104. [**Google Scholar**] [**CrossRef**]
6. Rachid, E.; Ahmed, M. Current status and future prospects of ceratitis capitata wiedemann (Diptera: Tephritidae) control in Morocco. *J. Entomol.* **2018**, *15*, 47–55. [**Google Scholar**] [**CrossRef**][**Green Version**]

7. Assouguem, A.; Kara, M.; Benmessaoud, S.; Mechchate, H.; El Jabboury, Z.; Farah, A.; Lazraq, A. Ceratitis capitata Wiedemann (Diptera:Tephritidae) in Moroccan Citrus orchards: Chemical and Sustainable Control Methods and Priorities for Future Research. *Trop. J. Nat. Prod. Res.* **2021**, *5*, 1703–1708. [**Google Scholar**]
8. Assouguem, A.; Kara, M.; Mansouri, I.; Imtara, H.; Alzain, M.N.; Mechchate, H.; Conte, R.; Squalli, W.; Farah, A.; Lazraq, A. Evaluation of the effectiveness of spirotetramat on the diaspine scale parlatoria pergandii in citrus orchards. *Agronomy* **2021**, *11*, 1562. [**Google Scholar**] [**CrossRef**]
9. Smaili, M.C.; El Ghadraoui, L.; Gaboun, F.; Benkirane, R.; Blenzar, A. Impact of some alternative methods to chemical control in controlling aphids (Hemiptera: Sternorrhyncha) and their side effects on natural enemies on young Moroccan citrus groves. *Phytoparasitica* **2014**, *42*, 421–436. [**Google Scholar**] [**CrossRef**][**Green Version**]
10. Smaili, M.C. Current Pest Status and the Integrated. Available online: **https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili+MC+%282017%29+Current+pest+status+and+the+integrated+pest+management+strategy+in+the+citrus+groves+in+Morocco.+In%3A+Abstracts+of+the+IOBC+citrus+working+group+meeting+on+citrus+pests%2C+disea** (accessed on 10 July 2021).
11. Xue, W.; Snoeck, S.; Njiru, C.; Inak, E.; Dermauw, W.; Van Leeuwen, T. Geographical distribution and molecular insights into abamectin and milbemectin cross-resistance in European field populations of Tetranychus urticae. *Pest Manag. Sci.* **2020**, *76*, 2569–2581. [**Google Scholar**] [**CrossRef**]
12. Migeon, A.; Nouguier, E.; Dorkeld, F.; Cbgp, U.M.R.; Ird, I.; Montpellier, C.; Cedex, M. Spider Mites Web: A comprehensive database for the Tetranychidae Alain. *Trends Acarol.* **2010**, 557–560. [**Google Scholar**] [**CrossRef**]
13. Grbić, M.; Van Leeuwen, T.; Clark, R.M.; Rombauts, S.; Rouzé, P.; Grbić, V.; Osborne, E.J.; Dermauw, W.; Ngoc, P.C.T.; Ortego, F.; et al. The genome of Tetranychus urticae reveals herbivorous pest adaptations. *Nature* **2011**, *479*, 487–492. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
14. Fakhour, S. L' acarien jaune, Tetranychus urticae Koch. (Acari: Tetranychidae) sur Maïs fourrager au Maroc: Impact et stratégies de lutte. In Proceedings of the Deuxième Colloque sur les Acariens des Cultures, Montpellier, France, 24–25 October 2005. [**Google Scholar**]
15. Nachman, G.; Zemek, R. Interactions in a tritrophic acarine predator-prey metapopulation system V: Within-plant dynamics of Phytoseiulus persimilis and Tetranychus urticae (Acari: Phytoseiidae, Tetranychidae). *Exp. Appl. Acarol.* **2003**, *29*, 35–68. [**Google Scholar**] [**CrossRef**] [**PubMed**]
16. Attia, S.; Grissa, K.L.; Lognay, G.; Bitume, E.; Hance, T.; Mailleux, A.C. A review of the major biological approaches to control the worldwide pest Tetranychus urticae (Acari: Tetranychidae) with special reference to natural pesticides: Biological approaches to control Tetranychus urticae. *J. Pest Sci.* **2013**, *86*, 361–386. [**Google Scholar**] [**CrossRef**]
17. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial insect community of Moroccan citrus groves: Assessment of their potential to enhance biocontrol services. *Egypt. J. Biol. Pest Control* **2020**, *30*, 47. [**Google Scholar**] [**CrossRef**]
18. De Maeyer, L.; Geerinck, R. The multiple target use of spirodiclofen (Envidor 240 SC) in IPM pomefruit in Belgium. *Commun. Agric. Appl. Biol. Sci.* **2009**, *74*, 225–232. [**Google Scholar**]
19. Ramdani, C.; El Fakhouri, K.; Sbaghi, M.; Bouharroud, R.; Boulamtat, R.; Aasfar, A.; Mesfioui, A.; Bouhssini, M. El Chemical Composition and Insecticidal Potential of Six Essential Oils from Morocco against Dactylopius opuntiae. *Insects* **2021**, *12*, 1007. [**Google Scholar**] [**CrossRef**]
20. Daniel, E.C.; Wyss, C.L. Applications de soufre en automne: Une nouvelle manière de lutter contre lériophyide à galles du poirier. *Rev. Suisse Vitic. Arboric. Hortic.* **2004**, *36*, 199–203. [**Google Scholar**]
21. Buitenhuis, R.; Brownbridge, M.; Brommit, A.; Saito, T.; Murphy, G. How to start with a clean crop: Biopesticide dips reduce populations of Bemisia tabaci (Hemiptera: Aleyrodidae) on greenhouse poinsettia propagative cuttings. *Insects* **2016**, *7*, 48. [**Google Scholar**] [**CrossRef**]
22. Attia, S.; Grissa, K.L.; Zeineb, G.G.; Mailleux, A.C.; Lognay, G.; Hance, T. Assessment of the acaricidal activity of several plant extracts on the phytophagous mite Tetranychus urticae (Tetranychidae) in Tunisian citrus orchards. *Bull. Soc. R. Belg. D'Entomol.* **2011**, *147*, 71–79. [**Google Scholar**]
23. Van Leeuwen, T.; Tirry, L.; Yamamoto, A.; Nauen, R.; Dermauw, W. The economic importance of acaricides in the control of phytophagous mites and an update on recent acaricide mode of action research. *Pestic. Biochem. Physiol.* **2015**, *121*, 12–21. [**Google Scholar**] [**CrossRef**]
24. Saber, M.; Ahmadi, Z.; Mahdavinia, G. Sublethal effects of spirodiclofen, abamectin and pyridaben on life-history traits and life-table parameters of two-spotted spider mite, Tetranychus urticae (Acari: Tetranychidae). *Exp. Appl. Acarol.* **2018**, *75*, 55–67. [**Google Scholar**] [**CrossRef**] [**PubMed**]
25. Bostanian, N.J.; Trudeau, M.; Lasnier, J. Management of the two-spotted spider mite, Tetranychus urticae [Acari: Tetranychidae] in eggplant fields. *Phytoprotection* **2003**, *84*, 1–8. [**Google Scholar**] [**CrossRef**][**Green Version**]

26. Hu, J.; Wang, C.; Wang, J.; You, Y.; Chen, F. Monitoring of resistance to spirodiclofen and five other acaricides in Panonychus citri collected from Chinese citrus orchards. *Pest Manag. Sci.* **2010**, *66*, 1025–1030. [**Google Scholar**] [**CrossRef**]
27. Faria, J.M.S.; Rodrigues, A.M. Essential Oils as Potential Biopesticides in the Control of the Genus *Meloidogyne*: A Review. *Biol. Life Sci. Forum* **2021**, *3*, 26. [**Google Scholar**] [**CrossRef**]
28. Assouguem, A.; Kara, M.; Mechchate, H.; Alzain, M.N.; Noman, O.M.; Imtara, H.; Hano, C.; Ibrahim, M.N.; Benmessaoud, S.; Farah, A.; et al. Evaluation of the Effect of Different Concentrations of Spirotetramat on the Diaspine Scale Parlatoria ziziphi in Citrus Orchards. *Agronomy* **2021**, *11*, 1840. [**Google Scholar**] [**CrossRef**]
29. Benyahia, H.; Talha, A.; Fadli, A.; Chetto, O.; Omari, F.E.; Beniken, L. Performance of 'Valencia late' sweet orange (Citrus sinensis) on different rootstocks in the gharb region (Northwestern Morocco). *Annu. Res. Rev. Biol.* **2017**, *20*, 1–11. [**Google Scholar**] [**CrossRef**]
30. Hassouni, T.; Belghyti, D. Distribution of gastrointestinal helminths in chicken farms in the Gharb region—Morocco. *Parasitol. Res.* **2006**, *99*, 181–183. [**Google Scholar**] [**CrossRef**]
31. Eur-lex EUR-Lex—31999L0045—EN—EUR-Lex. Available online: **https://eur-lex.europa.eu/legal-content/FR/ALL/?uri=celex:31999L0045** (accessed on 30 November 2021).
32. Bouharroud, R. Acariens clés des Agrumes au Maroc, Agriculture du Maghreb. Available online: **http://www.agri-mag.com/2017/06/acariens-cles-des-agrumes-au-maroc/** (accessed on 18 April 2021).
33. Martínez-Ferrer, M.T.; Jacas, J.A.; Ripollés-Moles, J.L.; Aucejo-Romero, S. Approaches for sampling the twospotted spider mite (Acari: Tetranychidae) on clementines in Spain. *J. Econ. Entomol.* **2006**, *99*, 1490–1499. [**Google Scholar**] [**CrossRef**]
34. Marullo, R.; Bonsignore, C.P.; Vono, G. Thrips: A review of sampling methods in relation to their habitats. *Bull. Insectol.* **2021**, *74*, 241–251. [**Google Scholar**]
35. Benziane, T.; Abbassi, M.; Bihi, T. Evaluation de deux méthodes de lutte intégrée contre les ravageurs en vergers d'agrumes. *J. Appl. Entomol.* **2003**, *127*, 51–63. [**Google Scholar**] [**CrossRef**]
36. Haddad, D.N.; Sadoudi, F.G.-M. Management of a main citrus pest black parlatoria scale Parlatoria ziziphi (lucas) (hemiptera: Diaspididae) in the mediterranean basin. *SciFed Virol. Res. J.* **2018**, *1*, 184–199. [**Google Scholar**]
37. Van Pottelberge, S.; Khajehali, J.; Van Leeuwen, T.; Tirry, L. Effects of spirodiclofen on reproduction in a susceptible and resistant strain of Tetranychus urticae (Acari: Tetranychidae). *Exp. Appl. Acarol.* **2009**, *47*, 301–309. [**Google Scholar**] [**CrossRef**] [**PubMed**]
38. Wang, Z.; Cang, T.; Wu, S.; Wang, X.; Qi, P.; Wang, X.; Zhao, X. Screening for suitable chemical acaricides against two-spotted spider mites, Tetranychus urticae, on greenhouse strawberries in China. *Ecotoxicol. Environ. Saf.* **2018**, *163*, 63–68. [**Google Scholar**] [**CrossRef**] [**PubMed**]
39. Egho, E.; Emosairue, S. Evaluation of native soap (local black soap) for the control of major insect pests and yield of cowpea (*Vigna unguiculata* (L) WALP in ASABA, Southern Nigeria. *Agric. Biol. J. N. Am.* **2010**, *1*, 938–945. [**Google Scholar**] [**CrossRef**]
40. ABD-RABOU, S. Evaluation of Aphytis melinus De Bach (Hymenoptera: Chalcidoidea: Aphelinidae) in Citrus Orchards as a Biocontrol Agent of Black Scale, Parlatoria ziziphi (Lucas) (Hemiptera: Coccoidea: Diaspididae) in Egypt. *J. Biol. Control* **2009**, *23*, 37–41. [**Google Scholar**] [**CrossRef**]
41. Gill, H.K.; Goyal, G. (Eds.) *Integrated Pest Management (IPM): Environmentally Sound Pest Management*; IntechOpen: London, UK, 2016; Available online: **https://www.intechopen.com/books/5252** (accessed on 28 January 2022).
42. Curkovic, T.; Araya, J.; Canales, C.; Medina, Á. Evaluation of two agriculture detergents as control alternatives for green peach aphid and twospotted spidermite, two pests affecting peach orchards in Chile. *Acta Hortic.* **2006**, *713*, 405–407. [**Google Scholar**] [**CrossRef**]
43. Curkovic, T. Detergents and Soaps as Tools for IPM in Agriculture. In *Integrated Pest Management (IPM): Environmentally Sound Pest Management*; IntechOpen: London, UK, 2016; Available online: **https://www.intechopen.com/chapters/51590** (accessed on 28 January 2022).
44. Sarbaz, S.; Goldasteh, S.; Zamani, A.A.; Solymannejadiyan, E.; Vafaei Shoushtari, R. Side effects of spiromesifen and spirodiclofen on life table parameters of the predatory mite, Neoseiulus californicus McGregor (Acari: Phytoseiidae). *Int. J. Acarol.* **2017**, *43*, 380–386. [**Google Scholar**] [**CrossRef**]
45. Fountain, M.T.; Harris, A.L. Non-target consequences of insecticides used in apple and pear orchards on *Forficula auricularia* L. (Dermaptera: Forficulidae). *Biol. Control* **2015**, *91*, 27–33. [**Google Scholar**] [**CrossRef**]
46. Bajwa, U.; Singh Sandhu, K. Effect of handling and processing on pesticide residues in food-a review. *J. Food Sci. Technol.* **2014**, *51*, 201–220. [**Google Scholar**] [**CrossRef**][**Green Version**]
47. Van Leeuwen, T.; Vontas, J.; Tsagkarakou, A.; Dermauw, W.; Tirry, L. Acaricide resistance mechanisms in the two-spotted spider mite Tetranychus urticae and other important Acari: A review. *Insect Biochem. Mol. Biol.* **2010**, *40*, 563–572. [**Google Scholar**] [**CrossRef**][**Green Version**]
48. Rincón, R.A.; Rodríguez, D.; Coy-Barrera, E. Botanicals against Tetranychus urticae Koch under Laboratory Conditions: A Survey of Alternatives for Controlling Pest Mites. *Plants* **2019**, *8*, 272. [**Google Scholar**] [**CrossRef**][**Green Version**]

49. Bayu, M.S.Y.I.; Ullah, M.S.; Takano, Y.; Gotoh, T. Impact of constant versus fluctuating temperatures on the development and life history parameters of Tetranychus urticae (Acari: Tetranychidae). *Exp. Appl. Acarol.* **2017**, *72*, 205–227. [**Google Scholar**] [**CrossRef**]
50. Abdallah, A.M.; Ismail, M.S.M.; AboGhalia, A.H.; Soliman, M.F.M. Factors affecting population dynamics of Tetranychus urticae and its predators on three economic plants in Ismailia, Egypt. *Int. J. Trop. Insect Sci.* **2019**, *39*, 115–124. [**Google Scholar**] [**CrossRef**]

Chapitre IV:

Évaluation de l'impact variétal de deux espèces d'agrumes sur les fluctuations de *Tetranychus urticae* (Acari : Tetranychidae) et surles acariens phytoséiides

Cette étude a fait l'objet d'une publication dans sustainability Journal : (IF= 3,89)

Assouguem, A.; Farah, A.; Ullah, R.; Korkmaz, Y.B.; Almeer, R.; Sayed, A.A.; Najda, A.; Lazraq, A.

Résumé

L'activité de *Tetranychus urticae* Koch, 1836, et de ses prédateurs (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromu*s sp., et *Phytoseiulus persimilis* Athias-Henriot, 1957) sur deux variétés d'agrumes (Nules (Mandarine) et Valencia late (Orange)) a été étudiée dans des vergers d'agrumes à Machraa Belksiri dans la région du Gharb au Maroc durant les années 2020-2021. Dans cet essai, durant la première année de suivi, nous avons détecté que sur la variété Valencia tardif (*Citrus sinensis*), l'occupation des feuilles par *T. urticae* était importante, avec 3200 formes mobiles (50%). Le prédateur *Typhlodromus* sp. a présenté 1385 (22%), suivi par *E. stipilatus* avec 1186 formes mobiles (18%), tandis que *P. persimilis* a présenté le plus petit nombre avec 621 formes (10%). A l'inverse, sur la variété Nules (*Citrus Clementina*), nous avons trouvé (52%) 2475 formes pour le ravageur *T. urticae. E. stipulatus* était le prédateur qui abandonnait le plus, avec 1344 (28%), suivi de *Typhlodromus* sp. avec 944 formes mobiles (22%) ; cependant, le prédateur *P. persimilis* était absent. Au cours de la deuxième année de suivi, dans la parcelle plantée avec la variété Valencia late, nous avons enregistré 2779 spécimens mobiles de *T. urticae* (45%). Pour le prédateur *Typhlodromus* sp., nous avons enregistré 1344 spécimens mobiles (22%). *E. stipulatus* a été enregistré avec 1240 spécimens mobiles (20%). *P. persimilis* a présenté le plus faible pourcentage, avec 14% (n = 847). Sur la variété Nules, nous avons eu 2573 spécimens mobiles de *T. urticae* (48%), 810 pour *Tyhphlodromus* sp. (15%), et 1412 pour *E. stipulatus* (26%), et *P. persimilis* avait 547 spécimens mobiles (10%). De nos résultats, on peut conclure que la lutte synergique par ces prédateurs peut réduire le taux de *T. urticae* et constitue une méthode alternative durable en l'absence de lutte chimique. En ce qui concerne l'effet de la variété des différents acariens étudiés, les variétés Nules et Valencia late n'ont montré aucun impact sur la variation de la densité d'*E. stipulatus* et de *T. urticae*, avec des moyennes relativement similaires, alors que sur le prédateur *Typhlodromus* sp. et *P. persimilis*, l'impact variétal était important.

Evaluation of the Varietal Impact of Two Citrus Species on Fluctuations of *Tetranychus urticae* (Acari: Tetranychidae) and Beneficial Phytoseiid Mites.

Amine Assouguem 1,2,* , Abdellah Farah 2 , Riaz Ullah 3 , Yesim Bulak Korkmaz 4, Rafa Almeer 5, Amany A. Sayed 6, Agnieszka Najda 7 and Abderrahim Lazraq 1

1 Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco; lazraqab@gmail.com

2 Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco; farah.abdellah1@gmail.com

3 Department of Pharmacognosy, College of Pharmacy, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia; rullah@ksu.edu.sa

4 Department of Plant Protection, Faculty of Agriculture, Ataturk University, Erzurum 25240, Turkey; yesim.bulak@atauni.edu.tr

5 Department of Zoology, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia; ralmeer@ksu.edu.sa

6 Zoology Department, Faculty of Science, Cairo University, Giza 12613, Egypt; amanyasayed@sci.cu.edu.eg 7 Department of Vegetable and Herbal Crops, University of Life Sciences, Lublin 50A Do´swiadczalna Street, 20-280 Lublin, Poland; agnieszka.najda@up.lublin.pl

*** Correspondence: assougam@gmail.com**

Abstract

The activity of *Tetranychus urticae* Koch, 1836, and its predators (*Euseius stipulatus* Athias-Henriot, 1960, *Typhlodromus* sp., and *Phytoseiulus persimilis* Athias-Henriot, 1957) on two citrus varieties (Nules (Mandarin) and Valencia late (Orange)) was studied in citrus orchards in Machraa Belksiri at the Gharb region of Morocco in the years 2020–2021. In this trial, during the first year of monitoring, we detected that on the Valencia late variety (*Citrus sinensis*), the occupancy of leaves by *T. urticae* was important, with 3200 mobile forms (50%). The predator *Typhlodromus* sp. presented 1385 (22%), followed by *E. stipilatus* with 1186 mobile forms (18%), while *P. persimilis* presented the lowest number with 621 forms (10%). Conversely, on the Nules variety (*Citrus Clementina*), we found (52%) 2475 forms for the pest *T. urticae*. *E. stipulatus* was the most abandoning predator, with 1344 (28%), followed by *Typhlodromus* sp., with 944 (22%); however, the predator *P. persimilis* was absent. From our results, it can be concluded that synergistic control by these predators can reduce the rate of *T. urticae* and constitutes a sustainable alternative method in the absence of chemical control. Regarding the effect of the variety of the different mites studied, the varieties Nules and

Valencia late showed no impact on the rates of *E. 1tipulates* and *T. urticae*, with relatively similar averages, while on the predator *Typhlodromus* sp. and *P. persimilis*, the varietal impact was important.

Keywords: citrus; varieties; monitoring; predator; pest; sustainable; alternative method; control; synergist

Introduction

In Morocco, the area cultivated with citrus has exceeded 130,000 ha, with a total annual production of more than 2.2 million tons, thanks to the strategies developed by the Ministry of Agriculture [**1**]. In addition, government policy has forecasted an estimated production of 2.5 to 3.5 million tons by 2022 [**2**]. The citrus fruits are mainly produced in the regions of Moulouya, Souss, Tadla, Haouz, Loukkos, Berkane, and Gharb [**3**]. Currently, the national citrus market is undergoing an extraordinary change, with a significant decline in exports to the European Union, from 70% to only 25–30%. In comparison, exports to Russia have increased from 45% to 50% of all Moroccan exports [**4**]. Unfortunately, this sector has been seriously affected in recent years by biotic and abiotic factors [**5**]. In addition to production and marketing complications, many pests and diseases have reduced the quantity and quality of citrus fruit [**6**]. Pests of primary economic importance include spider mites, thrips, aphids, medflies, and diaspine scales. [**7**,**8**,**9**].

Tetranychus urticae C. L. Koch, 1836, is native to the temperate zone, but it is frequently introduced in the tropical zone [**10**]. It is a phytophagous mite of the family Tetranychidae; this species is a highly polyphagous herbivore and a major agricultural pest worldwide that causes hard damages to economic crops [**11**,**12**,**13**]; it presents a notable pest of field crops, ornamentals, and annual and perennial plants [**14**]. It attacks (i) fruit trees, including apple, citrus, raspberry, and pear shrubs [**15**]; (ii) vegetables, including okra, cotton, cucumber, bean, tomato, and eggplant [**16**,**17**,**18**,**19**]; (iii) ornamentals, including dahlia, rose, gerbera, zinnia, and ganda [**20**]; and medicinal plants, including moringa (*Moringa oleifera* Lam.), metel (*Datura metel* L.), Alfalfa (*Medicago sativa* L.), Peppermint (*Mentha piperita* L.), rosemary (*Salvia rosmarinus* Spenn.), and common vervain (*Verbena offlicinalis* L.) [**21**,**22**,**23**,**24**,**25**].

Euseius stipulatus Athias-Henriot, 1960, (Acari: Phytoseiidae) was found in the Mediterranean citrus orchards [**24**]. It feeds on *Panonychus citri* and *T. urticae* and consumes pollen [**26**]. In Morocco, this predator was observed preying on *P. citri*, *T. urticae*, and *Tetranychus cinnabarinus* and played a role in biological control [**27**].

Phytoseiulus persimilis Athias-Henriot, 1957, (Acari: Phytoseiidae) is a specialist predator that feeds particularly on *Tetranychus* species and whose survival depends on the presence and quality of its prey [**28**]. In the Mediterranean zone, *Phytoseiulus persimilis* is a principal predator of *T. urticae* in open fields and in greenhouses [**29**].

Typhlodromus sp. are predacious mites preying on either tetranychid or eriophyid mites. Certain species are successfully used as biological agents [**30**]. *Typhlodromus* mites have a global distribution. In Africa, species have been recorded from Algeria, Morocco, Egypt, Sudan, Congo, and South Africa [**31**]. In Morocco, *Typhlodromus* sp. was often observed preying on *T. urticae* and *T. cinnabarinus* [**27**]. The goal of this study is to evaluate the varietal impact of two citrus species (Nules (Mandarin) and Valencia late (Orange)), on fluctuations of *T. urticae* and beneficial phytoseid mites (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*) during a two-year span.

1 Materials and Methods

1.1 Study Area

This study was performed in Mechra Bel Ksiri (34°34′00″ N, 5°57′00″ W), located north of Oued Sebou in the Gharb region at an altitude of 300–500 m above sea level (**Figure 20**). The Gharb area is Morocco's largest agricultural region (600 km^2) [**32**]. This area is well known for the production of cereals, citrus, and vegetables due to the suitable climate and soil characteristics [**33**]. This zone is characterized by its Mediterranean climate, with annual precipitations ranging between 460 and 600 mm, and an average temperature of 27 °C during summer and 13 °C during winter.

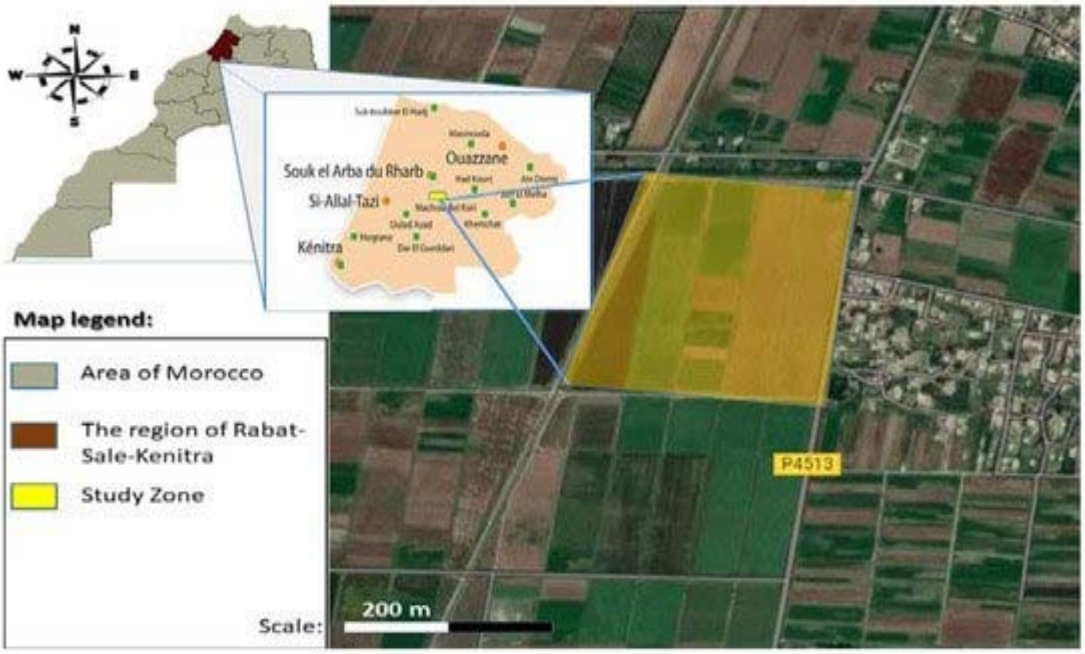


Figure 20. Location of studied citrus orchards.

1.2 Sampling Design

This experiment was conducted on two plots without chemical practices; the first is a plot of 4 Ha planted with the variety Valencia late (*Citrus sinensis*). The second one is a 4 Ha plot planted with the variety Clementine Nules (*Citrus clementina*). In this trial, the activity of *T. urticae* and its predators (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*) was monitored weekly.

In both plots, 10 trees belonging to a square block were selected and monitored weekly; on each tree, 10 leaves collected from different sun exposure sectors (North, East, South, and West) were inspected during 8 weeks (10 repetitions were performed independently) [**34**,**35**,**36**]. In the open field, the total number of predators and phytophagous mites (*T. urticae*) found were counted on both surfaces of the leaf using a professional 10× eye loupe. Surveys were conducted for 8 consecutive weeks per year during a two-year span. The dates for each week and year were as follows: in 2020, 12 April (week 1), 19 April (week 2), 26 April (week 3), 3 May (week 4), 10 May (week 5), 17 May (week 6), 24 May (week 7), and 1 June (week 8). In 2021, 16 April (week 1), 23 April (week 2), 30 April (week 3), 08 May (week 4), 15 May (week 5), 22 May (week 6), 29 May (week 7), and 6 June (week 8). Temperature data were collected in the field, using Davis Instruments Vantage Pro2.

1.3 Statistics

Experimental data were performed in Minitab software, version 1.1.19, LLC, State College, PA, USA [**37**]. The results were given as the SD amd mean. In addition, to evaluate the abandonment of each species of the studied mites, we calculated the percentage of mobile forms of *T. urticae* and their predators (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*) (specimen in question/total species studied). We checked the normality and homogeneity of the variance for all variables with the Kolmogorov–Smirnov test. To assess the impact of varietal and monitoring dates on mite evolution, we used the one-way analysis of variance test, followed by a Tukey post hoc test at $p < 0.05$ [**38**].

2 Results

2.1 Leaf Occupancy Rate by Mites in the Different Plots

After the first year of follow-up, on the variety Valencia late (**Figure 21**), the occupation of the leaves by *T. urticae* was most important with 50% (n = 3200) of mobile forms. The predator *Typhlodromus* sp. presented 22% (n = 1385), while the proportion of *E. stipulatus* was 18% (n = 1186); *P. persimilis* was the least with a percentage of 10% (n = 621).

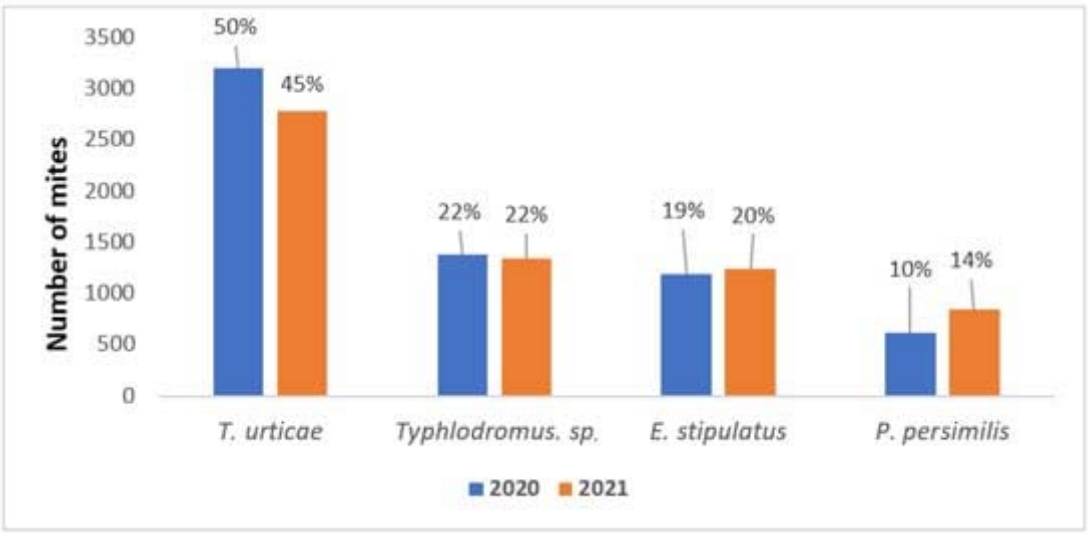


Figure 21 ; Abundance of the phytophagous mite *Tetranychus urticae* and their predators (*Euseius stipulatus*, *Typhlodromus* sp., and *Pytoseiulus persimilis*) during the whole monitoring period on the Valencia late variety.

The rate of leaf occupancy by these species on the variety Nules (**Figure 22**) was 52% (n = 2475) for the pest *T. urticae*. *E. stipulatus* was the most abundant predator on the trees of this variety with a proportion of 28% (n = 1344), followed by *Typhlodromus* sp. with 20% (n = 944), whereas the predator *P. persimilis* was absent

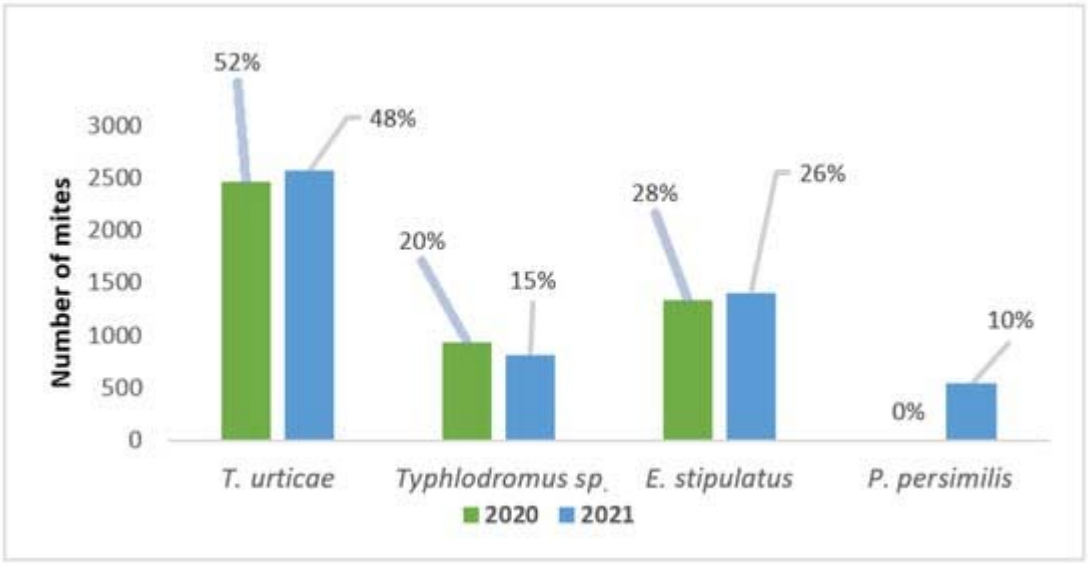


Figure 22. Abundance of the phytophagous mite *Tetranychus urticae* and their predators (*Euseius stipulatus*, *Typhlodromus* sp. and *Pytoseiulus persimilis*) during the whole monitoring period on the Nules variety.

During the second year of monitoring, in the plot planted with the Valencia late variety, we registered 2779 mobile specimens of *T. urticae* (45%). For the predator *Typhlodromus* sp., we recorded 1344 mobile specimens (22%). *E. stipulatus* was recorded with 1240 mobile specimens (20%). *P. persimilis* presented the lowest percentage, with 14% (n = 847).

On the Nules variety, we had 2573 mobile specimens of *T. urticae* (48%), 810 for *Tyhphlodromus* sp. (15%), and 1412 for *E. stipulatus* (26%), and *P. persimilis* had 547 mobile specimens (10%).

2.2 Varietal Impact on Mite Populations

Regarding the effect of the variety on the different mites studied (**Figure 23**), following the first year of monitoring, the Nules (V2) and Valencia late variety (V1) showed a significant impact on the evolution of *T. urticae* pests (**Table 16**), with an average of $40.00^{A} \pm 4.59$ on Valencia late and $30.94^{B} \pm 3.17$ on Nules. On the predator *Typhlodromus* sp., the varietal impact was important; on Valencia late, the average was $17.31^{A} \pm 1.86$, while on Nules, it was $11.80^{B} \pm 1.33$. On the other hand, the two varieties did not show any influence on *E. stipulatus*, with an average of $14.82^{A} \pm 1.51$ on Valencia late and $16.80^{A} \pm 1.41$ on Nules. *P. persimilis* was absent on Nules and low on Valencia late, with an average of $7.76^{A} \pm 1.40$.

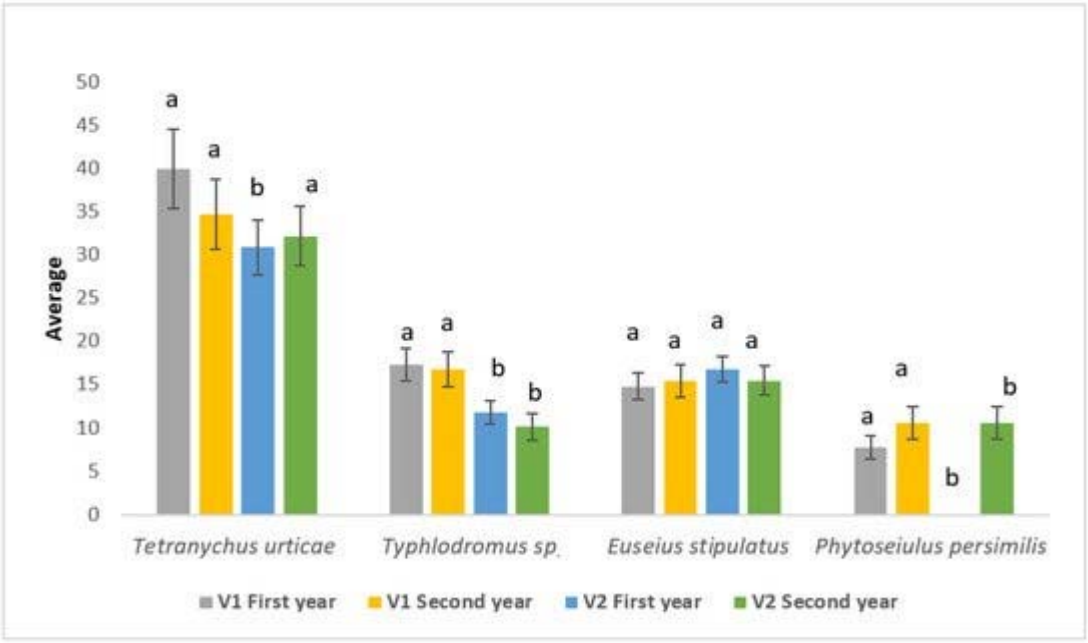


Figure 23. Comparison between the means of different mites, depending on the variety (V1: Valencia late variety; V2: Nules variety) in first year, 2020, and the second year, 2021. Values that do not share the same letter are significantly different ($p < 0.05$).

Table 16. Varietal impact on different mite populations in the first (2020) and second year (2021).

Year	Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
	Varietal impact on *T. urticae*	1	4141	4141.2	4.51	0.035 *
	Varietal impact on *E. stipulatus*	1	156.0	156.0	0.80	0.373
2020	Varietal impact on *Typhlodromus* sp.	1	1216	1215.51	18.15	0.000 *
	Varietal impact on *P. persimilis*	1	2410	2410.26	135.12	0.000 *
	Varietal impact on *T. urticae*	1	265	265.2	0.38	0.540
	Varietal impact on *E. stipulatus*	1	184.9	184.9	0.88	0.350
2021	Varietal impact on *Typhlodromus* sp.	1	1782	1782.23	46.75	0.000 *
	Varietal impact on *P. persimilis*	1	562.5	562.50	22.42	0.000 *

* Statistically significant *p*-values ($p < 0.05$).

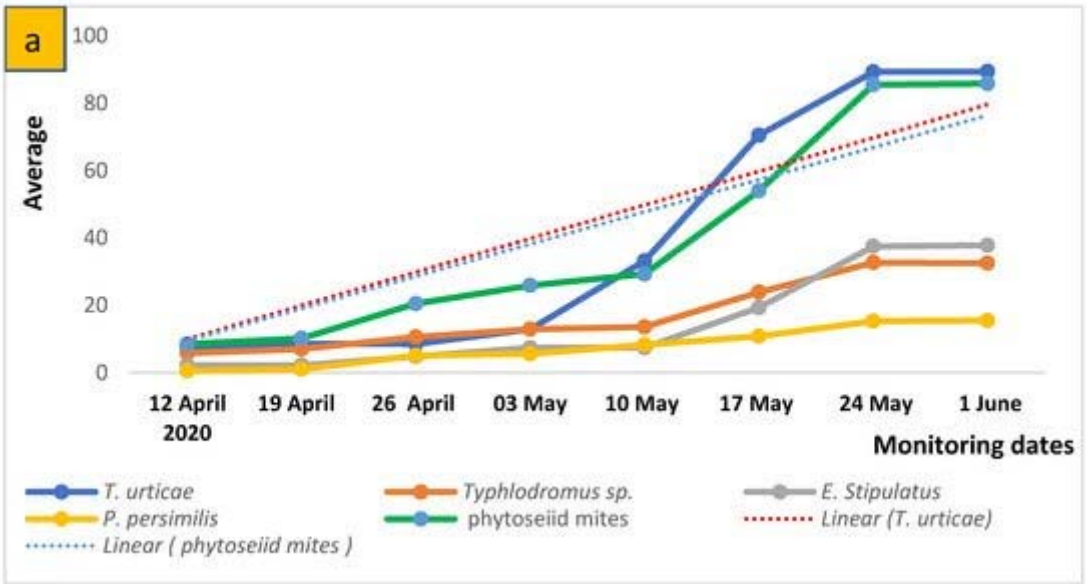
In the second year of follow-up (**Figure 23**), the two varieties did not have an influence on the evolution of *T. urticae* and *E. stipulatus,* with $34.74^{A} \pm 3.35$ on Valencia late and $32.16^{A} \pm 3.42$ on Nules for *T. urticae*. There were $17.65^{A} \pm 2.34$ on Valencia late and $15.50^{A} \pm 1.78$ on Nules for *E. stipulatus*.

On the contrary, for *Typhlodromus* sp. and *P. persimilis*, the varietal impact was significant (**Table 16**), with an average of $16.80^{A} \pm 2.21$ on Valencia late and $10.12^{B} \pm 1.94$ on

the Nules variety for the first one and $10.59^{A} \pm 2.51$ on Valencia late and $06.84^{B} \pm 1.56$ on the Nules variety for the second one.

2.3 Evolution of Mites on the Two Varieties according to the Follow-Up Dates

On the Valencia late variety, during the first year of follow-up (2020), we noticed that the average of *T. urticae* was low between the first week (12 April) and the fourth week (3 May) (**Figure 24**). These averages were between $7.60^{E} \pm 1.90$ and $12.90^{D} \pm 1.18$ when the temperature was between 23 °C and 27 °C (**Table 17**). From the 5th week (10 May) when the temperature was higher than 30 °C, the average of *T. urticae* had an important increase, increasing from $33.20^{C} \pm 4.18$ (10 May) to $89.40^{A} \pm 6.05$ (1 June; week 8). Similarly, the predator *E. stipulatus* showed a significant increase from the first week to the last week of monitoring; this average increased from $2.20^{D} \pm 1.23$ (12 April) to $37.81^{A} \pm 5.20$ (1 June). Equally, the predator *Typhlodrumus* sp. gradually increased from $5.8^{E} \pm 1.93$ (12 April; 25 °C) to $32.50^{A} \pm 3.97$ (1 June; 37 °C). *P. persimilis* increased from the first week ($0.50^{D} \pm 0.1$) to the last week ($15.50^{A} \pm 3.50$).



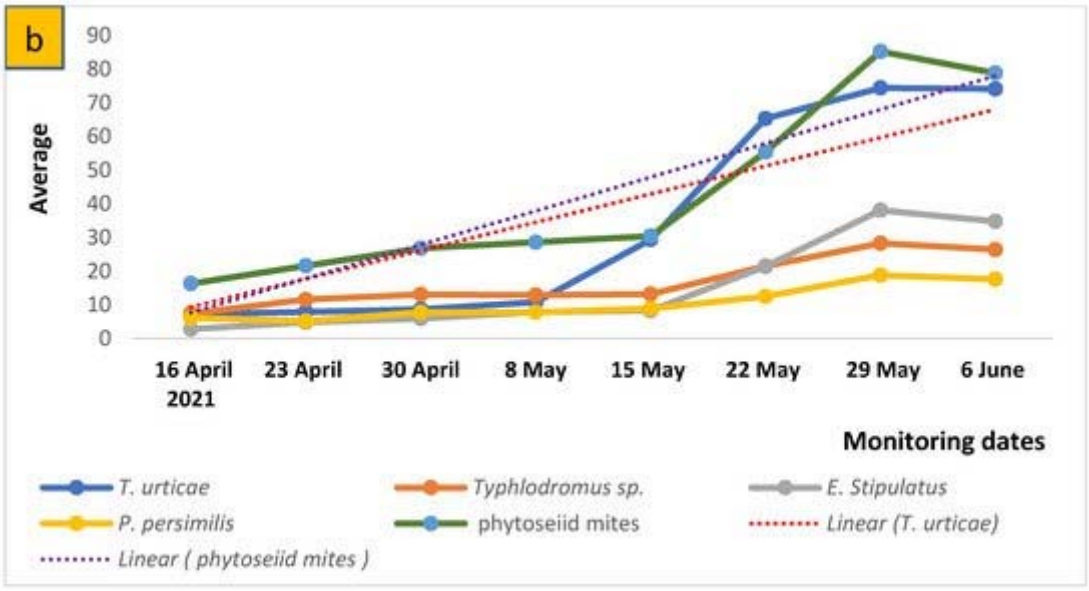


Figure 24. Evolution of *T. urticae* and their predators on Valencia late (V1) (a) in the first year, 2020, and (b) second year, 2021, according to the different follow-up dates (Phytoseiid mites: *E Stipulatus* + *P. persimilis* + *Typhlodromus* sp.).

Table 17. Temperatures recorded during the monitoring period.

Follow-Up Date, 1st Year	12April (Week 1)	19 April (Week 2)	26 April (Week 3)	3 May (Week 4)	10 May (Week 5)	17May (Week 6)	24May (Week 7)	1June (Week 8)
Temperature, 1st year	25 °C	27 °C	23 °C	27 °C	30 °C	32 °C	34 °C	37 °C
Follow-Up date, 2nd year	16April (Week 1)	23April (Week 2)	30April (Week 3)	08May (Week 4)	15May (Week 5)	22 May (Week 6)	29May (Week 7)	6June (Week 8)
Temperature, 2nd year	23 °C	25 °C	25 °C	27 °C	33 °C	33 °C	37 °C	35 °C

During the second year of monitoring, 2021 (**Figure 24**), in the plot planted with Valencia late variety, the average of *T. urticae* remained low during the first 4 weeks with similar statistical means, with $7.30^{D} \pm 1.93$ in week 1 (16 April) and $10.80^{D} \pm 2.45$ in week 4 (8 May). Hereafter, the average of *T. urticae* increased significantly to reach $74.10^{A} \pm 6.41$ on the last date of sampling (6 June). The same results were observed for the three phytoseiid mites, with stability in the number from week 1 to week 4, with $7.40^{D} \pm 2.01$ for *Typhlodromus* sp., $2.80^{D} \pm 1.01$ for *E. stipulatus*, and $5.20^{C} \pm 1.52$ for *P. persimilis*. Then, a significant increase of the averages during the last 4 weeks was observed to reach $26.40^{A} \pm 4.10$ for *Typhlodromus* sp., $34.80^{A} \pm 4.13$ for *E. stipulatus,* and $17.60^{A} \pm 2.34$ for *P. persimilis* in week 8.

On the Nules variety, during the first year of follow-up (2020), **Figure 25** shows that *T. urticae*, *E. stipulatus*, and *Typhlodromus* sp. had a significant increase from week 1 (12 April) to week 8 (June 1), while *P. persimilis* was absent. The averages of *T. urticae, E. stipulatus*, and *Typhlodromus* sp. increased from $3.20^{E} \pm 1.03$, $3.30^{E} \pm 1.25$, and $2.80^{C} \pm 1.47$ (12 April; 25 °C) to $58.40^{A} \pm 3.86$, $35.70^{A} \pm 5.97$, and $16.00^{A} \pm 2.76$ (1 June; 37 °C), respectively.

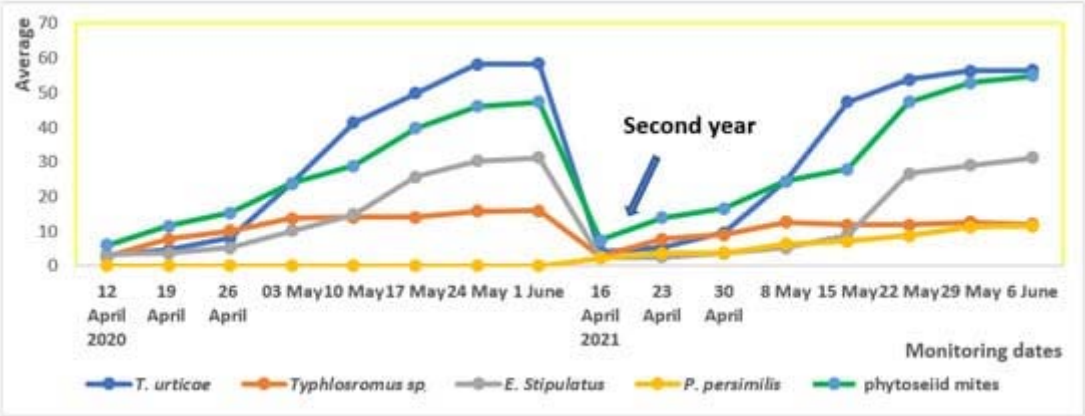


Figure 25. Evolution of *T. urticae* and its predators on Nules (V2) in first year, 2020, and second year, 2021, according to the different follow-up dates (Phytoseiid mites: *E. stipulatus* + *Typhlodromus* sp. + *P. persimilis*).

During the second year (2021), *T. urticae* had a significant increase from the third week where it was $9.60^{D} \pm 1.73$ (30 April) to reach $56.40^{A} \pm 6.43$ in the last week (6 June). *Typhlodromus* sp. did not have a significant increase, as we experienced, during the first year; the average remained almost stable from the third week, with $9.20^{A} \pm 2.36$, to the last week, with $12.70^{A} \pm 2.88$. Conversely, *P. persimilis* appeared on this variety since the first week (16 April), with an average of $2.20^{E} \pm 0.76$, to reach $11.60^{A} \pm 2.14$ in the last week (6 June). On both varieties, the density of phtoseiid mites was higher than that of *T. urticae* during the first four weeks of monitoring, whereas the density of *T. urticae* exceeded that of the phtoseiid mites during the last four weeks.

3 Discussion

According to our nationwide investigation, this is the first research that has focused on the study of the varietal impact on the evolution of spider mites and beneficial phytoseiid populations. These results are the first data provided to compare the evolution of mites on different citrus varieties in Africa, which is of great importance for further comparative research in order to know the infestation rates and the spread rate of pests according to the variety category.

During the two years of follow-up, without the use of any chemical intervention, we noticed that the evolution of *T. urticae* exceeded that of their predators (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*). Much research conducted in the open field and in greenhouses confirms that pests are a problem of diverse global crops [**39**,**40**]. It is a generalist species that can feed on hundreds of host plants and produces a significant destruction to field, greenhouse, and horticultural crops. It can produce silk threads to protect itself from predators or to disperse from plant to plant [**41**,**42**]. On the Valencia late variety, during the two years of monitoring, the abundance of the three predators (*E. stipulatus*, *Typhlodromus* sp., and *P. persimilis*) exceeded 50%. Likewise, on the Nules variety, the rate of these predators was approximately 50%, which presented the same rate of *T. urticae*; from our results it can be concluded that the synergic control by these predators can reduce the rate of *T. urticae*. A study conducted in Italy showed that the simultaneous release of beneficial phytoseiid mites, *Amblyseius aberrans* and *Typhlodromus pyri,* in a vineyard infested by *Panonychus ulmi* provided significant control [**43**]. In Morocco, the new introduction in citrus orchards of the predators *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) and *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) against the oriental mite *Eutetranychus orientalis* and *T. urticae* ensures good results [**5**]. Similarly, in Spain, the control of *T. urticae* through releases of the predatory mites *P. persimilis*, *N. californicus*, *A. swirskii* Athias-Henriot, 1962, and *Orius laevigatus* Fieber, 1860, (Hemiptera: Anthocoridae) showed significant results. Besides, the combined release of *O. laevigatus* with *A. swirskii* gave efficient control of the principal pests of bell pepper [**44**].

During the second year, the emergence of *P. persimilis* on the Nules variety caused a decrease in the number of *Typhlodromus* sp. throughout the monitoring period (8 weeks). In the similar results found by [**45**] in Spain, the release of *P. persimilis* alone was better than combined releases. A study was conducted in Florida to develop a sustainable control method ("Predator-In-First" (PIF)) against pepper pests. The use of the phytoseiid mite *Amblyseius swirskii* in the regulation of several pepper pests (*Bemisia tabaci* Gennadius, 1889, *Frankliniella occidentalis* Pergande, 1895, and *Polyphagotarsonemus latus* Banks) under greenhouse and field conditions was very effective. Results suggest that the application of *A. swirskii* alone can help regulate several pepper pests and ensure improved crop yield [**46**]. However, a simultaneous release of multiple predators may cause competition between the species [**47**].

In the first year of monitoring, our results show that the two varieties of Nules and valencia late have a significant impact on the evolution of *T. urticae* and the two predators (*Typhlodromus* sp. and *P. persimilis).* The same results were obtained by [**48**,**49**], who showed that the variety could induce an impact on the evolution of the pests and predators. Another study was performed in the open field on five cotton varieties to compare the infestation degree by the pests *Aphis gossypii* Glover, 1877, (Hemiptera: Aphididae) and *Amrasca devastans* Dist. (Hemiptera: Cicadellidae). The results showed that the type of variety could influence the infestation level [**50**].

Our results show that the rate of *T. urticae* increased significantly from the first week (12 April) to the last week of monitoring (1 June); this was due to the fluctuation in temperature from 25 °C to 37 °C recorded during the follow-up. Identical results were obtained on clementine in the Gharb region (Morocco), where the orchards were isolated for 3 cropping annuals and without the practice of acaricide treatments in order to investigate the severity of infestation by *T. urticae* [**51**]; this study showed that the infestation degree of the trees was 10% in mid-April and increased rapidly to 87% in July. A study realized by [**52**] confirmed that temperature is the most important environmental factor affecting insect population dynamics.

Conclusions

Our results highlight two key pieces of information: (1) The data register that variety can induce an impact on the evolution of pests and predators. (2) The density of the mites can change according to the monitoring dates. In addition, the establishment of an integrated long-term ecological monitoring program and the incorporation of new technologies into surveillance programs is an urgent need to control pests. These programs must take into consideration climatic conditions, plant and pest phenology, infestation rates, and the rate of spread of the pests in each country. All these elements are proposed to control the pests, respect the environment, and promote the expansion of predators.

Author Contributions

Methodology, data curation, software, A.A.; writing—supervision, editing, A.L. and A.F.; supervision, editing, R.U. and Y.B.K.; funding, resource, editing R.A.; supervision, editing, validation, Revision, A.N.; Editing, Writing, A.A.S. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by Researchers Supporting Project number (RSP-2021/96), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All related data are within the manuscript.

Acknowledgments

The authors would like to extend their sincere appreciation to the Researchers Supporting Project number (RSP-2021/96), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Assouguem, A.; Kara, M.; Mechchate, H.; Alzain, M.N.; Noman, O.M.; Imtara, H.; Hano, C.; Ibrahim, M.N.; Benmessaoud, S.; Farah, A.; et al. Evaluation of the Effect of Different Concentrations of Spirotetramat on the Diaspine Scale *Parlatoria ziziphi* in Citrus Orchards. *Agronomy* **2021**, *11*, 1562. [**Google Scholar**] [**CrossRef**]
2. Afechtal, M.; Djelouah, K.; Cocuzza, G.; D'Onghia, A.M. Large Scale Survey of *Citrus Tristeza Virus* (CTV) and Its Aphid Vectors in Morocco. *Acta Hortic.* **2015**, *1065*, 753–757. [**Google Scholar**] [**CrossRef**]
3. ASPAM Campagne Agrumicole 2020–2021: Les Professionnels Tablent Sur Des Exportations de 630,000 Tonnes—La Vie éco. 2021. Available online: **https://www.lavieeco.com/** (accessed on 30 January 2022).
4. Montaigne, E.; Hadad-Gauthier, F.E.; Khefifi, L. Challenges in Citrus Market Chains in Tunisia and Morocco. In *Sustainable Agricultural Development*; Springer: Cham, Switzerland, 2015; pp. 227–253. [**Google Scholar**]
5. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial insect community of Moroccan citrus groves: Assessment of their potential to enhance biocontrol services. *Egypt. J. Biol. Pest Control* **2020**, *30*, 1–15. [**Google Scholar**] [**CrossRef**]
6. Oubelkacem, A.; Scardigno, A.; Choukr-Allah, R. Treated Wastewater Reuse on Citrus in Morocco: Assessing the Economic Feasibility of Irrigation and Nutrient Management Strategies. *Integr. Environ. Assess. Manag.* **2020**, *16*, 898–909. [**Google Scholar**] [**CrossRef**]
7. Vono, G.; Bonsignore, C.P.; Marullo, R. A Comprehensive Thrips Species Assessment for Eco-Consistent Management of Infestations in Mediterranean Citrus Crops. *Horticulturae* **2022**, *8*, 137. [**Google Scholar**] [**CrossRef**]
8. Mohammed, K.; Karaca, İ.; Agarwal, M.; Newman, J.; Ren, Y. Age-specific life tables of *Aonidiella aurantii* (Maskell) (hemiptera: Diaspididae) and its parasitoid *Aphytis melinus* debach (hymenoptera: Aphelinidae). *Turkish J. Agric. For.* **2020**, *44*, 180–188. [**Google Scholar**] [**CrossRef**]
9. Assouguem, A.; Kara, M.; Benmessaoud, S.; Mechchate, H.; Jabboury, Z.E.; Farah, A.; Lazraq, A. Tropical Journal of Natural Product Research *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) in Moroccan Citrus orchards. *Chem. Sustain. Control. Methods Priorities Future Res.* **2021**, *5*, 1703–1708. [**Google Scholar**]
10. Helle, W.; Sabelis, M.W. *Spider Mites Their Biology, Natural Enemies and Control Volume 1A*; Elsevier: Amsterdam, The Netherlands, 1985; pp. 75–90. [**Google Scholar**]
11. Lagziri, M.; Benicha, M.; M'rabet, R.; Amrani, A. El Influence de l'usage préventif des pesticides sur les acariens *Tetranychus urticae* et *Phytoseiulus persimilis* (Acari: Tetranychidae, Phytoseiidae) présents en cultures de fraisiers du Nord du Maroc. *Biotechnol. Agron. Soc. Environ.* **2015**, *19*, 355–363. [**Google Scholar**]
12. Xue, W.; Snoeck, S.; Njiru, C.; Inak, E.; Dermauw, W.; Van Leeuwen, T. Geographical distribution and molecular insights into abamectin and milbemectin cross-resistance in European field populations of *Tetranychus urticae*. *Pest Manag. Sci.* **2020**, *76*, 2569–2581. [**Google Scholar**] [**CrossRef**]

13. Vacante, V. The Handbook of Mites of Economic Plants: Identification, Bio-Ecology. Available online: **https://books.google.co.ma/books?hl=fr&lr=&id=yc4_CwAAQBAJ&oi=fnd&pg=PR3&dq=Vacante+V.+2016+—+The+handbook+of+mites+of+economic+plants+—+Wallingford:+CABI+Publishing.+p&ots=owucks8JhR&sig=1Q-_htz0V9EuSINyaxQ7C7D9RPs&redir_esc=y#v=onepage&q&f=false** (accessed on 17 October 2021).
14. Seham, A.; Ezz El-Dein, H.A.A.; Amira, A.; Mesbah, E.; Doaa, A.A.E.-A. Provided for non-commercial research and education use. Not for reproduction, distribution or commercial use. *Hepatoprotective Agents Rats* **2020**, *12*, 25–40. [**Google Scholar**]
15. Mariethoz, J.; Baillod, M.; Linder, C.; Antonin, P.; Mittaz, C. Distribution, Méthodes de Contröle et Stratégies de Lutte Chimique et Biologique Contre l'acarien Jaune, "Tetranychus urticae" Koch, Dans les Cultures de Framboisiers—Dialnet. Available online: **https://dialnet.unirioja.es/servlet/articulo?codigo=2984817** (accessed on 16 April 2021).
16. Gulati, R. Incidence of Tetranychus cinnabarinus (Boisd.) Infestation in Different Varieties of *Abelmoschus esculentus* L. Available online: **https://agris.fao.org/agris-search/search.do?recordID=IN2004000229** (accessed on 16 April 2021).
17. Reddy, G.V.P.; Baskaran, P. Damage potential of the spider mite *Tetranychus ludeni* (Acari: Tetranychidae) on four varieties of eggplant. *Int. J. Trop. Insect Sci.* **2006**, *26*, 48–56. [**Google Scholar**] [**CrossRef**]
18. Acari, K.; Tomato, T. Growth Stage Based Economic Injury Levels for Two Spotted Spider *Lycopersicon esculentum* Mill. *Trop. Agric. Res.* **2010**, *22*, 54–65. [**Google Scholar**]
19. Haque, M.; Islam, T.; Naher, N.; Mainul Haque, M. Seasonal abundance of spider mite *Tetranychus urticae* Koch on vegetable and ornamental plants in Rajshahi. *Univ. J. Zool. Rajshahi Univ.* **2011**, *30*, 37–40. [**Google Scholar**] [**CrossRef**][**Green Version**]
20. Silva, E.A.; Reis, P.R.; Carvalho, T.M.B.; Altoé, B.F. *Tetranychus urticae* (Acari: Tetranychidae) on *Gerbera jamesonii* Bolus and Hook (Asteraceae). *Brazilian J. Biol.* **2009**, *69*, 1121–1125. [**Google Scholar**] [**CrossRef**][**Green Version**]
21. Luo, Z. Analysis of the effect of reasonable close planting on respiration characteristics of alfalfa (*Medicago sativa* L.) artificial grassland. *Turkish J. Agric. For.* **2021**, *45*, 533–540. [**Google Scholar**] [**CrossRef**]
22. Logan, J.G.; Birkett, M.A. Juvenile hormonal activity of mono- and polyenehomobenzenes in *Drosophila virilis*, *Spodoptera frugiperda* and *Araschnia levana*. *Pest Manag. Sci.* **2007**, *63*, 809–814. [**Google Scholar**] [**CrossRef**]
23. Mudyiwa, S.; Gadzirayi, C.; Mupangwa, J.; Gotosa, J.; Nyamugure, T. Constraints And Opportunities For Cultivation Of *Moringa oleifera* In The Zimbabwean Smallholder Growers. *Int. J. Agric. Res. Innov. Technol.* **2013**, *3*, 12–19. [**Google Scholar**] [**CrossRef**]
24. Abdallah, A.M.; Ismail, M.S.M.; AboGhalia, A.H.; Soliman, M.F.M. Factors affecting population dynamics of *Tetranychus urticae* and its predators on three economic plants in Ismailia, Egypt. *Int. J. Trop. Insect Sci.* **2019**, *39*, 115–124. [**Google Scholar**] [**CrossRef**]
25. Abo-Elmaged, T.M.; Ali, A.W.M.; Abdel-Rahman, M.A.A.; Abd-Allah, A.H.A. Activity of the two spotted spider mite, *Tetranychus urticae* (Koch) (Acari) infesting cucumber plants in upper Egypt. *Int. J. Trop. Insect Sci.* **2021**, *41*, 463–469. [**Google Scholar**] [**CrossRef**]
26. Ferragut, F.; Laborda, R.; Costa-Comelles, J.; García-Marí, F. Feeding behavior of *Euseius stipulatus* and *Typhlodromus phialatus* on the citrus red mite *Panonychus citri* [Acari: Phytoseiidae, Tetranychidae]. *Entomophaga* **1992**, *37*, 537–544. [**Google Scholar**] [**CrossRef**]
27. Smaili, M.C.; Abbassi, M.; Boutaleb, J.A.; Blenzar, A. Richesse spécifique des ennemis naturels associés aux vergers d'agrumes au Maroc: Intérêt et implication pour la lutte biologique. *EPPO Bull.* **2013**, *43*, 155–166. [**Google Scholar**] [**CrossRef**]
28. Attia, S.; Grissa, K.L.; Lognay, G.; Bitume, E.; Hance, T.; Mailleux, A.C. A review of the major biological approaches to control the worldwide pest *Tetranychus urticae* (Acari: Tetranychidae) with special reference to natural pesticides: Biological approaches to control *Tetranychus urticae*. *J. Pest Sci.* **2013**, *86*, 361–386. [**Google Scholar**] [**CrossRef**]
29. Kazak, C.; Karut, K.; Doker, I. Indigenous populations of *Neoseiulus californicus* and *Phytoseiulus persimilis* (Acari: Phytoseiidae): Single and combined releases against *Tetranychus urticae* (Acari: Tetranychidae) on greenhouse eggplant. *Int. J. Acarol.* **2015**, *41*, 108–114. [**Google Scholar**] [**CrossRef**]
30. Croft, B.A.; Van De Baan, H.E. Ecological and genetic factors influencing evolution of pesticide resistance in tetranychid and phytoseiid mites. *Exp. Appl. Acarol.* **1988**, *4*, 277–300. [**Google Scholar**] [**CrossRef**]
31. Auger, P.; Migeon, A.; Ueckermann, E.A.; Tiedt, L.; Navajas, M. Descriptions of some *Typhlodromus* species from tanzania (Mesostigmata: Phytoseiidae). *Acarologia* **2013**, *53*, 383–415. [**Google Scholar**] [**CrossRef**]
32. Hassouni, T.; Belghyti, D. Distribution of gastrointestinal helminths in chicken farms in the Gharb region—Morocco. *Parasitol. Res.* **2006**, *99*, 181–183. [**Google Scholar**] [**CrossRef**] [**PubMed**]

33. Benyahia, H.; Talha, A.; Fadli, A.; Chetto, O.; Omari, F.E.; Beniken, L. Performance of 'Valencia late' sweet orange (*Citrus sinensis*) on different rootstocks in the gharb region (Northwestern Morocco). *Annu. Res. Rev. Biol.* **2017**, *20*, 1–11. [**Google Scholar**] [**CrossRef**]
34. Bouharroud, R. Acariens Clés des Agrumes au Maroc, Agriculture du Maghreb. Available online: **http://www.agri-mag.com/2017/06/acariens-cles-des-agrumes-au-maroc/** (accessed on 18 April 2021).
35. Martínez-Ferrer, M.T.; Jacas, J.A.; Ripollés-Moles, J.L.; Aucejo-Romero, S. Approaches for sampling the two spotted spider mite (Acari: Tetranychidae) on clementines in Spain. *J. Econ. Entomol.* **2006**, *99*, 1490–1499. [**Google Scholar**] [**CrossRef**]
36. Marullo, R.; Bonsignore, C.P.; Vono, G. Thrips: A review of sampling methods in relation to their habitats. *Bull. Insectology* **2021**, *74*, 241–251. [**Google Scholar**]
37. Minitab Statistical Software Data Analysis Software|Statistical Software Package|Minitab. Available online: **https://www.minitab.com/en-us/products/minitab/** (accessed on 25 January 2022).
38. Abad-Moyano, R.; Pina, T.; Dembilio, Ó.; Ferragut, F.; Urbaneja, A. Survey of natural enemies of spider mites (Acari: Tetranychidae) in citrus orchards in eastern Spain. *Exp. Appl. Acarol.* **2009**, *47*, 49–61. [**Google Scholar**] [**CrossRef**]
39. Van Leeuwen, T.; Vontas, J.; Tsagkarakou, A.; Dermauw, W.; Tirry, L. Acaricide resistance mechanisms in the two-spotted spider mite *Tetranychus urticae* and other important Acari: A review. *Insect Biochem. Mol. Biol.* **2010**, *40*, 563–572. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
40. Tehri, K. Tehri 2014 A review on reproductive strategies in two spotted spider mite. *J. Entomol. Zool. Stud.* **2014**, *2*, 35–39. [**Google Scholar**]
41. Sedaratian, A.; Fathipour, Y.; Moharramipour, S. Comparative life table analysis of *Tetranychus urticae* (Acari: Tetranychidae) on 14 soybean genotypes. *Insect Sci.* **2011**, *18*, 541–553. [**Google Scholar**] [**CrossRef**]
42. Golizadeh, A.; Ghavidel, S.; Razmjou, J.; Fathi, S.A.A.; Hassanpour, M. Comparative life table analysis of *Tetranychus urticae* koch (Acari: Tetranychidae) on ten rose cultivars. *Acarologia* **2017**, *57*, 607–616. [**Google Scholar**] [**CrossRef**]
43. Duso, C.; Pasqualetto, C.; Camporese, P. Role of the predatory mites Amblyseius aberrans (Oud.), *Typhlodromus pyri* Scheuten and *Amblyseius andersoni* (Chant) (Acari, Phytoseiidae) in vineyards. *J. Appl. Entomol.* **1991**, *112*, 298–308. [**Google Scholar**] [**CrossRef**]
44. Bouagga, S.; Urbaneja, A.; Pérez-Hedo, M. Combined use of predatory mirids with *Amblyseius swirskii* (acari: Phytoseiidae) to enhance pest management in sweet pepper. *J. Econ. Entomol.* **2018**, *111*, 1112–1120. [**Google Scholar**] [**CrossRef**]
45. Albendín, G.; García, M.D.C.; Molina, J.M. Multiple natural enemies do not improve two spotted spider mite and flower western thrips control in strawberry tunnels. *Chil. J. Agric. Res.* **2015**, *75*, 63–70. [**Google Scholar**] [**CrossRef**][**Green Version**]
46. Kumar, V.; Mehra, L.; Mckenzie, C.L.; Osborne, L.S. "Predator-In-First": A Preemptive Biological Control Strategy for Sustainable Management of Pepper Pests in Florida. *Sustainability* **2020**, *12*, 7816. [**Google Scholar**] [**CrossRef**]
47. Croft, B.A.; Macrae, I.V. Biological control of apple mites—Impact of Zetzellia mali (Acari, Stigmaeidae) on *Typhlodromus pyri* and *Metaseiulus occidentalis* (Acari, Phytoseiidae). *Environ. Entomol.* **1993**, *22*, 865–873. [**Google Scholar**] [**CrossRef**]
48. Amin, M.R.; Ahad, M.A.; Hossain, M.H.; Hossain, S.M.A.; Tithi, D.A. Characteristics of some cotton varieties in relation to seasonal abundance of pests, predators and their impact on yield and quality. *J. Agrofor. Environ.* **2008**, *2*, 67–70. [**Google Scholar**]
49. Amin, M.R.; Miah, M.S.; Rahman, H.; Nancy, N.P.; Bhuiyan, M.K.A. Functional and group abundance of insects on eggplant. *Bangladesh J. Agric. Res.* **2018**, *4*, 647–653. [**Google Scholar**] [**CrossRef**]
50. Amin, M.; Afrin, R.; Suh, S.; Kwon, Y. Infestation of sucking insect pests on five cotton cultivars and their impacts on varietal agronomic traits, biochemical contents, yield and quality. *SAARC J. Agric.* **2016**, *14*, 11–23. [**Google Scholar**] [**CrossRef**][**Green Version**]
51. Hmimina, M.; Allam, L.; Ougass, Y.; Marmouche, A. Circonstances des pullulations de *Tetranychus urticae* Koch (Tetranychidae: Acarina) en verger d'agrumes. *IOBC wprs Bull.* **1995**, *18*, 35. [**Google Scholar**]
52. Skendžić, S.; Zovko, M.; Živković, I.P.; Lešić, V.; Lemić, D. The impact of climate change on agricultural insect pests. *Insects* **2021**, *12*, 440. [**Google Scholar**] [**CrossRef**]

Chapitre V:

Évaluation de l'effet de différentes méthodes de lutte écologiques sur le ravageur *Panonychus citri* [Acari : Tetranychidae] et sur ses prédateurs dans les vergers d'agrumes

Cet article est en phase finale de publication dans la revue d'Open chemistry

Résumé

Pour évaluer l'efficacité de diverses méthodes de contrôle sur le ravageur *Panonychus citri* McGregor 1916 et ses prédateurs ; *Euseius stipulatus* Athias Henriot, 1960, *Phytoseiulus persimilis* Athias henriot, 1957 et *Typhlodromus* sp. Quatre traitements ont été appliqués dans des vergers plantés par *Citrus Clementina* dans la région du Gharb au Maroc (T0= traité par l'eau seulement, T1= spirodiclofen 0.5L/Ha, T2= 5% de savon noir 125L/Ha T3= mélange de deux détergents). Les résultats obtenus pendant la période de suivi ont montré que les traitements au savon noir, au spirodiclofen et aux deux détergents ont permis une diminution de la population de *P. citri* par rapport aux parcelles traitées à l'eau pendant toute la période de suivi. Nous avons trouvé 5044 formes mobiles de *P. citri* dans la parcelle traitée à l'eau uniquement, 1544 formes dans la parcelle traitée au spirodiclofen, 3002 formes dans la parcelle traitée au savon noir, et 1567 formes mobiles dans la parcelle traitée aux deux détergents. Cette étude a démontré que les trois traitements utilisés avaient un impact sur les prédateurs survivants par rapport au témoin (T0), tandis que l'impact du spirodiclofen sur les acariens phytoséiides était plus important que celui du savon noir et des détergents. Par contre, l'augmentation de la température en fonction des semaines de suivi a montré un effet significatif sur l'évolution des acariens étudiés.

Evaluation of eco-friendly control methods on the pest *Panonychus citri* [Acari: Tetranychidae] and its predators in citrus orchards

Amine Assouguem[1,2*], Mohammed Kara[3], Saoussan Annemer[2], Rafa Almeer [4], Amany A. Sayed [5] , Ilaria Peluso[6], Sezai Ercisli7 , Abdellah Farah[2] and Abderrahim Lazraq[1]

1 Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco abderrahim.lazraq@usmba.ac.ma (AL), assougam@gmail.com (AA)
2 Laboratory of Applied Organic Chemistry, Faculty of sciences and technology, Sidi Mohamed Ben Abdellah University, Imouzzer street, Fez B.O. Box 2202, Morocco farah.abdellah@gmail.com (AF), saoussan.annemer@usmba.ac.ma (SA)
3 Laboratory of Biotechnology, Conservation and Valorisation of Naturals Resources (LBCVNR), Faculty of Sciences Dhar El Mehraz, Sidi Mohamed Ben Abdellah University, B.P. 1796 Atlas, Fez 30000, Morocco;
4 Department of Zoology, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia; ralmeer@ksu.edu.sa (R.A)
5 Zoology Department, Faculty of Science, Cairo University, Giza 12613, Egypt; amanyasayed@sci.cu.edu.eg (A.A.S)
6 Research Centre for Food and Nutrition, Council for Agricultural Research and Economics (CREA-AN),Rome, Italy i.peluso@tiscali.it
7 Department of Horticulture, Faculty of Agriculture, Ataturk University, 25240 Erzurum, Turkey. sercisli@gmail.com (S.E.)
* Correspondence: assougam@gmail.com (A.A)

Abstract*:*

To assess the effectiveness of diverse control methods on the pest *Panonychus citri* McGregor 1916 and its predators; *Euseius stipulatus* Athias Henriot, 1960, *Phytoseiulus persimilis* Athias henriot, 1957 and *Typhlodromus* sp.. Four treatments were applied in orchards planted by *Citrus Clementina* in the Gharb area of Morocco (T0= treated by water only, T1= spirodiclofen 0.5L/Ha, T2= 5% black soap 125L/Ha T3= mixture of two detergents). Results obtained during the follow-up period showed that the black soap, spirodiclofen and two detergents treatments provided a decrease in the *P. citri* population in comparison with plot treated by water during the whole monitoring period. We found 5044 mobile forms of *P. citri* in the plot treated by water only, 1544 forms in the plot treated with spirodiclofen, 3002 forms in the plot treated with black soap, and 1567 mobile forms in the plot treated with two detergents. This study demonstrated that all three treatments used had an impact on the survived predators compared to the control (T0), while the impact of spirodiclofen on beneficial phytoseiid mites was greater than that of black soap and detergents. Although, the increase in temperature according to the follow-up weeks showed a significant effect on the evolution of the studied mites.

Keywords: detergents, citrus, black soap, phytoseiid mites, and eco-friendly.

Introduction

Through the combined efforts of the professional agricultural community and the Green Morocco Plan, the citrus industry has experienced a significant expansion in recent years [1]. These efforts have focused on encouraging the equipment of farms, the renewal of old plantations and the extension of areas [2,3], the use of certified seedlings [4], the modernization of the tool for the development of production [5], the rationalization of the use of irrigation water and the promotion of exports [6].

Depending on the results of the general inventory of citrus guided by the Ministry of Agriculture in 2020 [4], Morocco produced about 2.62 million tons of citrus of which 715,000 tons were reserved for export [1,7], representing a value of over 4 billion dirhams, according to the Ministry of Agriculture. The sector creates nearly 16 million working days annually [8]. It generates an added value of 4,792 MDH and an employment productivity of nearly 318 DH per day [6].

The acaricide spirodiclofen (ENVIDOR 240 SC, BAYER SA) belongs to the ketoenol family. It acts by direct contact and by ingestion as an inhibitor of lipid biosynthesis. It has a powerful ovicidal action, controls all larval stages and pupal development and considerably reduces the fertility of females [9].

Black soap is a black substance, easily biodegradable and an excellent insecticide [10]. This product is effective on various pests such as thrips, whiteflies, aphids, mealy bugs, mites, etc., by simple contact, it asphyxiates them by blocking their respiratory system [11]. Moreover, it does not produce toxic residues and it doesn't affect the predators. This treatment is allowed by the organic agriculture specifications; EEC regulation 2092/91. [12,13].

The two detergents Oni (sodium C12-13 parenth sulfate, and sodium C14-17 alkyl sec sulfonate) and Tide (sodium C10-16 alkylbenzene sulfonate, propylene glycol and sodium borate), are not classed as hazardous according to the European Directive 99/45/EC [14].

In Morocco, especially in the Gharb region, *Panonychus citri* McGregor 1916 (Acari: Tetranychidae) was considered as a primary pest with significant damage on infected trees [15,16]. Of all the mite species, the citrus red mite is identified as a major pest [6]. Its control is achieved by natural predatory mites such as *Phtoseiulus persimilis*, *Euseius stipulatus* and *Typhlodromus* sp. [17,18]. Unfortunately, chemical products such as spirodiclofen used against

various citrus pests are considered toxic to phytoseiids and reduce their effectiveness [19–21]. Therefore, it is in this context that this work aims to detect the impact of black soap and detergents in comparison with spirodiclofen against *P. citri* on the one hand, and on the activity of predatory mites, namely, *Phytoseiulus persimilis, Typhlodromus* sp. and *Euseius stipulatus* on the other hand.

1 Materials and Methods

1.1 Study area

This study was performed in Mechraa BelKsiri, northeast of the province of Sidi Kacem, situated in the Gharb area of northern Morocco (Fig26.). The study site was located at a low altitude of 300-500 m above sea level. The Gharb region is the highest agricultural area in Morocco (600 Km2) [22]. This zone is known for the production of citrus, cereals, and vegetable crops due to the suitable characteristics of the climate and soil [23]. It is characterized by a Mediterranean climate with annual rainfall ranging from 470 to 620mm/year, and temperature average of 28°C in summer and 13°C in winter. [24].

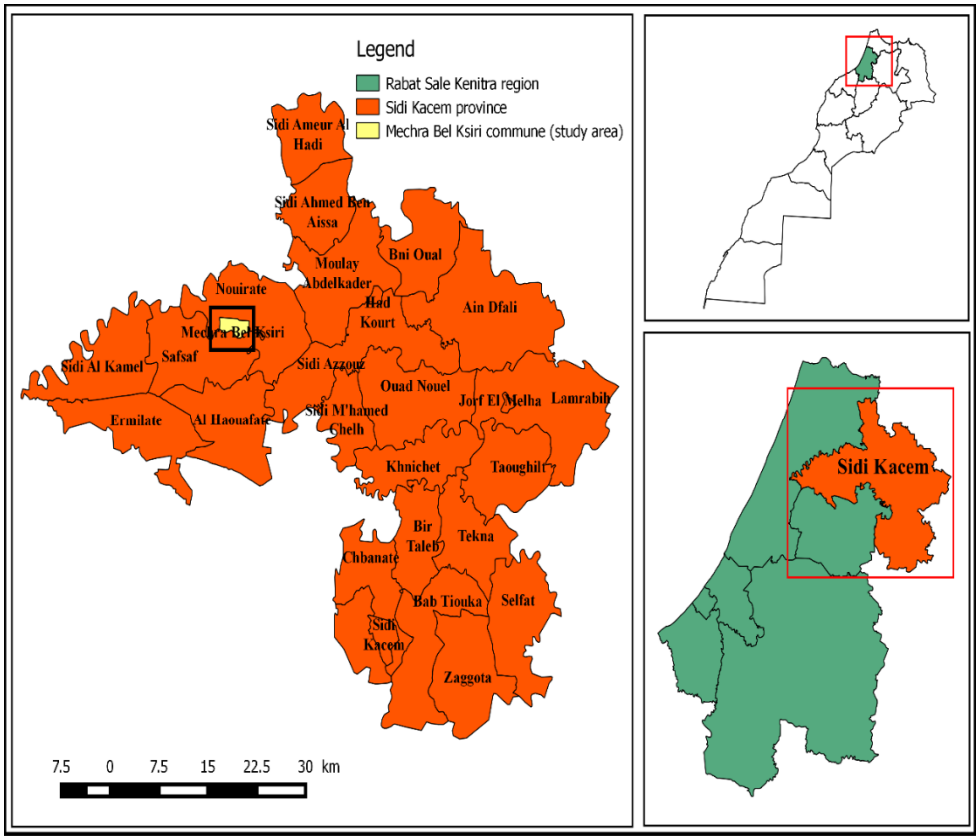


Figure 26. Geographical localisation of the studied orchard (Source: Administrative Division of Morocco, 2015).

1.2 Sampling Design

To assess the impact of black soap, spirodiclofen and a mixture of detergents on *Panonychus citri* populations and their predators (*Phytoseiulus, persimilis Typhlodromus* sp. and *Euseius stipulatus*). An orchard of Nules (*Citrus Clementina*) was selected. Spirodiclofen product was used because of its efficiency against a large range of biting-sucking pests, including spider mites. The orchard covers 4 hectares of *Citrus Clementina* trees. The orchard was divided into 4 plots of 1 Hectare (Fig27.), and each plot was sprayed with a typical concentration of the selected product. T0= control experiment. T1 = spirodiclofen 0.5 L/Ha which is the proposed dose to control citrus spider mites. T2 = 125 L/Ha black soap (5%). and T3 = two detergents mixture 4 L/Ha of Oni product and 2 L/Ha of Tide product. These two detergents are frequently used by local farmers to control spider mites, and reduce the application of accaricides. 2500 litres of spray solution was pulverized by a trailed sprayer on each one-hectare plot, with six litres of spray for each tree. To estimate the effect of each product used, Ten trees belonging to a square block were chosen and followed each week. On each tree, 10 leaves collected from different directions (North, South, East and West) and at different heights of the tree (1.5 to 3m) were examined during 8 weeks. Ten repetitions were carried out independently. We left two untreated lines around 12 meters between treated plots to avoid overlapping treatments. The collected leaves were transferred immediately into referenced polyethylene bags in the laboratory for observation. The different mobile forms of the studied mites on each leaf were determined and counted on both leaf surfaces under a binocular microscope. Inspections were performed three days after treatment applications: April 12 (w1), April 19 (w2), April 26 (w3), May 3 (w4), May 10 (w5), May 17 (w6), May 24 (w7) and June 1 (w8). Temperature data were collected in the field, using Davis Instruments Vantage Pro2.

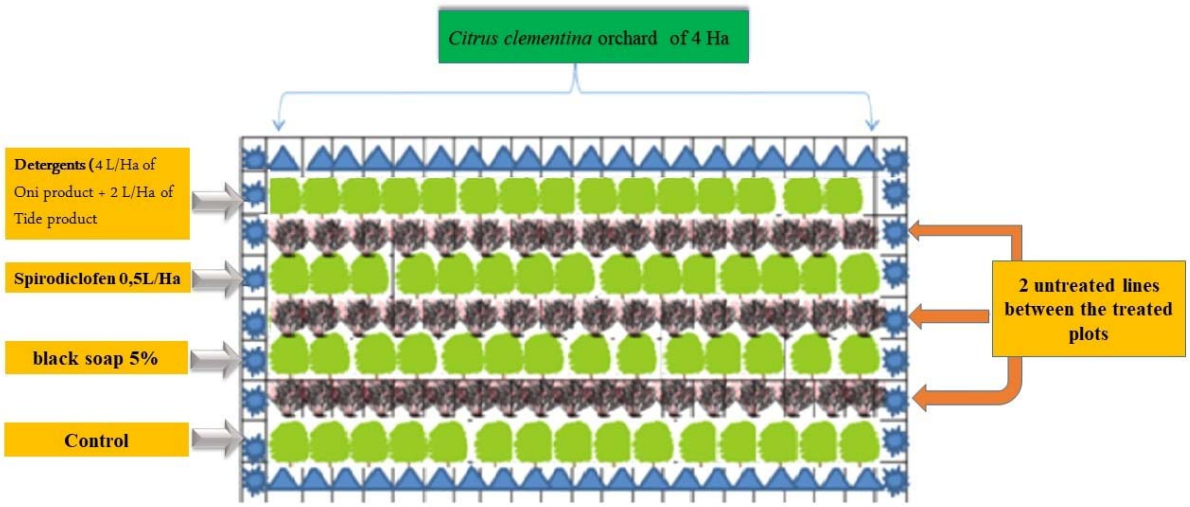


Figure 27. The various types of control treatments employed in Nules orchards.

1.3 Statistics

Data statistics were obtained using Minitab software, version 1.1,19, LLC. USA. The results were given as means and percentages ±SD. The impact of different treatments, monitoring dates, and their interactions was compared using the univariate general linear model (GLM), followed by a Tukey post hoc test at $p<0.05$ [23]. We tested normality and homogeneity of variance for all variables with the Kolmogorov-Smirnov test. Principal component analyses (PCA) and hierarchical cluster analyses (HCA) were performed using JMP Pro 14 software (SAS company, Cary, Carolina, USA) to elucidate the relationship between the different mites studied and the treatments tested.

2 Results

2.1 Leaf occupancy rate by mites in the different plots

During the follow-up period, the occupancy of the examined leaves by the pest *P. citri* on the untreated plot (T0) was important with n=5044 motile forms, which presents 22% of the mites sampled in the 4 plots, *Typhlodromus* sp. was the most abandoning predator on this plot with 1599 motile forms 7%, followed by *P. persimilis* with a percentage of 6% (n=1328) and finally *E. stipulatus* with 4% n=847.

In the plot treated with spirodiclofen (T1), a significant decline in the number of mites studied was observed, *P. citri* showed a poroportion of 7% with 1544 mobile forms, whereas for the predator *P. persimilis* 731 mobile forms were observed (3%), *E. stipulatus* showed a proportion

of 2% (n=500 mobile forms), and finally 589 mobile forms (3%) were counted for *Typhlodromus* sp..

In the plot managed with black soap (T2), we registered 3002 mobile forms (13%) for the pest *P. citri,* 4% (n=979) for the predator *P. persimilis*, 6% (n=1309) for *Typhlodromus* sp., and only 3% (n=777) for *E. stipulatus*.

In the plot sprayed with detergents (T3), we registered only 7% (n=1567) of pest *P. citri*, for the predators 4% (n=959) of *P. persimilis*, 6% (n=1271) of *Typhlodromus* sp., and finally 3% (n=766) of *E. stipulatus* (Fig28.).

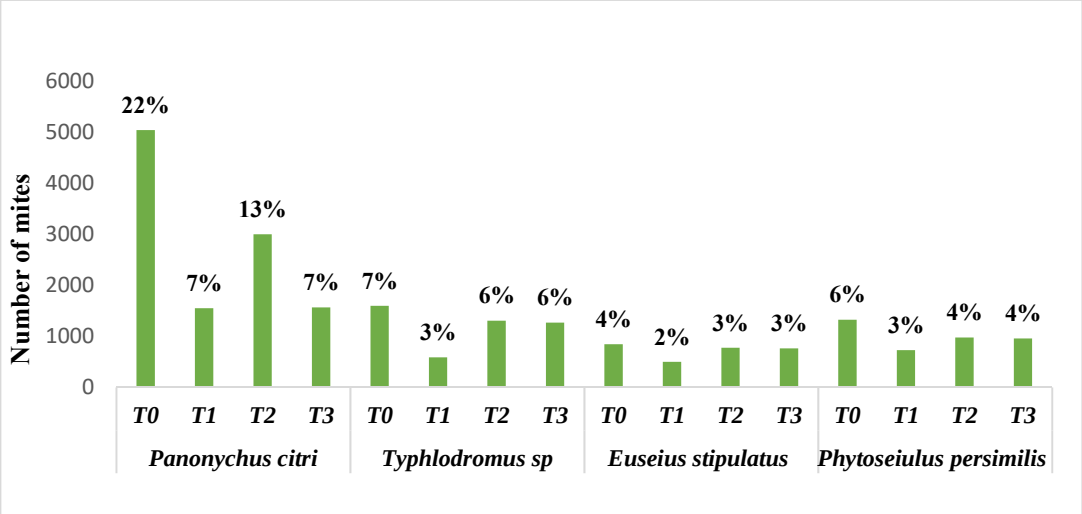


Figure 28. The proportion of different mites studied (*Panonychus citri* phytophagous mite and its predators; *Euseius stipulatus, Phytoseiulus persimilis* and *Typhlodromus* sp.) according to the different products applied T0= Control experiment, T1= Spirodiclofen, T3= black soap; T3= Oni + tide product)

2.2 The influence of treatments on the different mites studied

The results in Table 18 show that the interaction between treatment employed and monitoring dates has a significant effect on the variation of the averages of the different mites examined. Regarding the performance of the treatments used on the mites studied during the two months of follow-up, the treatment with detergents and spirodiclofen provided a strong control of the pest *P. citri* compared to the black soap which was less effective (Table 19), while on the predators (*E. stipulatus*, *P. persimilis*, and *Typhlodropmus* sp.) black soap and detergents treatment were less harmful compared to the chemical (spirodiclofen) (fig29.).

Spirodiclofen treatment (T1) significantly reduced *P. citri* populations with a mean of 19.43C±2.52 compared to the control (T0) 63.05A±7.20. The same result was observed with the detergent treatment, which reduced *P. citri* levels to an average of 19.59C±2.18. Black soap

reduced the numbers of this pest with a mean of 37.52B±4.42 compared to the control; however, this treatment was less effective on *P. citri* populations compared to the spirodiclofen and detergent treatment (Table 19).

Compared to the plot treated by water only (T0) which had an average of 19.99A±2.56 for *Typhlodromus* sp., we observed that the black soap (T2) and two detergents (T3) treatments were less harmful on the phytoseiid mite *Typhlodromus* sp. with means of 16. 36B±2.25 in the plot treated with black soap and 15.89B±2.32 in the one pulverized with detergents, while spirodiclofen treatment (T2) showed the most harmful impact on the *Typhlodromus* sp. population with a mean of 7.36C±1.13.

For *E. stipulatus* predator, the mean was 10.59A±1.63 in the plot sprayed with water only (T0). It was 9.71A±1.25 in the plot treated with black soap (T2) and 9.57A±1.41 in the plot treated with two detergents (T3). Whereas, the mean of this population was low in the plot treated with spirodiclofen (T1) with a mean of 6.23B±1.37.

The three treatments used had a similar impact on the predator *P. persimilis*, for the black soap treatment, we had an average of 12.23B±1.95. With detergents, the average was 11.99B±2.05, while it was 9.13B±1.24 on the plot treated with spirodiclofen, whereas, it was 16.60A±2.22 on the plot treated only with water.

Table 20 and Figure 29 shows that there is a positive correlation between the temperature and different mite populations studied (*Phytoseiulus persimilis, P. citri, Typhlodromus* sp. and *Euseius stipulatus*). Figure 30 shows a strong correlation between the last three weeks (6th to 8th week) and the different mites studied. It was medium with week 4 and 5. This correlation was negative between the first three weeks (week 1,2 and 3) and the Four mites studied.

Table 18. Variance analysis of different mite densities using general linear model (GLM) according to follow-up dates, treatments and its interactions (M: Monitoring).

Species	Source	DF	Adj SS	Adj MS	F-Value	P-Value
	Monitoring dates	7	183474	26210,6	3215,61	0,000*
P. citri	Treatments	3	101861	33953,6	4165,56	0,000*
	M.dates*Treatments	21	65625	3125	383,39	0,000*
	Monitoring dates	7	16444	2349,14	266,15	0,000*
***Typhlodromus* sp.**	Treatments	3	6865	2288,28	259,35	0,000*
	M.dates*Treatments	21	2454	116,85	13,24	0,000*
	Monitoring dates	7	9458,2	1336,88	299,35	0,000*
E. stipulatus	Treatments	3	873,4	291,12	65,19	0,000*
	M.dates*Treatments	21	405,9	19,33	4,33	0,000*
	Monitoring dates	7	19017	2716,76	254,84	0,000*
P. persimilis	Treatments	3	2276	758,60	72,26	0,000*
	M.dates*Treatments	21	288	3070	10,66	0,000*

*Statistically significant p-values ($p < 0.05$)

Table 19. Means of different species studied according to the products applied in Nules orchards.

	P. citi	***Typhlodromus* sp.**	***E. stipulatus***	***P. persimilis***
Control experiment (T0)	$63,05^{A}$±7.20	19.99^{A}±2.56	10.59^{A}±1.63	16.60^{A}±2,22
Spirodiclofen 0,5L/Ha (T1)	19.43^{C}±2,52	7.36^{C}±1.13	6.23^{B}±1.37	9.13^{B}±1.24
Black soap 5% (T2)	37.52^{B}±4,42	16.36^{B}±2.25	9.71^{A}±1.25	12.23^{B}±1.95
Detergent (T3)	$19,59^{C}$±2.18	15.89^{B}±2.32	9.57^{A}±1.41	11.99^{B}±2.05

Table 20. Correlation matrix between the variables (Temperature, *P. citri, E. stipulatus, Typhlodromus* sp. and *P. persimilis)*

	Temperature	***P. citri***	***Typhlodromus* sp.**	***E. stipulatus***	***P. persimilis***
Temperature	1,0000	0,6765	0,7656	0,8860	0,8474
P. citri	0,6765	1,0000	0,8318	0,8055	0,8873
Typhlodromus sp.	0,7656	0,8318	1,0000	0,9191	0,9113
E. stipulatus	0,8860	0,8055	0,9191	1,0000	0,9649
P. persimilis	0,8474	0,8873	0,9113	0,9649	1,0000

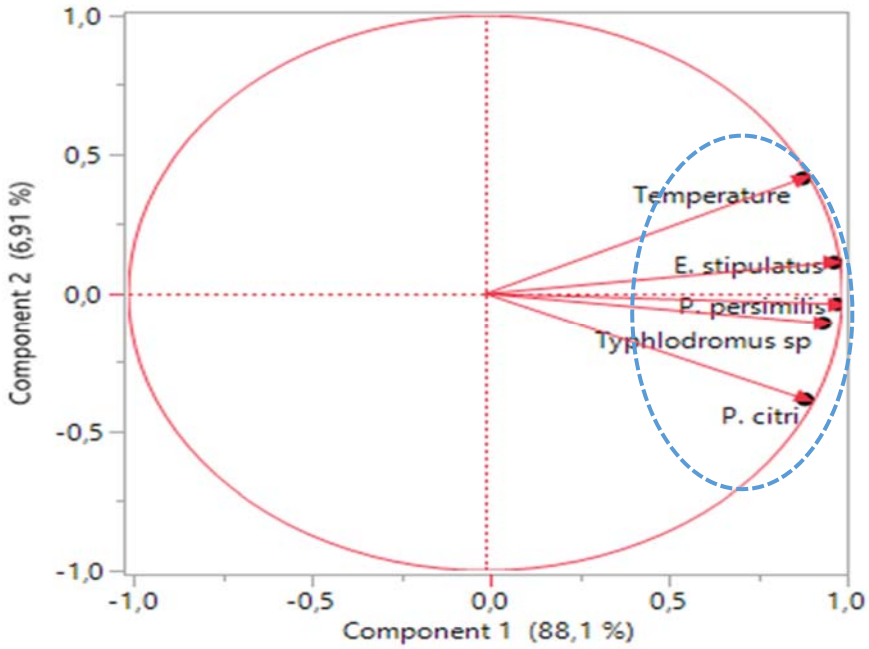


Figure 29. Loading plot that presents the projection of the variables on the first and second principal components.

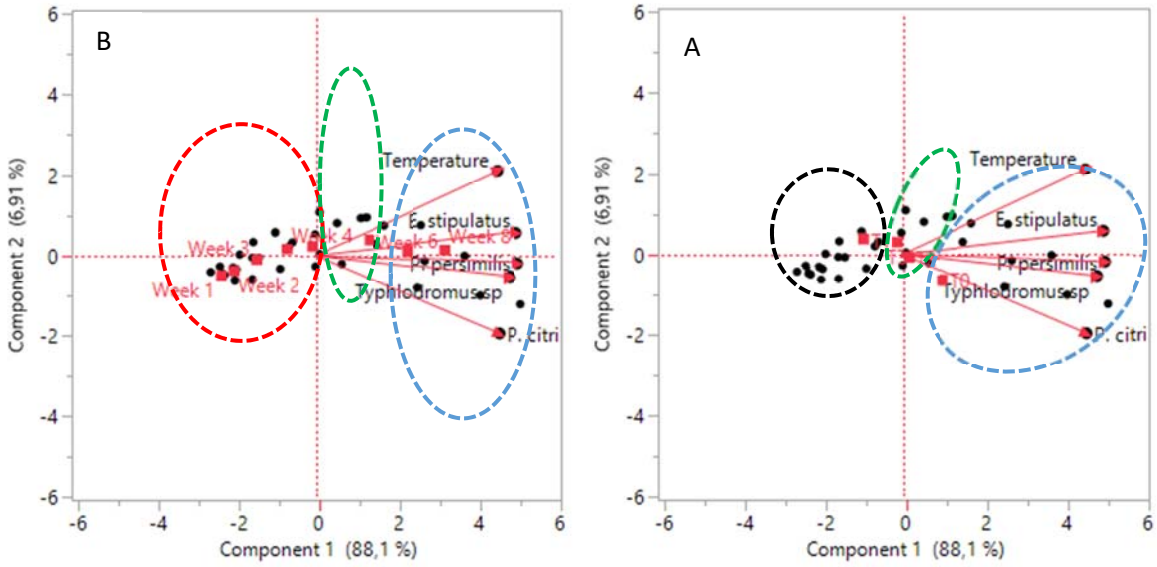


Figure 30. . Principal component analysis (PCA) presents the projection of the variables and the mite populations on the first and second principal components. (A): Biplot according to the different weeks. (B): Biplot according to the different treatment used in Nules orchard T0= Control experiment; T1 = spirodiclofen, T2= black soap; T3= Detergents and follow-up weeks

2.3 The evolution of the mites according to the treatments and the follow-up weeks.

Three days after application of the treatments, we observed a significant decrease in *P. citri*; we obtained during the first week an average of 9.00E ±1.26, 11.00F±1.54 for the black soap, and 9.10D±2.41 for the detergent treatment (Table 21). Conversely, during the same week in the untreated plot T0, this average was 18.10F±2.30. Despite the increase in T° from 27 to 34°C from week 1 to week 5 (Table 22), *P. citri* showed a slight increase in their numbers during the first 5 weeks after spirodiclofen treatment compared to the average reached in the untreated plot (Fig 31.), at week 5 these means were 14.90D±2. 41 in the spirodiclofen-treated plot and 43.20C±4.56 in the untreated plot, beyond that, this pest expanded significantly in the last 3 weeks to an average of 41.90A±4.75 in the spirodiclofen-treated plot and 138.6A±10.46 in the untreated plot in week 8, when the temperature reached 39°C.

For the treatment with detergents, we observed a similar results to those obtained with spirodiclofen, these products provided a significant decrease of the pest *P. citri* during the eight weeks of follow-up. During the last week of follow-up these averages were 43.50A±3.44 in the plot treated with detergents and 138.6A±10.46 in the untreated plots.

Despite the temperature increase from 27°C to 32°C, the black soap treatment ensured a significant reduction in *P. citri* population during the first 4 weeks after its spraying compared to the untreated plot (Fig31.). During the 4th week, these means were 15.50E±2.54 in the plot treated with black soap and 30.00D±4.34 in the untreated plot. The number of this pest increased during the last 4 weeks of monitoring (week 5 to 8) in the plot treated with black soap to reach 81.60A±5.69 in the 8th week.

Concerning the influence of the treatments on the predators according to the dates, the three treatments used had an impact on the abundance of the three predatory mites, this influence was superior by the spirodiclofen treatment compared to the detergent and black soap treatments (fig31.).

For *Typhlodromus* sp. in the untreated plot, the number of this predator was 6.90D ±1.43 in the first week and increased to 34.50A±2.77 in the last week of monitoring (W8), but after spirodiclofen spraying, the average number of *Typhlodromus* sp. was 2.80F ±0.93 in the first week and increased to 13.40A±2. 17 in the last week (W8), for the detergent treatment this average was 7.60E±1.49 in week 1 to reach 27.30A±3.55 in week 8, and finally the black soap which showed the least harmful impact on the *Typhlodromus* sp. population, in week 1 was 5.00E ±1.77 to reach 32.90A±4.12 in week 8.

for the predator *E. stipulatus*, the results were similar to those obtained for *Typhlodromus* sp. where the black soap treatment showed the least dangerous impact with almost similar averages for those obtained in the untreated plot followed by detergents and finally spirodiclofen; in the last week of monitoring, the average was 13. 50A±2.59 in T1 (spirodiclofen) and 20.60A±2.86 in T2 (black soap) and 17.70A±2.12 in T3 (detergent).

For *P. persimilis* detergents and black soap showed the least harmful impact, in the last week of monitoring, in the plot treated with detergents we had an average of 23.80A±2.87, in the plot treated with black soap the average was 25.40A±2.76, and 17.60A±2.21 in the plot treated with spirodiclofen. while on the untreated plot we had 35.30A±2.89.

To better evaluate the classification of the samples (weeks) based on temperature, *P. citri*, *E. stipulatus*, *Typhlodromus* sp. and *P. persimilis*, a hierarchical classification analysis was carried out (Fig32.). The results of this analysis indicated a distinct differentiation between the two clusters. The first cluster represented weeks 1, 2 and 3. The second cluster represented weeks 6, 7 and 8. It is notable that weeks 4 and 5 were included in both clusters. Therefore, they represented the intermediary between the two clusters. In the first cluster (weeks 1 to 3), the temperature as well as the presence of mites population (*P. citri*, *E. stipulatus*, *Typhlodromus* sp. and *P. persimilis*) were minimal (in blue). However, the second cluster (weeks 6 to 8), represents the opposite of the first cluster, the temperature and the presence of mite populations were maximal (in red). PCA and HCA analyses confirmed that presence of mites population was significantly affected by dates (weeks) and temperature (environmental conditions).

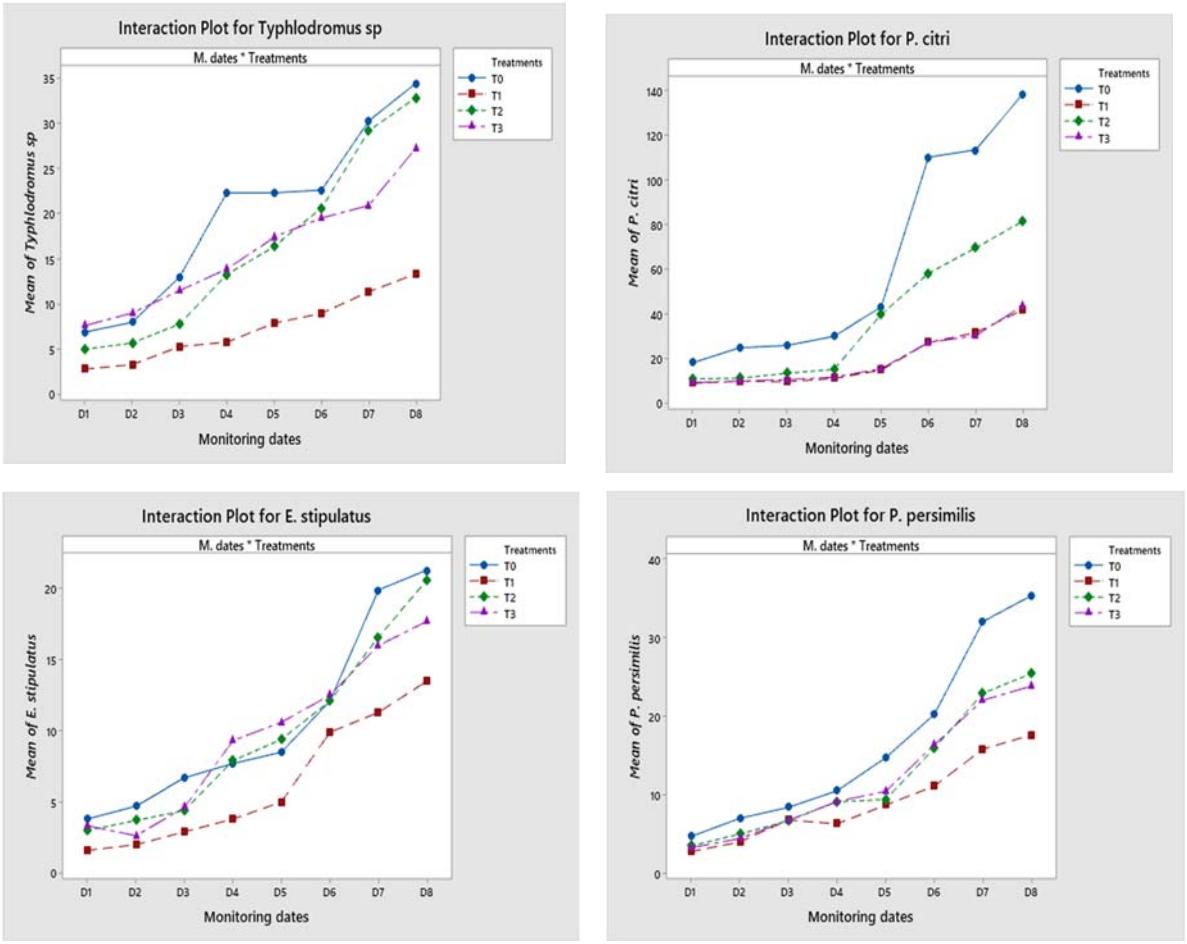


Figure 31. Fluctuation of *P. citi* and its predators in the four treatments used

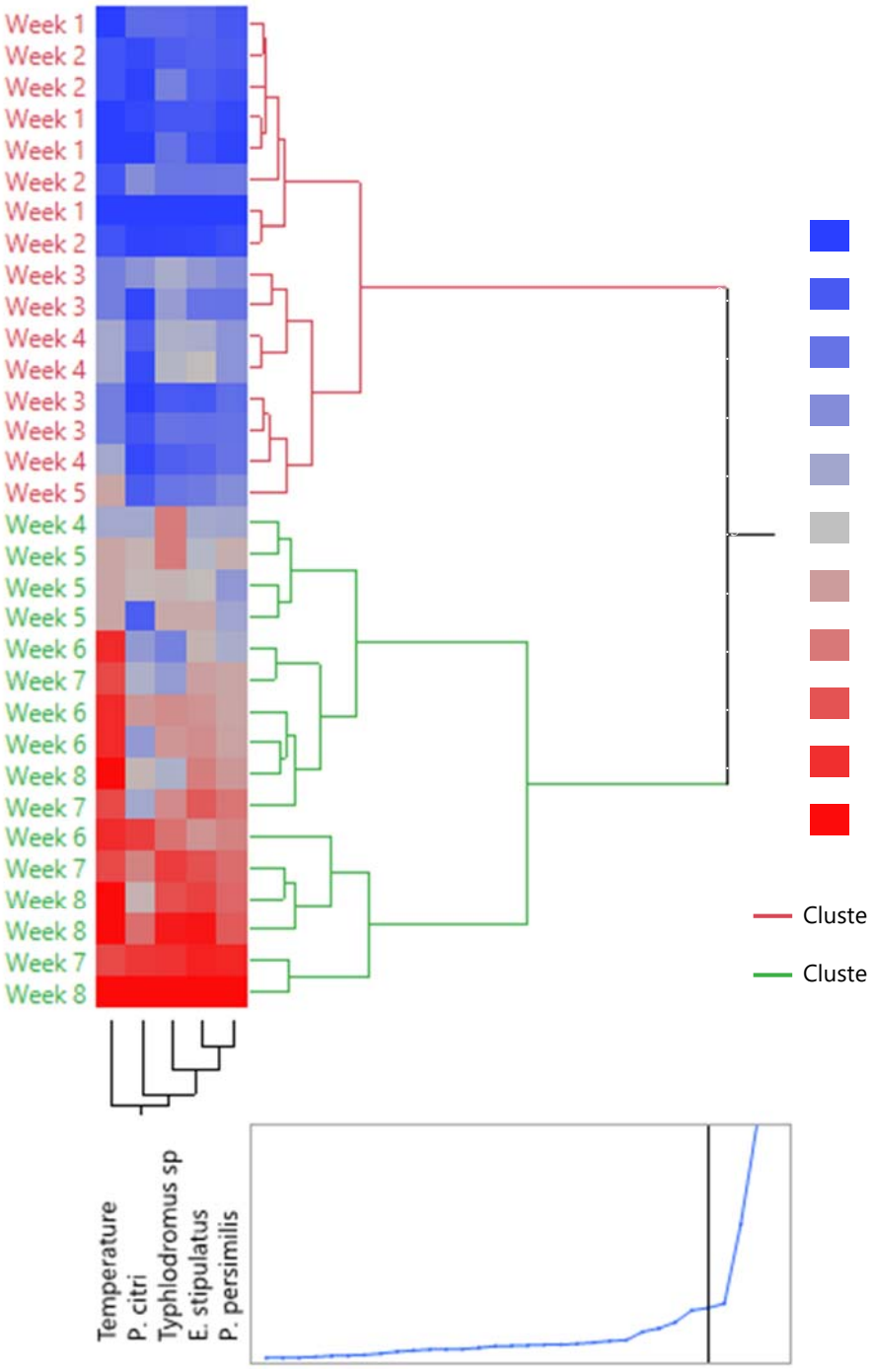


Figure 32. Hierarchical Cluster analysis of samples of Nules variety using the squared Euclidean distance between classes.

Table 21. Means of the different species studied (PC: *P. citri*; ES: *E. stipulatus*; TY: *Typhlodromus* sp.; PP*: P. persimilis*) in the four treatments used Control experiment (T0), spirodiclofen (T1), black soap (T2) and detergents (T3) according to follow-up dates

	PC-TO	PC-T1	PC-T2	PC-T3	TY-T0	TY-T1	TY-T2	TY-T3	ES-T0	ES-T1	ES-T2	ES-T3	PP-T0	PP-T1	PP-T2	PP-T3
W1	$18.10^{F}\pm2.30$	$9.00^{E}\pm1.26$	$11.00^{F}\pm1.54$	$9.10^{D}\pm2.41$	$6.90^{D}\pm1.43$	$2.80^{F}\pm0.93$	$5.00^{E}\pm1.77$	$7.60^{E}\pm1.49$	$3.80^{D}\pm1.61$	$1.60^{D}\pm0.84$	$3.00^{E}\pm1.35$	$2.60^{D}\pm1.45$	$4.70^{E}\pm1.56$	$2.80^{E}\pm1.32$	$3.50^{E}\pm1.23$	$3.20^{E}\pm1.23$
W2	$24.90^{E}\pm2.55$	$9.90^{E}\pm1.61$	$11.20^{F}\pm2.43$	$9.70^{D}\pm2.34$	$8.00^{D}\pm1.34$	$3.30^{F}\pm1.14$	$5.70^{E}\pm1.54$	$9.0^{DE}\pm1.24$	$4.70^{CD}\pm1.32$	$2.00^{D}\pm1.41$	$3.70^{E}\pm1.33$	$3.30^{D}\pm1.13$	$7.00^{DE}\pm1.12$	$4.00^{DE}\pm1.36$	$5.00^{DE}\pm1.56$	$4.40^{DE}\pm1.42$
W3	$25.90^{E}\pm2.69$	$9.70^{E}\pm1.56$	$13.50^{E}\pm2.08$	$10.40^{D}\pm2.31$	$13.00^{C}\pm1.56$	$5.30^{E}\pm1.45$	$7.80^{E}\pm1.73$	$11.50^{DE}\pm2.54$	$6.70^{CD}\pm1.54$	$2.90^{CD}\pm1.21$	$4.40^{E}\pm1.56$	$4.60^{D}\pm1.63$	$8.40^{DE}\pm2.15$	$6.30^{CD}\pm1.44$	$6.70^{CDE}\pm1.54$	$6.70^{CDE}\pm1.32$
W4	$30.00^{D}\pm4.34$	$11.10^{DE}\pm2.34$	$15.50^{E}\pm2.54$	$11.50^{CD}\pm2.44$	$22.30^{B}\pm2.87$	$5.80^{E}\pm1.16$	$13.30^{D}\pm2.45$	$13.90^{CD}\pm2.47$	$7.70^{C}\pm1.70$	$3.80^{CD}\pm1.67$	$7.90^{D}\pm1.45$	$9.30^{C}\pm1.55$	$10.50^{CD}\pm2.41$	$6.80^{CD}\pm1.55$	$9.10^{CD}\pm1.26$	$9.10^{CD}\pm1.41$
W5	$43.20^{C}\pm4.56$	$14.90^{D}\pm2.41$	$39.90^{D}\pm4.16$	$15.30^{C}\pm2.34$	$22.30^{B}\pm2.45$	$7.90^{D}\pm1.51$	$16.40^{D}\pm2.49$	$17.40^{BC}\pm2.30$	$8.50^{BC}\pm1.87$	$5.00^{C}\pm1.61$	$9.40^{D}\pm2.19$	$10.60^{BC}\pm2.45$	$14.70^{BC}\pm2.87$	$8.70^{BC}\pm1.45$	$9.40^{C}\pm1.45$	$10.40^{C}\pm2.43$
W6	$110.20^{B}\pm9.79$	$27.20^{C}\pm3.11$	$58.20^{C}\pm5.22$	$27.10^{B}\pm3.79$	$23.40^{B}\pm1.84$	$9.00^{C}\pm1.67$	$20.60^{C}\pm3.21$	$19.50^{B}\pm2.94$	$12.10^{B}\pm1.54$	$9.90^{B}\pm2.24$	$12.10^{C}\pm2.85$	$12.50^{B}\pm2.44$	$20.20^{B}\pm2.97$	$11.10^{B}\pm2.43$	$15.90^{B}\pm2.12$	$16.30^{B}\pm2.24$
W7	$113.5^{B}\pm10.62$	$31.70^{B}\pm4.54$	$69.60^{B}\pm6.12$	$30.10^{B}\pm3.29$	$30.30^{A}\pm3.84$	$11.40^{A}\pm2.44$	$29.20^{B}\pm3.43$	$20.90^{B}\pm2.54$	$19.90^{A}\pm2.19$	$11.30^{AB}\pm2.45$	$16.60^{B}\pm2.76$	$16.00^{A}\pm2.67$	$32.00^{A}\pm3.56$	$15.80^{A}\pm3.01$	$22.890^{A}\pm3.12$	$22.00^{A}\pm2.67$
W8	$138.6^{A}\pm10.46$	$41.90^{A}\pm4.75$	$81.60^{A}\pm5.69$	$43.50^{A}\pm3.44$	$34.50^{A}\pm2.77$	$13.40^{A}\pm2.17$	$32.90^{A}\pm4.12$	$27.30^{A}\pm3.55$	$21.30^{A}\pm2.75$	$13.50^{A}\pm2.59$	$20.60^{A}\pm2.86$	$17.70^{A}\pm2.12$	$35.30^{A}\pm2.89$	$17.60^{A}\pm2.21$	$25.40^{A}\pm2.76$	$23.80^{A}\pm2.87$

Table 22. Temperatures recorded during the monitoring period

Follow-up date	May 04	May 11	May 18	May 25	June 1	June 7	June 12	June 19
Temperature	27	28	30	32	34	38	37	39

3 Discussion

The resistance developed by pests against acaricides, allowing exceptional spread. Thus, the biodiversity of natural enemies including beneficial phytoseiid mites on the national and international territories has started to decline strongly. This work aims to evaluate the impact of detergents, black soap and spirodiclofen on the pest *P. citri* on the one hand and on beneficial phytoseiid mites on the other hand.

During the whole monitoring period we found 5044 motile forms of *P. citri* on the untreated plot, 1544 forms on the plot treated with spirodiclofen, 3002 forms on the plot treated with black soap and 1567 forms on the plot treated with detergents; the results obtained showed that the three treatments used, ensured a decrease in the population rate of the pest *P. citri* in comparison with the untreated plot. The same results were reported by [25–27], spirodiclofen spraying ensured a decrease in the survival rate and fecundity of *P. citri*. In addition, black soap also showed significant efficacy against several insects such as *Myzus persicae* Sulzer 1776,

Bemisia tabaci Gennadius, 1889 eggs, adults and larvae) on poinsettia cuttings in greenhouse, and against *Aphis craccivora* Koch, 1854, *parlatoria ziziphi* Lucas, 1853 in the field [10,13]. The three treatments used in our study had an impact on the predators surveyed compared to the control. While the impact of spirodiclofen was greater than that of the mixture of two detergents and black soap. The spirodiclofen effect was studied on *Neoseiulus californicus* McGregor, 1954 predator of *Tetranychus urticae*, the results indicated that adverse consequences on population growth parameters were important [28]. In a trial plot of apple trees treated with spirodiclofen, its use in a conventional chemical control program reduced populations of Forficula auricularia (Dermaptera) Linnaeus, 1758 which is an important generalist predator regulating the populations of several pests. [29]. A number of studies confirm that black soap and detergents can replace the use of chemical treatments and are an excellent alternative for integrated pest management [30–32].

Regarding the impact of treatments according to the dates on *P. citri*, we noticed that treatments with black soap ensured a decrease in the abundance of this pest during the first 4 weeks, on the other hand, treatments with detergents and spirodiclofen ensured a significant control during the whole follow-up period which lasted 2 months, These can be explained by the high toxicity of the chemical products[33], Repetitive monthly spraying of black soap, which is less toxic to the plant and predators, and the condition of the agroecosystem in general can significantly control pests in orchards [10]. A study was conducted in Florida to develop a sustainable control method ("Predator-In-First" (PIF)) against pepper pests. The use of the phytoseiid mite *Amblyseius swirskii* in the regulation of several pepper pests; *Bemisia tabaci* Gennadius, 1889 *Frankliniella occidentalis* Pergande, 1895, and *Polyphagotarsonemus latus* Banks under greenhouse and field conditions was very effective. Results suggest that the application of *A. swirskii* alone or in combination with sustainable control methods, can help regulate several pepper pests and ensure improved crop yield [34].

Our results show that the rate of *P. citri* increased significantly from the first week (May 4) to the last week of monitoring (June 19), this is due to the increase in temperature from 28°C to 39°C, the same results were obtained on clementine in the Gharb area of Morocco. This study showed that the degree of infestation of the trees was 10% in mid-April and increased rapidly to 87% in July [35]. The study by [36] also showed that the increase in temperature plays a major role in the evolution of mite populations.

Conclusions

Our findings highlight three key messages: 1) black soap and mixture of two detergents can replace pesticides and remain important tools in integrated pest management if used properly. 2) Repetitive spraying of ecological products can ensure the reduction of pest levels in the long term, 3). The release of natural enemies can be ensured after 5 weeks after the treatment with these products since their persistence does not exceed 4 weeks according to our results.

Author Contributions All authors contributed to the study conception and design. Material preparation, data collection [Amine Assouguem], analysis were performed by [Amine Assouguem], [Rafa Almeer], [Mohammed Kara] and [Saoussan Annemer]. The first draft of the manuscript was written by [Mostafa El Khomsi], [Agnieszka Najda], [Riaz Ullah], [Sezai Ercisli], [Amany A. Sayed], [Abdellah Farah] and [Abderrahim Lazraq]. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding: This research was funded by Researchers Supporting Project number (RSP-2021/96), King Saud University, Riyadh, Saudi Arabia.

Acknowledgments: The authors would like to extend their sincere appreciation to the Researchers Supporting Project number (RSP-2021/96), King Saud University, Riyadh, Saudi Arabia.

Availability of data and materials : All related data are within the manuscript.

Declarations

Competing Interests: The authors declare no conflict of interest.

Ethical Approval: Not applicable.

Consent to Participate: Not applicable.

Consent to Publish: All the authors agree for consent for publication.

References

1. Assouguem, A.; Kara, M.; Benmessaoud, S.; Mechchate, H.; Jabboury, Z. El; Farah, A.; Lazraq, A. Tropical Journal of Natural Product Research *Ceratitis Capitata* Wiedemann (Diptera : Tephritidae) in Moroccan Citrus Orchards : Chemical and Sustainable Control Methods and Priorities for Future Research. **2021**, *5*, 1703–1708.

2. Smaili, M.C.; Abbassi, M.; Boutaleb, J.A.; Blenzar, A. Richesse Spécifique Des Ennemis Naturels Associés Aux Vergers d'agrumes Au Maroc: Intérêt et Implication Pour La Lutte Biologique. *EPPO Bulletin* **2013**, *43*, 155–166, doi:10.1111/epp.12013.

3. Vicente, C.; Boutaleb, A.; Lebrun, PH. Quelles Stratégies de Lutte Contre Les Acariens Ravageurs Du Pommier Au Maroc. *Parasitica* **2003**, *59*, 25–41.

4. Trade, F. Les Chiffres Clés de La Filière Agrumiculture Available online: https://www.fellah-trade.com/fr/filiere-vegetale/chiffres-cles-agrumiculture (accessed on 11 December 2021).

5. Smaili MC, Afellah M, A.A. Contribution à La Mise En Place d'un Système de Lute Intégrée Sur Clémentinier Dans La Région Du Gharb Available online: https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili+MC%2C+Afellah+M%2C+Aarab+A+%282001%29+Biologie%2C+écologie+et+lutte+biologique+contre+Phyllocnistis+citrella+Stain.+sur+clémentinier+dans+la+région+du+Gharb.+In+%3A+Abstracts+of+the+"I+Coll+de (accessed on 10 July 2021).

6. Mazih, A. Status of Citrus IPM in the Southern Mediterranean Basin Morocco, North Africa. *Acta Horticulturae* **2015**, *1065*, 1097–1104, doi:10.17660/ActaHortic.2015.1065.138.

7. Smaili, M.C.; El Ghadraoui, L.; Gaboun, F.; Benkirane, R.; Blenzar, A. Impact of Some Alternative Methods to Chemical Control in Controlling Aphids (Hemiptera: Sternorrhyncha) and Their Side Effects on Natural Enemies on Young Moroccan Citrus Groves. *Phytoparasitica* **2014**, *42*, 421–436, doi:10.1007/s12600-013-0379-9.

8. Jaouad, M.; Moinina, A.; Ezrari, S.; Lahlali, R. Key Pests and Diseases of Citrus Trees with Emphasis on Root Rot Diseases: An Overview. *J. Agri. Sci* **2020**, *1*, 149–160.

9. Field, C.; Ramdani, C.; Fakhouri, K. El; Sbaghi, M.; Bouharroud, R.; Boulamtat, R.; Aasfar, A.; Mesfioui, A.; Bouhssini, M. El Chemical Composition and Insecticidal Potential of Six Essential Oils from Morocco against Dactylopius Opuntiae. **2021**.

10. Egho, E.; Emosairue, S. Evaluation of Native Soap (Local Black Soap) for the Control of Major Insect Pests and Yield of Cowpea (Vigna Unguiculata (L) WALP in ASABA, Southern Nigeria. *Agriculture and Biology Journal of North America* **2010**, *1*, 938–945, doi:10.5251/abjna.2010.1.5.938.945.

11. Aniwanou, C.T.S.; Sinzogan, A.A.C.; Deguenon, J.M.; Sikirou, R.; Stewart, D.A.; Ahanchede, A. Bio-Efficacy of Diatomaceous Earth, Household Soaps, and Neem Oil against Spodoptera Frugiperda (Lepidoptera: Noctuidae) Larvae in Benin. *Insects* **2021**, *12*, 1–18, doi:10.3390/insects12010018.

12. C Daniel, E Wyss, C.L. Applications de Soufre En Automne: Une Nouvelle Manière de Lutter Contre Lériophyide à Galles Du Poirier. *Revue suisse de Viticulture, Arboriculture et Horticulture* **2004**, *36*.

13. Boutaleb Joutei, A.; Bassy, F. Essais de Lutte Chimique et Biologique Contre Les Acariens (*Tetranychus Urticae* Koch) et Les Pucerons (Myzus Persicae Sulzer) Sur Cultures Maraîchères Dans La Région Du Saïs. *Travaux de l'Institut Scientifique, Série Zoologie,* **2009**, *45*.

14. Eur-lex EUR-Lex - 31999L0045 - EN - EUR-Lex Available online: https://eur-lex.europa.eu/legal-content/FR/ALL/?uri=celex:31999L0045 (accessed on 30 November 2021).

15. Smaili, M.C.; Abbassi, M.; Boutaleb, J.A.; Blenzar, A. Richesse Spécifique Des Ennemis Naturels Associés Aux Vergers d'agrumes Au Maroc: Intérêt et Implication Pour La Lutte Biologique. *EPPO Bulletin* **2013**, *43*, 155–166, doi:10.1111/epp.12013.

16. Elaini, R.; Asadi, R.; Naish, N.; Koukidou, M.; Ahmed, M. Evaluation of Rearing Parameters of a Self-Limiting Strain of the Mediterranean Fruit Fly, *Ceratitis Capitata* (Diptera: Tephritidae). *Insects* **2020**, *11*, 1–11, doi:10.3390/insects11100663.

17. Ferragut, F.; Laborda, R.; Costa-Comelles, J.; García-Marí, F. Feeding Behavior of Euseius Stipulatus and Typhlodromus Phialatus on the Citrus Red Mite *Panonychus Citri* [Acari: Phytoseiidae, Tetranychidae]. *Entomophaga* **1992**, *37*, 537–544, doi:10.1007/BF02372323.

18. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial Insect Community of Moroccan Citrus Groves: Assessment of Their Potential to Enhance Biocontrol Services. *Egyptian Journal of Biological Pest Control* **2020**, *30*, 0–15, doi:10.1186/s41938-020-00241-0.

19. Masui, S.; Katayama, H.; Kaneko, S. Status and Use of Biological Control of Insect Pests in Citrus IPM. *Japanese Journal of Applied Entomology and Zoology* **2018**, *62*, 137–148, doi:10.1303/jjaez.2018.137.

20. McMurtry, J.A. Some Predaceous Mites [Phytoseiidae] on Citrus in the Mediterranean Region. *Entomophaga* **1977**, *22*, 19–30, doi:10.1007/BF02372986.

21. Franco, J.C.; Garcia-Marí, F.; Ramos, A.P.; Besri, M. Survey on the Situation of Citrus Pest Management in Mediterranean Countries. *Integrated control in citrus fruit crops. Lisbon, 26-27 September 2005. IOBC wprs Bull 29(3)* **2006**, 335–346.

22. Hassouni, T.; Belghyti, D. Distribution of Gastrointestinal Helminths in Chicken Farms in the Gharb Region - Morocco. *Parasitology Research* **2006**, *99*, 181–183, doi:10.1007/s00436-006-0145-8.

23. Benyahia, H.; Talha, A.; Fadli, A.; Chetto, O.; Omari, F.E.; Beniken, L. Performance of 'Valencia Late' Sweet Orange (Citrus Sinensis) on Different Rootstocks in the Gharb Region (Northwestern Morocco). *Annual Research and Review in Biology* **2017**, *20*, 1–11, doi:10.9734/ARRB/2017/37924.

24. Saguem Sara; Majida El Alami El Moutaouakil Study on the Spread of Procambarus Clarkii at Gharb (Morocco) and Its Impact on Rice Growing. *Journal of Agricultural Science and Technology A* **2019**, *9*, 81–92, doi:10.17265/2161-6256/2019.02.002.

25. Acari, M.; Ahmed, M.M.; Abdelwines, M.A. Article Sublethal Effects of Cyflumetofen and Spirodiclofen on Biological Parameters Of. **2021**, *10*, 467–480.

26. Hu, J.; Wang, C.; Wang, J.; You, Y.; Chen, F. Monitoring of Resistance to Spirodiclofen and Five Other Acaricides in Panonychus Citri Collected from Chinese Citrus Orchards. *Pest Management Science* **2010**, *66*, 1025–1030, doi:10.1002/PS.1978.

27. Nauen, R. Spirodiclofen: Mode of Action and Resistance Risk Assessment in Tetranychid Pest Mites. *Journal of Pesticide Science* **2005**, *30*, 272–274, doi:10.1584/jpestics.30.272.

28. Sarbaz, S.; Goldasteh, S.; Zamani, A.A.; Solymannejadiyan, E.; Vafaei Shoushtari, R. Side Effects of Spiromesifen and Spirodiclofen on Life Table Parameters of the Predatory Mite, *Neoseiulus Californicus* McGregor (Acari: Phytoseiidae). *International Journal of Acarology* **2017**, *43*, 380–386, doi:10.1080/01647954.2017.1325396.

29. Fountain, M.T.; Harris, A.L. Non-Target Consequences of Insecticides Used in Apple and Pear Orchards on *Forficula Auricularia* L. (Dermaptera: Forficulidae). *Biological Control* **2015**, *91*, 27–33, doi:10.1016/J.BIOCONTROL.2015.07.007.

30. Tomislav, C.S. Les Détergents et Les Savons Comme Outils Pour La Lutte Intégrée Dans l'agriculture | IntechOpen Available online: https://www.intechopen.com/chapters/51590 (accessed on 9 December 2021).

31. Bajwa, U.; Singh Sandhu, K. Effect of Handling and Processing on Pesticide Residues in Food-a Review. *Journal of food science and technology* **2014**, doi:10.1007/s13197-011-0499-5.

32. Singh, N.; Wang, C.; Cooper, R. HOUSEHOLD AND STRUCTURAL INSECTS Potential of Essential Oil-Based Pesticides and Detergents for Bed Bug Control. *J. Econ. Entomol* **2014**, *107*, 2163–2170, doi:10.1603/EC14328.

33. Van Leeuwen, T.; Tirry, L.; Yamamoto, A.; Nauen, R.; Dermauw, W. The Economic Importance of Acaricides in the Control of Phytophagous Mites and an Update on Recent Acaricide Mode of Action Research. *Pesticide Biochemistry and Physiology* **2015**, *121*, 12–21, doi:10.1016/j.pestbp.2014.12.009.

34. Kumar, V.; Mehra, L.; Mckenzie, C.L.; Osborne, L.S. "Predator-In-First": A Preemptive Biological Control Strategy for Sustainable Management of Pepper Pests in Florida. *Sustainability* **2020**, doi:10.3390/su12187816.

35. Hmimina, M.; Allam, L.; Ougass, Y.; Marmouche, A. Circonstances Des Pullulations de *Tetranychus urticae* Koch (Tetranychidae: Acarina) En Verger d'agrumes. *IOBC/wprs Bull.* **1995**, *18*, 35.

36. Tello Mercado, V.; Loyola, E.R.; Soto, T.R. Post-Embryonicdevelopment and Life Tableparameters of *Neoseiulus californicus* on *Tetranychus desertorum* and *Panonychus citri* (Acari: Phytoseiidae, Tetranychidae) under Laboratory Conditions. *Gayana* **2020**, *84*, 54–63, doi:10.4067/S0717-65382020000100054.

Chapitre VI

Évaluation de l'effet de quatre huiles essentielles seules et en mélange avec un produit chimique contre *Tetranychus urticae* et *Eutetranychus orientalis*

Cette étude à fait l'objet d'une publication en Evidence-Based Complementary and Alternative Medicine journal (IF 2,65)

Assouguem, A.; Kara, M.; Ramzi, A.; Annemer, S.; Kowalczyk, A.; Ali, E.A.; Moharram, B.A.; Lazraq, A.; Farah, A. Evaluation of the Effect of Four Bioactive Compounds in Combination with Chemical Product against Two Spider Mites *Tetranychus urticae* and *Eutetranychus orientalis* (Acari : Tetranychidae). **2022**.

Résumé

Actuellement, la lutte contre les parasites à l'aide d'acaricides chimiques inquiète les écologistes et les professionnels de la santé, car ces produits chimiques endommagent l'écosystème et favorisent le développement de la résistance des acariens phytophage. De telles inquiétudes exigent une réaction rapide et approfondie en recherchant de nouvelles méthodes alternatives et écologiques. Ces dernières années, l'utilisation des huiles essentielles dans les pratiques de lutte antiparasitaire a fait son apparition. Les huiles essentielles ont été considérées comme des agents potentiels de lutte contre les nuisibles, car elles ont démontré qu'elles avaient une large gamme de bioactivité et qu'elles possédaient une toxicité de contact et de fumigation. En outre, les principaux avantages de nombreux acaricides à base de plantes résident dans leur faible toxicité pour les agroécosystèmes. Les acaricides botaniques composés d'huiles essentielles peuvent s'avérer être un bon choix pour remplacer les acaricides synthétiques plus persistants. Dans cette étude, l'effet acaricide de quatre huiles essentielles dérivées de plantes contre les adultes de deux ravageurs importants des cultures, *Tetranychus urticae* (Koch) 1836 et *Eutetranychus orientalis* (Klein) 1936 à été étudié. La toxicité du fumigant a révélé que toutes les huiles essentielles testées - *Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., et *Origanum compactum* Benth (famille des Lamiaceae) - présentaient un effet acaricide. A la plus forte dose (625 µl/ml), les mortalités enregistrées se situaient entre 91-98% et 92-99% à 24h et 48h, respectivement pour *T. urticae*, et entre 90-98% et 94-99% à 24h et 48h, respectivement pour *E. orientalis*. L'huile essentielle de *Mentha pulegium* L. représente la plus forte activité contre *E. orientalis* et *T. urticae*. Pour la combinaison binaire entre les HE (Huiles Essentielles) et l'acaricide à base de la matière active acéquinocyl, les résultats ont montré que le mélange HE (huile essentielle) *O. compactum* + acéquinocyl présente un effet acaricide important sur *T. urticae* et *E. orientalis* avec 99% à 24h et 100% à 48h de mortalité, suivi par *M. pulegium* EO+ acéquinocyl avec 92 à 24h et 95% à 48h pour *T. urticae* ainsi que

99% à 24h et 100% à 48h pour *E. orientalis* de mortalité. Alors que le mélange de *L. stoechas* EO+ acéquinocyl a présenté la plus faible activité contre *T. urticae* et *E. orientalis* avec 82-87% à 24h et 86-90% à 48h, respectivement. Les mélanges (*M. pulegium* EO+ acéquinocyl, *R.officinalis* EO+ acéquinocyl, et *O. compactum* EO + acéquinocyl) ont exercé un effet acaricide élevé contre *E. orientalis*. Ces résultats prometteurs pourraient aider à développer des pesticides botaniques qui pourraient être utilisés dans la gestion intégrée des parasites.

Evaluation of the Effect of Four Bioactive Compounds in Combination with Chemical Product against Two Spider Mites *Tetranychus urticae* and *Eutetranychus orientalis* (Acari: Tetranychidae)

Amine Assouguem 1,2* Mohammed Kara ,3 Amal Ramzi,1 Saoussan Annemer,1 Alicja Kowalczyk ,4 Essam A. Ali,5 Bushra Abdulkarim Moharram ,6* Abderrahim Lazraq,2 and Abdellah Farah1

[1]*Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technologies, Sidi Mohamed Ben Abdellah University, Route d'Imozzer, Fez, Morocco.*
[2]*Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Street, Fez P.O. Box 2202, Morocco;*
[3]*Laboratory of Biotechnology and Conservation and Valorization of Natural Resources (LBCVRN) (ex LBPRN), Sidi Mohamed Ben Abdellah University, Fez B.P. 1796, Morocco;*
[4]*Department of Environmental Hygiene and Animal Welfare, Wrocław University of Environmental and Life Sciences, Chełmo ´nskiego 38C, 51-630 Wrocław, Poland:*
[5]*Department of Pharmaceutical Chemistry, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia;*
[6]*Department of Pharmacognosy, Faculty of Pharmacy, Sanaa University, Sanaa Yemen*

Correspondence: bushramoharam@yahoo.com; assougam@gmail.com;

Abstract:

Currently, pests control using chemical acaricides constitutes worries for ecologists and health care people as these chemical products create damage to the ecosystem as well as the development of spider mites resistance. Such concerns request deep and rapid feedback by looking for new alternative and eco-friendly methods. In recent years, a new field is evolving on the use of essential oils in the pest management practices. Essential oils have been considered as potential pest management agents, because they demonstrate to have a broad range of bioactivity, possess contact and fumigant toxicity. In addition, the major advantages of many plant-based acaricides lie in their low toxicity to agroecosystems. Botanical acaricides composed of essential oils may prove to be good choice to the more persistent synthetic acaricides. In this study, the acaricidal effect of four plant-derived essential oils against adults of the two important crop pests, *Tetranychus urticae* (Koch) 1836 and *Eutetranychus orientalis* (Klein) 1936. The fumigant toxicity revealed that all the essential oils tested *Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., and *Origanum compactum* Benth (Lamiaceae family) displayed an acaricidal effect. At the highest dose (625 µl/ml), mortalities recorded were found between 91-98% and 92-99% at 24h and 48h, respectively for *T. urticae*, and between 90-98% and 94-99% at 24h and 48h, respectively for *E. orientalis*. The *Mentha*

pulegium L. essential oil represents the highest activity against *E. orientalis* and *T. urticae*. For the binary combination between the EOs (Essential Oils) and the acaricide based on the active ingredient acequinocyl, the results showed that the mixture of *O.compactum* EO (essential oil) + acequinocyl exhibited an important acaricidal effect on *T. urticae* and *E. orientalis* with 99% at 24h and 100 % at 48h of mortality, followed by *M. pulegium* EO+ acequinocyl with 92 at 24h and 95% at 48h for *T. urticae* as well as 99% at 24h and 100% at 48h for *E. orientalis* of mortality. Whereas, the mixture of *L. stoechas* EO+ acequinocyl presented the lowest activity against *T. urticae* and *E. orientalis* with 82-87% at 24h and 86-90% at 48h, respectively. The mixtures (*M. pulegium* EO+ acequinocyl, *R.officinalis* EO+ acequinocyl, and *O. compactum* EO + acequinocyl) exerted a high acaricidal effect against *E. orientalis*. These promising results could help to develop botanical pesticides that could be used in integrated pest management.
Keywords: acaricides; acequinocyl; chemical acaricide; environnemental conditions; essential oils; pest management

Introduction

Spider mites including *Tetranychus urticae (*Koch) 1836 *and Eutetranychus orientalis (*Klein) 1936 are a major pest of citrus in many countries including Morocco [1,2], these two pests cause considerable losses to citrus crops [3,4]. In recent years, these pests which have become of great economic importance [5,6], by sucking the cellular juice of the leaves cause yellowing, necrosis and leaf fall which weakens the plant and reduces the photosynthetic capacity [7]. Their control is often provided by intensive and preventive chemical control [8,9]. In Morocco, the Acequinocyl, Abamectin, Malathion, Spirodiclofen, Bifenazate, Fenpyroximate, Fenazaquin, Tebufenpyrad, Propargite, Milbemectine, Bifenthrine, Dicofol, Clofentezine, Maltodextrine, and Pyridaben are the most acaricides employed to control spider mites including *T. urticae* and *E. orientalis* under greenhouses and field [1,10]. Despite advantages such as easy use, the decrease of pests numbers, and their immediate action when compared to natural extracts from plants [11]. This approach has considerable limitations; the examination of the spectrum activity of the functional components used throughout the globe demonstrates that 72% of insecticides, 28% of fungicides and 46% of acaricides are globally toxic towards auxiliary arthropods and public health [12,13].

Acequinocyl is a naphthoquinone compound discovered in the 1970s by DuPont [14]. It is a proacaricide that breaks down into the active metabolite, a deacetylated product. A mechanistic study showed that the deacetylated metabolite of acequinocyl inhibits respiration

in mitochondria at the ubiquinol oxidation site (Q0) of complex III of the electron transfer chain [15,16].

The control by *Mentha pulegium, Lavandula stoechas, Rosmarinus officinalis, and Origanum compactum* (Lamiaceae family) can be used as alternative approaches for control, Essential oils include a plentiful interest for researchers who always try through their scientific studies to discover the great potential of these substances as anti-inflammatory, antioxidant, antimicrobial, and ac agents [17,18]. Plants from the Lamiaceae family including *M. pulegium, L. stoechas, R. officinalis*, and *O. compactum* are well known for their acaricidal dynamic, biological activities and many reports have demonstrated the existence of different compounds like terpenes, iridoids, flavonoids and phenolic constituents the species of this family [19,20]. Moreover, it had been conveyed that the two Lamiaceae plants, *M. pulegium* and *R. officinalis* have multiple significant acaricidal activities against spider mites [21,22]. *M. pulegium* possesses several acaricidal properties; this aromatic plant has demonstrated antioxidant and anticholinesterase, anthelmintic, antimicrobial, insecticidal, and acaricidal effect [23–25]. Similarly, *R. officinalis* is well known for its beneficial effect as a medicinal mechanism and it also showed an acaricidal potential against pests [26]. The objective of this work was to evaluate the acaricidal effect of four essential oils derived from *M. pulegium, L. stoechas, R. officinalis*, and *O. compactum*, alone and in combination with a chemical acaricide based on acequinocyl, against two spider mites: *T. urticae* and *E. orientalis.*

1 Materials and Methods

1.1 Plant material and extraction of essential oils

Samples of *Lavandula stoechas, Mentha pulegium and Origanum compactum* (Lamiaceae family) were collected between April and June (the flowering stage) in the mountainous area that is located in the rural community of Timezgana (Northeastern of Morocco, 34° 34' 48" North, 4° 43' 48" West), at an altitude of approximately 800 m.

Samples of *Rosmarinus officinalis* comes from the experimental garden of the faculty of science and technology of Fez. The collected plants were identified at the National Agency for Medicinal and Aromatic Plants in Taounate, Morocco.

These products were chosen on the basis of their availability and their effectiveness as natural acaricide.

1.2 Chromatographic analysis

Chemical analysis of all essential oils was realized using a Gas Chromatography coupled with Mass Spectrometry (GC/MS) and coupled with Flame Ionization Detection (GC-FID). The GC /MS analysis was utilized for identification, while GC-FID analysis was used for quantification of components.

1.2.1 Gas chromatography (GC-FID) analysis

Gas chromatography analyses for all the samples were realized using a Hewlett-Packard (HP 6890) gas chromatograph equipped with an HP-5 capillary column (30 m × 0.25 mm, film thickness of 0.25 µm), FID a detector, and an injector fixed at 275 °C. The oven temperature was at 50 °C for five min and then rising to 250 °C at 4 °C/min. The Nitrogen (1.8 mL/min) was utilized as carrier gas. The samples were diluted to 1/50 in methanol and the injected volume was 1 µL using a split mode of ratio: 1/50, flow: 72.1 mL/min. The relative proportions of the EOs components were reported as percentages determined using peak-area normalization. The retention indices (RI) on HP-5 MS column, were identified using homologous series of (C8– C28) alkanes.

1.2.2 GC/MS analysis

Chemical analysis was carried out using a Hewlett-Packard gas chromatograph (HP 6890) coupled to a mass spectrometer (HP 5973). The column utilized was HP-5MS (cross-linked 5% PHME siloxane) (30 m x 0.25 mm, film thickness 0.25 µm). The column temperature was set at 50°C and increased to 250°C at a rate of 2°C/min. The carrier gas is helium at 1.5 mL/min, using split mode ratio: 1/74.7, flow rate: 112 mL/min. MS identities of components were confirmed using the NIST 98 spectral library. The ion source temperature of 230 °C with ionization voltages of 70 eV and a scan mass range of 35–450 m/z. The identification of the components was also confirmed by comparing the elution order of the compounds with the relative retention indices reported in the literature.

1.3 Spider mites

The adults spider mites of *Tetranychus urticae* and *Eutetranychus orientalis* (Acarina: Tetranychidae) were collected from a farmer in Fez city 34°02′36″N, 05°00′12″W planted by (*Citrus aurantium* L., 1753) not previously treated with chemical products (Acaricides). The collected leaves were transferred directly into referenced polyethylene bags to the laboratory for inspection. *T. urticae* and *E. orientatlis* spider mites on each leaf were determined and counted on both leaf surfaces using a binocular microscope before and after the addition of the tested products.

1.4 Toxicity test

The acaricidal tests were conducted according to the methodology of Sertkaya et al., 2010 with slight modification. Firstly, various doses (39.06, 78.125, 156.25, 312.5, 625µl/L) of each EO and the chemical acaricide (Kanemite, 15%) were prepared. Thereafter, twenty adults of each Tetranychidae species (*T. urticae* and *E. orientalis*) survived in *Citrus* leaves were placed in Glass Petri dishes (90mm×20mm). Disks of filter papers that were previously attached to the interior surface of the petri dish cover were impregnated with 10 µl of each concentration. DMSO (0.01%) was used as a negative control. Five replications of treatments and controls were carried out. The toxicity was evaluated after 24h and 48h of exposure, and the mortality was calculated using the formula of Abbott (1)

$$\%\ Mortality\ Corrected\ = \left[\frac{\%\ Mortality\ Observed - \%\ Mortality\ Control}{100 - \%\ Mortality\ Control}\right] \times\ 100. \quad (1)$$

1.5 Statistical treatment

Mortality percentages were analyzed by the SPSS software (IBM SPSS Statistics 25.0). The obtained results were also examined with OriginPro 2021 software to determine the significant effect between mean values using the Tukey test (a probability of $p \leq 0.05$ regarded as statistically significant). The different-principal component analysis was carried out by using the JMP Pro 14. The LD_{50} values were estimated using a probit regression analysis (with SPSS software) according to Finney's mathematical methods [27].

2 Results

2.1 Chemical composition of the four tested Eos

As presented in Table 23, *M. pulegium* EO was dominated by r (+)-pulegone (74.03%), carvone (5.45%), and dihydrocarvone (3.66%). *L. stoechas* EO was characterized by camphor (43.97%), fenchone (30.39%), camphene (4.09 %), borneol (2.92%), and α-pinene (2.84%). Whereas 1,8 cineole (29.31%), camphor (24,66%), and α-pinene (12.76%) were the main components in *R. officinalis*. EO. Thymol (30.05%), carvacrol (25.33%), and γ-Terpinene (17.23%) presented the main volatile components in *O. compactum* EO.

Table 23. The major chemical constituents of the four EOs

Compound	RI [a]	RI [b]	% Relative peak area			
			M. pulegium	*L. stoechas*	*R. officinalis*	*O. compactum*
α-pinene	939	932	0.42	2.84	12.76	2.24
Camphene	953	946	—	4.09	2.47	Tr
α-Terpinene	1002	1007	—	—	Tr	3.45
p-Cymene	1026	1022	—	0.32	0.09	11.22
1,8- cineole	1033	1033	—	1.42	31.15	Tr
γ-Terpinene	1062	1024	—	0.34	—	17.23
Fenchone	1088	1087	—	30.39	—	Tr
Camphor	1143	1146	—	43.97	26.96	0.14
Borneol	1165	1166	—	2.92	5.46	0.42
Dihydrocarvone	1194	1191	3.66	—	—	—
R (+)-pulegone	1238	1233	74.03	—	Tr	—
Carvone	1242	1239	5.45	0.12	—	Tr
Thymol	1290	1293	—	—	—	30.05
Carvacrol	1298	1291	—	—	—	25.33
Total %			83.56	86.41	78.89	90.08

2.2 Toxicity of EOs on *Tetranychus urticae* and *Eutetranychus orientalis*

The Fig 33 and Fig 34 illustrate the significance differences of the acaricidal effects of the four EOs and the chemical acaricide on *Tetranychus urticae* and *Eutetranychus orientalis* according to mortality time (Fig (a)) and different concentration (Fig (b)). A significant difference (p <0.05) was noted between *M.pulegium, R. officinalis, L. stoechas,* and *O. compactum* (p=0.008) as well as between the four EOs and acaricide (p=0.009) in terms of mortality (%). In addition, a significant

difference was observed between concentration (C1, C2, C3, and C4) of EOs and acaricide (p=0.004) in terms of mortality (%). However, no significant difference (p >0.05) was detected between Eos and acaricide (p=0.08) in terms of concentration C5, except *R. officinalis* EO for *T. urticae*. No significant difference was found between mortality time of the four Eos and acaricide (p=0.18) in terms of *Tetranychus urticae* and *Eutetranychus orientalis* mortality. It could be said that the mortality vary according to the oil and the acaricide tested and the treated mite species, generally; it was concentration-dependent. Indeed, *M.pulegium* and *O. compactum* EOs were the most effective against the two mites at all concentrations used, yet all EOs caused more than 90% of mortalities at the highest dose (C5: 625µl/L). These results showed the important acaricidal potential of the different EOs. The chemical acaricide, Kanemite with the acequinocyl as the active molecule also displayed toxicity that varied in function of doses.

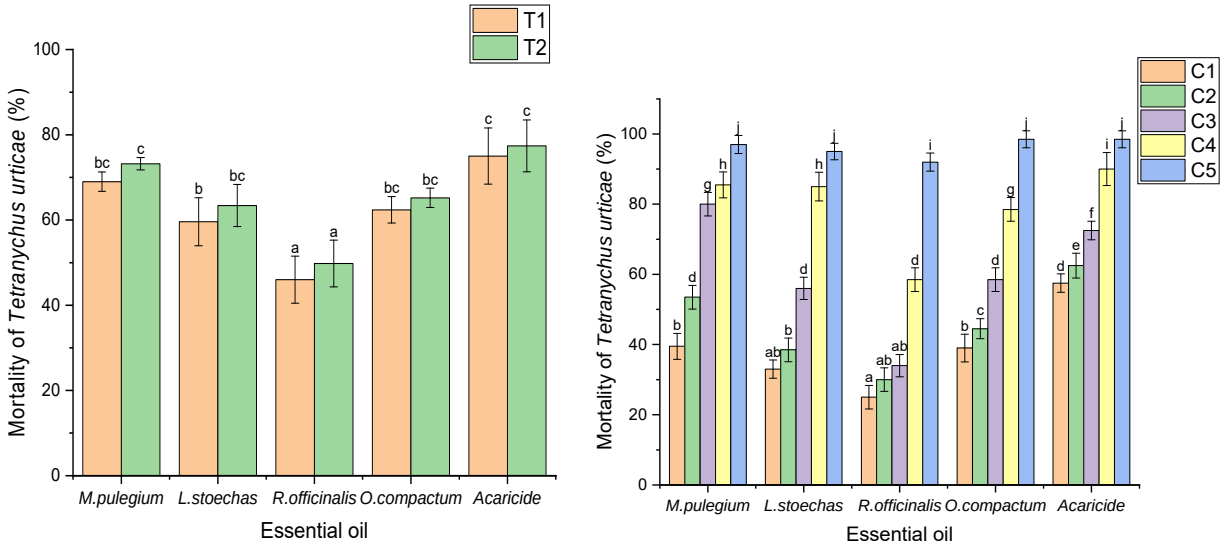


Figure 33. Mortality rate (%) of *Tetranychus urticae* adults (a) according to mortality time. T1: 24h; T2: 48h, (b) according to various concentrations. C1: 39.06 µl/l, C2: 78.125 µl/l, C3: 156.25 µl/l; C4: 312.5 µl/l, C5: 625 µl/l. Different letters indicate significant differences according to Tukey test.

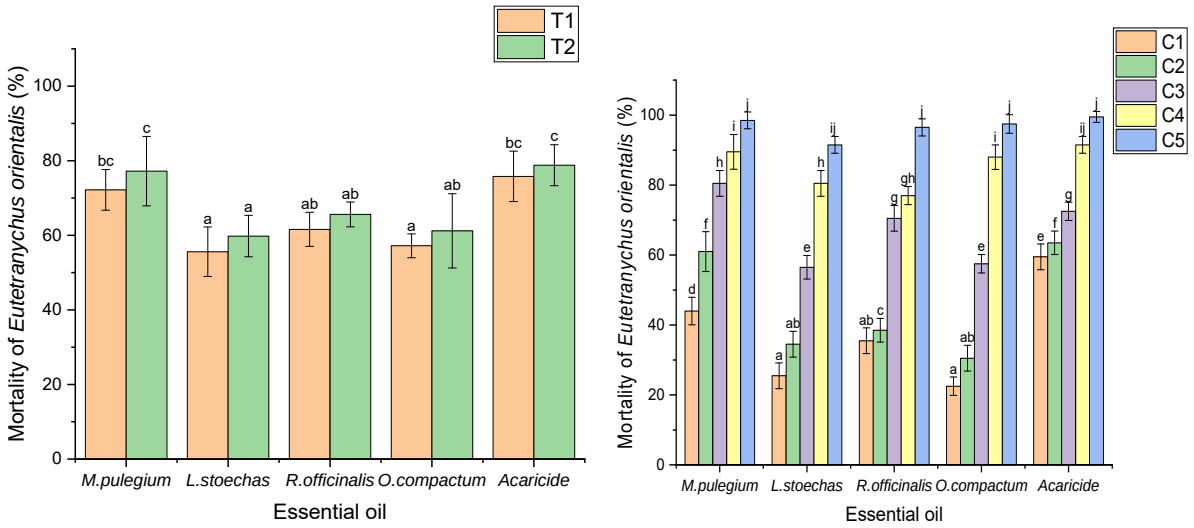


Figure 34. Mortality rate (%) of *Eutetranychus orientalis* adults (a) according to mortality time. T1: 24h; T2: 48h, (b) according to various concentrations. C1: 39.06 µl/l, C2: 78.125 µl/l, C3: 156.25 µl/l; C4: 312.5 µl/l, C5: 625 µl/l. Different letters indicate significant differences according to Tukey test.

The lethal doses (LD_{50}) values obtained for each essential oil and the chemical acaricide are presented in Table 24. It was found that *M. pulegium* EO, *O.compactum* EO, and the chemical acaricide displayed the lowest LD 50 values on adults of *Tetranychus urticae* after 24h (65.78, 87.92, and 36.25 µl/L air, respectively) and after 48 h of treatment (56.1, 79.72, and 32.09 µl/L air, respectively. For *Eutetranychus orientalis*, the lowest LD 50 values were obtained for *M. pulegium* EO, *R. officinalis* EO, and the acaricide after 24h (59.10, 88.2, and 34.07 µl/L air, respectively) and after 48h of exposure (47.37, 82.44, and 29.15 µl/L air, respectively). The Chi-square test was not significant at 5% for all samples (EOs and the acaricide), which means a goodness of fit.

Table 24. LD50 values calculated for *Tetranychus urticae*, and *Eutetranychus orientalis*

Spider mites species	sample	LD_{50} (µl/L air) (24 h) (95% CI*)	Slope (24 h)	Intercept (24 h)	Df	X2	LD_{50} (µl/L air) (48 h) (95% CI)	Df	X2	Slope (48 h)	Intercept (48 h)
Tetranychus Urticae	*M. pulegium*	65.78 (44.63-10110.12)	1.69 ±0.17	1.93±0.38	4	4.21	56.1 (33.8-69.5)	4	4.68	1.86±0.18	1.75 ±0.41
	L. stoechas	100.03 (85.88-120.12)	1.80 ±0.24	1.41±0.55	4	2.64	85.35 (65.15-115.12)	4	2.89	1.87±0.27	1.38 ±0.60
	R. officinalis	171.87 (163.24-184.96)	1.59 ±0.41	1.44±0.91	4	1.95	141.51 (120.39–162.10)	4	2.28	1.67 ±0.48	1.40 ±0.07
	O.compactum	87.92 (68.15-99.65)	1.29 ±0.27	2.50±0.56	4	3.92	79.72 (58.9-95.42)	4	4.10	1. 79±0.33	1.27±0.75
	Chemical acaricide	36.25 (27.77-52.48)	1.42± 0.37	2.79±0.83	4	4.62	32.09 (19.81-61.10)	4	4.9	1.72 ±0.35	2.21±0.78
Eutetranychus orientalis	*M. pulegium*	59.10 (40.5-78.9)	1.86 ±0.15	1.71±0.35	4	3.99	47.37 (39.80-63.65)	4	4.51	1.91 ±0.19	1.80 ±0.42
	L. stoechas	120.87 (101.19-146.62)	1.79 ±0.14	1.26 ±0.31	4	1.98	100.35 (85.98-121.72)	4	2.15	1.75 ±0.15	1.50 ±0.33
	R. officinalis	88.2 (66.6-112.24)	1.76 ±0.28	1.57±0.63	4	3.10	82.44 (70.06-109.2)	4	3.84	1.89 ±0.24	1.43 ±0.54
	O.compactum	112.77 (89.5-135.7)	2.36± 0.24	0.16±0.54	4	2.92	96.85 (81.45-140.16)	4	3.8	2.38 ±0.27	0.28±0.61
	Chemical acaricide	34.07 (25.10-50.23)	1.49± 0.29	2.72±0.62	4	4.49	29.15 (17.43-29.65)	4	4.95	1.47 ±0.27	2.84±0.57

2.3 Toxicity of the EOs and the acaricide on *Tetranychus urticae* and *Eutetranychus orientalis*

As shown in Fig-35. The four binary mixtures exhibited an important acaricidal effect on both *Tetranychus urticae and E. orientalis* after 24h and 48h of treatment. A significant difference ($p < 0.05$) was indicated in the mortality percentage of *T. urticae* between the *M. pulegium* EO+ chemical acaricide (acequinocyl), *L, stoechas* EO+ chemical acaricide (acequinocyl), and *O. compactum* EO+ chemical acaricide (acequinocyl (p=0.014), while no significant difference was identified between *M. pulegium* EO+ chemical acaricide (acequinocyl) and *R. officinalis* EO+ chemical acaricide (acequinocyl) *(*p=0.031). No significant difference ($p > 0.05$) was identified between *M. pulegium* EO+ chemical acaricide (acequinocyl), *R. officinalis* EO+ chemical acaricide (acequinocyl), and *O. compactum* EO+ chemical acaricide (acequinocyl) (p=1.00), whereas a significant difference ($p < 0.05$) was found between *L, stoechas* EO+ chemical acaricide (acequinocyl) and the three mixtures in terms of the mortality percentage of *Eutetranychus orientalis* (p=0.544). There was no significant in the mortality time of the four Eos and acaricide in terms of *Tetranychus urticae* and *Eutetranychus orientalis* (p=0.115). The binary combination (*M. pulegium* EO+ chemical acaricide*)* and (*O.compactum* EO+ chemical acaricide) exerted a high acaricidal effect against *Tetranychus urticae* with 92±2.74-99±2.23% at 24h and 95±3.54-100±0.00% of mortalities, respectively. However, the mixtures (*M. pulegium* EO+ chemical acaricide, *R. officinalis* EO+ chemical acaricide, and *O.compactum* EO+ chemical acaricide) were the most effective on spider mites adults of *E. orientalis* with 99±2.24% at 24h and 100±0.00% at 48h of mortality. These results are very relevant and proved the acaricidal potential of EOs if they compared of the individual one.

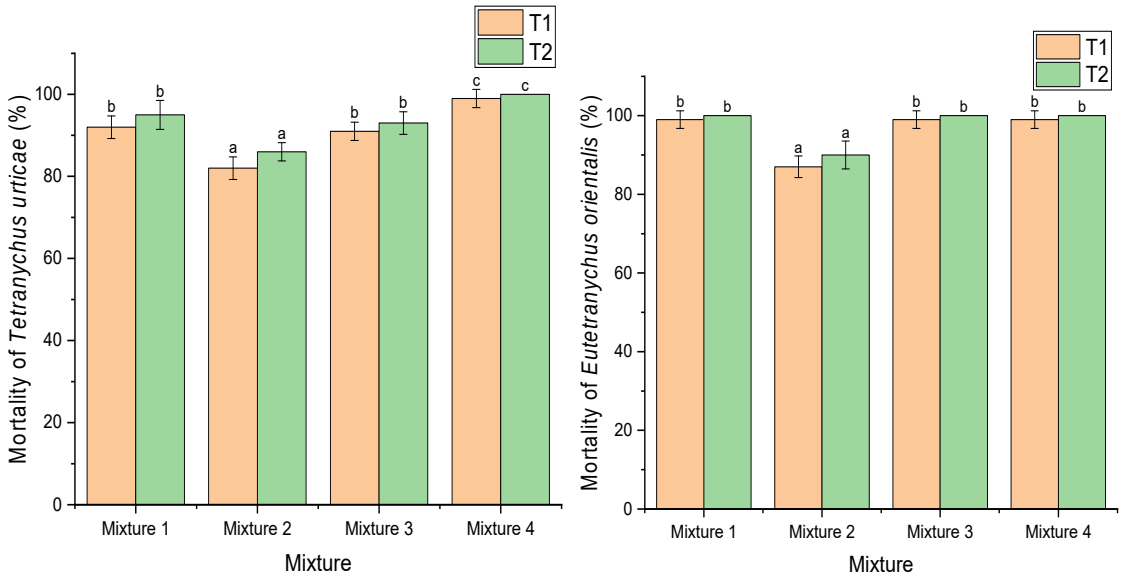


Figure 35. Mortality rate (%) of *Tetranychus urticae* adults according to various binary mixture of Eos and acaricide. (b) Mortality rate (%) of *Eutetranychus orientalis* adults according to various binary mixture of Eos and acaricide. Mixture 1: *M. pulegium* EO+acaricide; Mixture 2: *L. stoechas* EO+acaricide; Mixture 3: *R. officinalis* EO+acaricide; Mixture 4: *O.compactum* EO+acaricide. T1: 24h; T2: 48h. Different letters indicate significant differences according to Tukey's test ($p \leq 0.05$).

2.4 Principal component analysis

2.4.1 The effect of the main compounds of the four tested Eos and the their acaricidal activity

The first Principal component analysis (PCA) allowed identifying the existence of correlations (positive and negative) between the major compounds of the four essential oils and the acaricidal activity against *E. orientalis* and *T. urticae* in 24 hours and 48 hours. The correlations of the different parameters studied is shown in a correlation matrix (Table 22).

The loading plot (Fig 36 (a)) and the correlation matrix (Table 25) revealed some correlation between the variables studied. A strong positive correlation (>0.7) between (a) α-pinene and LD 50 of T.urticae, (b) 1,8- cineole and LD 50 of *T.urticae*, and (c) Borneol and LD 50 of *T.urticae*,. A medium positive correlation (0.6-0.5) between fenchone and LD 50 of *E.Orientalis*. A strong negative correlation (>-0.7) between (a) dihydrocarvone and LD 50 *E.Orientalis*, (b) r(+)-pulegone and LD 50 *E.Orientalis*, and (c) carvone and LD 50 of E.Orientalis. That means that when the amount of 1,8-cineole, α-pinene, and borneol compounds increased with increased the LD 50 of *T.urticae*, and when the LD 50 of *E. Orientalis* was low, the amount of dihydrocarvone, r(+)-pulegone, and carvone were important. The biplot (Fig 36 (b)) showed that essential oils of *L. stoechas* and *R. officinalis* are dominated by the highest amount of 1,8-cineole, α-pinene, borneol and fenchone compounds and they require a high concentration to eliminate *E. Orientalis*. However, *O. compatum* essential oil is

presented by high amount of thymol and α-terpinene compounds. The *M. pulegium* was characterized by having the highest amount of r(+)-pulegone and carvone compounds and they require a lowest concentration to eliminate *E. Orientalis.*

Based to the result from Fig 36 (a,b), it can be concluded that *M. pulegium* essential oil exhibited the best acaricide activity of the four essential oils. In fact, this can be explained by a high amount of r(+)-pulegone and carvone compounds in *M. pulegium* essential oil (74,03 and 5,45 %, respectively) compared to *L. stoechas*, *R. officinalis* and *O. compatum* (the absence of these compounds), but the contributions of others compounds should also be noted. The effect of synergy could also be the origin of this activity.

Table 25. Correlation matrix between the main compounds of the four essential oils and LD50 of *E.Orientalis* and *T.urticae*

	α-pinene	Camphene	α-Terpinene	p-Cymene	1,8-cineole	γ-Terpinene	Fenchone	Camphor	Borneol	Dihydrocarvone	R(+)-pulegone	Carvone	Thymol	Carvacrol	LD $_{50}$ *E.Orientalis*	LD $_{50}$ *T.urticae*
α-pinene	1	0.39	-0.28	-0.28	0.99	-0.28	-0.21	0.4	0.92	-0.5	-0.5	-0.51	-0.28	-0.28	0.02	0.99
Camphene	0.39	1	-0.55	-0.53	0.32	-0.53	0.81	1	0.72	-0.55	-0.55	-0.53	-0.55	-0.55	0.52	0.49
α-Terpinene	-0.28	-0.55	1	1	-0.35	1	-0.33	-0.54	-0.47	-0.33	-0.33	-0.34	1	1	0.42	-0.27
p-Cymene	-0.28	-0.53	1	1	-0.36	1	-0.31	-0.53	-0.46	-0.35	-0.35	-0.36	1	1	0.44	-0.27
1,8- cineole	0.99	0.32	-0.35	-0.36	1	-0.36	-0.29	0.33	0.88	-0.35	-0.35	-0.36	-0.35	-0.35	-0.14	0.96
γ-Terpinene	-0.28	-0.53	1	1	-0.36	1	-0.32	-0.53	-0.47	-0.34	-0.34	-0.35	1	1	0.44	-0.27
Fenchone	-0.21	0.81	-0.33	-0.31	-0.29	-0.32	1	0.81	0.19	-0.33	-0.33	-0.31	-0.33	-0.33	0.61	-0.09
Camphor	0.4	1	-0.54	-0.53	0.33	-0.53	0.81	1	0.73	-0.55	-0.55	-0.53	-0.54	-0.54	0.52	0.5
Borneol	0.92	0.72	-0.47	-0.46	0.88	-0.47	0.19	0.73	1	-0.58	-0.58	-0.58	-0.47	-0.47	0.21	0.95
Dihydrocarvone	-0.5	-0.55	-0.33	-0.35	-0.35	-0.34	-0.33	-0.55	-0.58	1	1	1	-0.33	-0.33	-0.87	-0.59
R(+)-pulegone	-0.5	-0.55	-0.33	-0.35	-0.35	-0.34	-0.33	-0.55	-0.58	1	1	1	-0.33	-0.33	-0.87	-0.59
Carvone	-0.51	-0.53	-0.34	-0.36	-0.36	-0.35	-0.31	-0.53	-0.58	1	1	1	-0.34	-0.34	-0.86	-0.6
Thymol	-0.28	-0.55	1	1	-0.35	1	-0.33	-0.54	-0.47	-0.33	-0.33	-0.34	1	1	0.42	-0.27
Carvacrol	-0.28	-0.55	1	1	-0.35	1	-0.33	-0.54	-0.47	-0.33	-0.33	-0.34	1	1	0.42	-0.27
LD $_{50}$ *E.Orientalis*	0.02	0.52	0.42	0.44	-0.14	0.44	0.61	0.52	0.21	-0.87	-0.87	-0.86	0.42	0.42	1	0.14
LD $_{50}$ *T.urticae*	0.99	0.49	-0.27	-0.27	0.96	-0.27	-0.09	0.5	0.95	-0.59	-0.59	-0.6	-0.27	-0.27	0.14	1

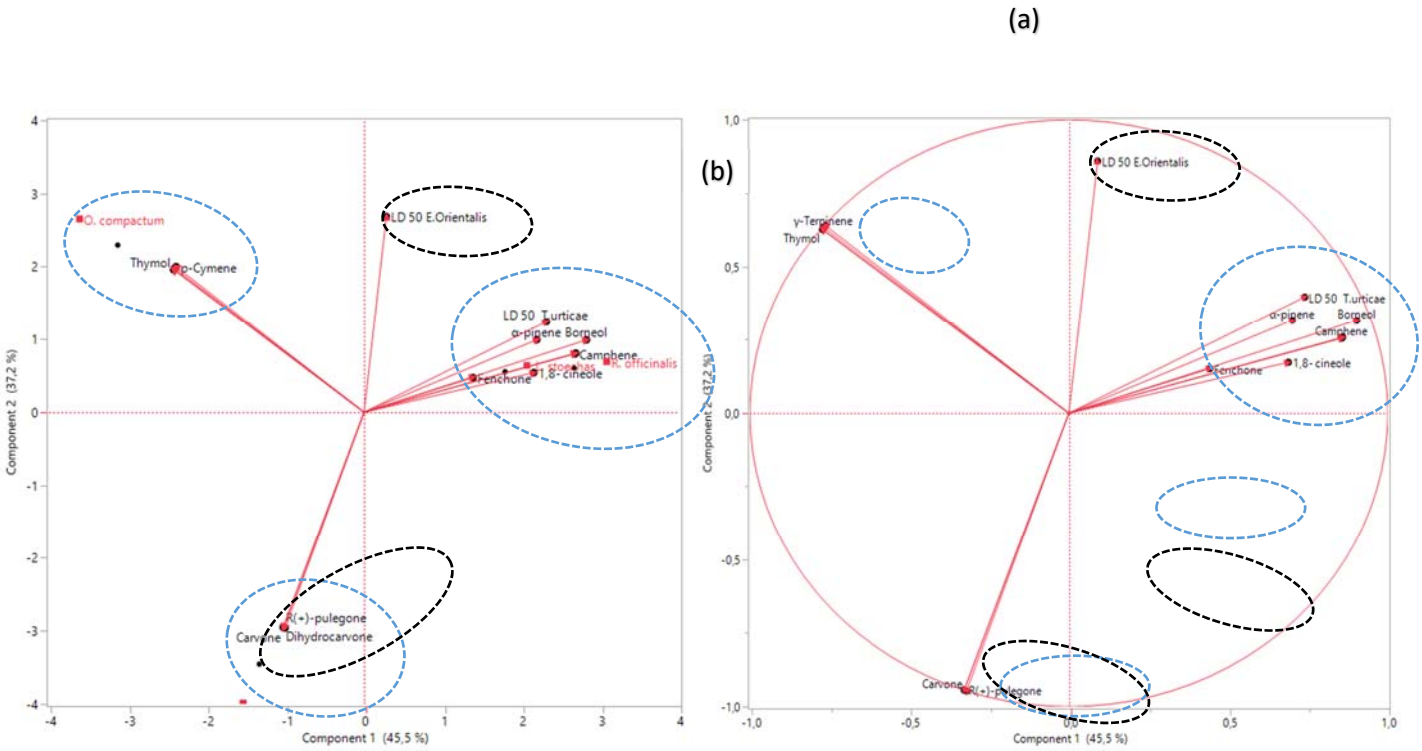


Figure 36. Principal component analyses of the main compounds in regards to the four essential oils. (a): Loading plot of the projection of the variables (main compounds) on the first and second principal components; (b): Biplot of the projection of the variables on the individuals (the four essential oils) on the first and second principal components.

2.5 The effect of the concentrations of the four tested Eos and their acaricidal activity

The second PCA permeated to identify the similar acaricidal activity effect of essential oil and concentration, the first principal component analysis was carried out. The individuals are represented by four essential oil samples (*M.pulegium*, *L. stoechas*, *O. compactum* and *R. officinalis*) in five different concentrations (C1, C2, C3, C4, and C5). The variables are represented by acaricidal activity against *E. orientalis* and *T. urticae* in 24 hours and 48 hours.

The biplot (Fig 37 (a)) demonstrated that the distribution of individuals (concentration) in accordance with PC1 and PC2 shows that individuals were separated into three main groups. These results indicated that the concentration has an effect on the acaricidal activity, as previously shown by ANOVA. The first group is consisted of C1 (39.06 µl/ml) and C2 (78.125 µl/ml), or the low concentration. The second group is composed of C4 (312.5 µl/ml) and C5 (625 µl/ml), or the high concentration. The third groups were C3 (156.25 µl/ml), or the medium concentration. This graph indicated that when the concentration was high, the acaricidal activity against *E. orientalis* and *T. urticae* was elevated, and when the concentration was low, the acaricidal activity against *E. orientalis* and *T. urticae* was decreased. The biplot (Fig 37 (b)) showed that the acaricidal activity against *E. orientalis* and *T. urticae* improved when the *M.pulegium* essential oil was used. In contrast, the *L. stoechas* and *O. compactum* essential oils

revealed a medium acaricidal activity against *T. urticae*. In addition, the *R. officinalis* showed a medium acaricidal activity against *E. orientalis*.

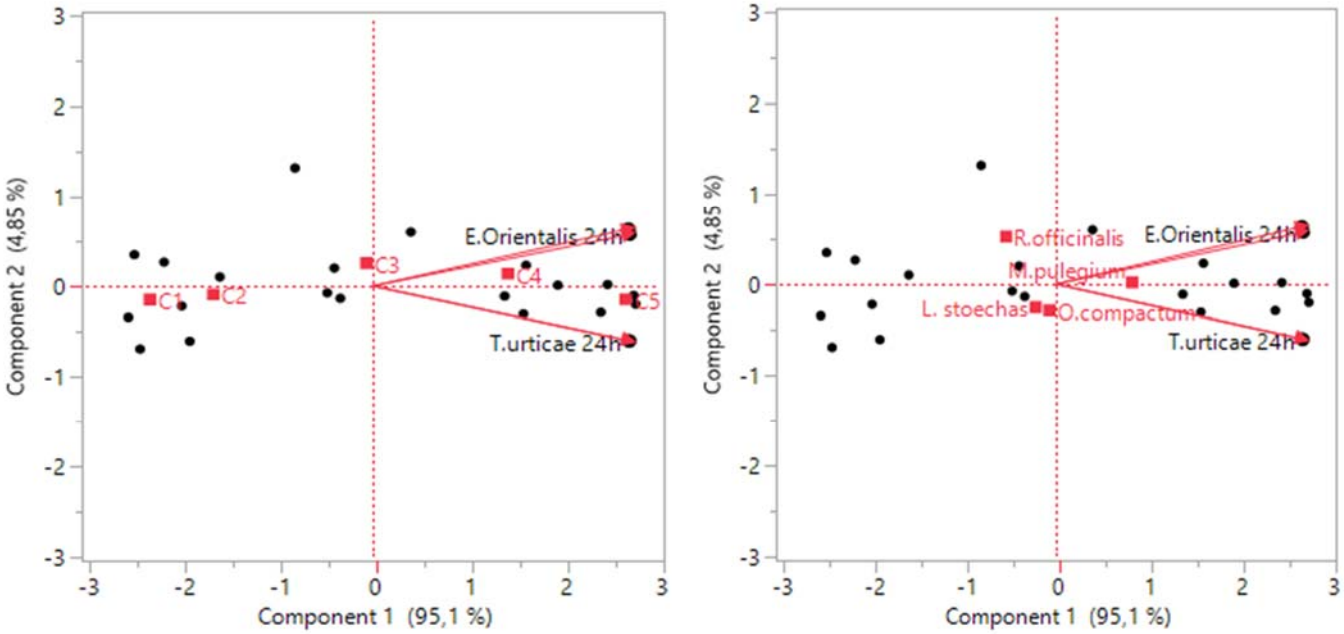
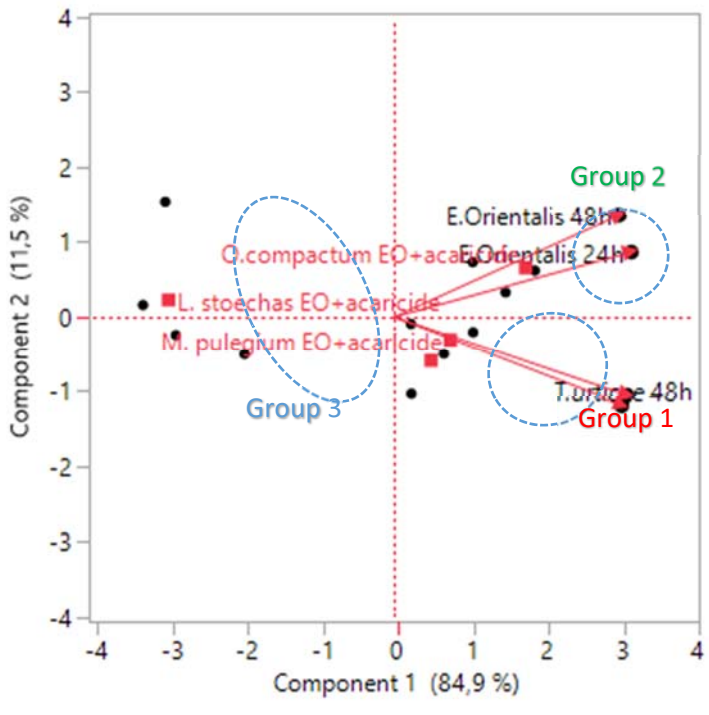


Figure 37. Principal component analyses of acaricidal activity against *E. orientalis* and *T. urticae* adults in regards to the four essential oils and concentrations. (a): Biplot of the projection of the variables and the individuals according to concentrations on the first and second principal components; (b): Biplot of the projection of the variables and the individuals according to essential oils on the first and second principal components

2.6 The effect of the four mixture between acaricide and tested Eos and their acaricidal activity

The third PCA was enabled to determine the similar mixtures that have the same acaricidal activity between the four mixtures studied (*M. pulegium* EO + acaricide, *R. officinalis* EO + acaricide, *O. compactum* EO + acaricide and *L. stoechas* EO + acaricide).

The biplot (Fig 38) illustrated that the individuals (mixtures) divided in to 3 main groups. The first group was the mixture of *M. pulegium* EO + acaricide and *R. officinalis* EO + acaricide. The second group was the mixture of *O. compactum* EO + acaricide. The third group was *L. stoechas* EO + acaricide. The mixture of (a) *M. pulegium* EO + acaricide and (b) *R. officinalis* EO + acaricide showed the same acaricidal activity, a medium effect against the *T. urticae* and a low effect against *E. orientalis*. This graph also indicated that the acaricidal activity has been improved with the mixture of *O. compactum* EO + acaricide (synergetic effect), while the mixture of *L. stoechas* EO + acaricide presented a low acaricidal activity against the *E. orientalis* and *T. urticae* (antagonistic effect).



C

Figure 38. Biplot of the projection of the acaricidal activity against *T.urticae* and *E. orientalis* adults and the four mixtures on the first and second principal components.

2.7 The Hierarchical Cluster Analysis

The Hierarchical Cluster Analysis (HCA) allowed us to better classificates the studied samples (the four essential oils) according to the acaricidal activity against the *E. orientalis* and *T. urticae* (Fig 39). As a confirmations of the third PCA, the individuals were divided into three main clusters: cluster 1 (*M. pullegium* EO +acaricide and *R. officinalis* EO +acaricide) characterized by a high acaricidal activity against *T. urticae*, while it was characterized by a low acaricidal activity against the *E. orientalis*. However, cluster 2 (*O. compactum* EO +acaricide) was characterized by a high acaricidal activity against the *E. orientalis* and *T. urticae*. The cluster 3 (*L. stoechas* EO +acaricide), was featured by a low acaricidal activity against the *E. orientalis* and *T. urticae*. Both the PCA and HCA concluded that the acaricidal activity against the *E. orientalis* and *T. urticae* were significantly influenced by adding the acaricide in essential oils. A synyrgetic effect with *O. compactum* EO +acaricide and an antagonistic effect with *L. stoechas* EO +acaricide.

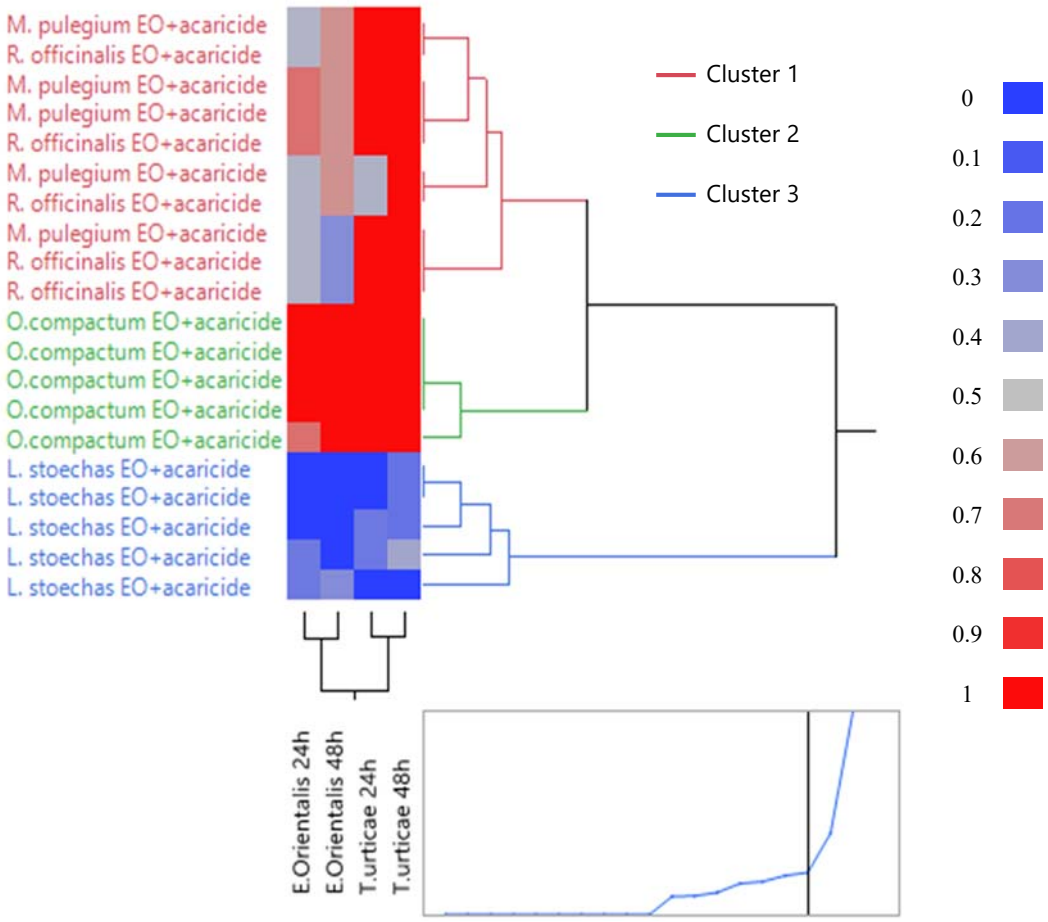


Figure 39. Hierarchical cluster analysis of the four mixtures against *E. orientalis* and *T. urticae* adults.

3 Discussion

In the commercial orchards, the protection against pests is currently assured by intensive and preventive chemical product. Despite advantages such as rapid action in reducing the number of pests and their ease of use compared to natural plant extracts. [20], this strategy has many limitations; the examination of the action spectrum of the active components used throughout the world reveals that 46% of acaricides, are globally toxic towards auxiliary arthropods and public health [1,28]. The extracts of plants are remarkably rich in toxins and inhibitors and can be the source of many insecticidal and acaricidal substances exploitable in the control of pests [29,30]. On the contrary, the problem of volatility and the high cost causes several limitations of their usage [31], The essential oils lose their force against environmental conditions. Nanoformulation is a method that may preserve the pesticide performance of plant essential oils [31,32].

Phytochemical products are environmentally friendly, target-specificity, decreased the number of applications, higher acceptability, suitability for rural areas, low cost, biodegradable, easy preparation, and universally accepted. Botanicals are used as an alternative to synthetic acaricides and have been projected as a tool in the future for spider mites control agents, which are shown to function as highly polyphagous herbivore and primary agricultural pests in the world that provokes hard damage to crops.

In this study, *Mentha pulegium, Lavandula stoechas, Rosmarinus officinalis, and Origanum compactum* (Lamiaceae family) EOs showed an acaricidal potential towards adults of the two crop pests, *Tetranychus urticae* and *Eutetranychus orientalis*. Indeed, the mortality varied according to the EO tested, the concentrations used, and the mite species.

R. officinalis was often effective against agricultural crop pests including tetranychid mites [22,33]. The essential oil of *R. officinalis* and mixtures of its main constituents gave good results in the control of *T. urticae* Koch, on bean and tomato plants [34].

Thymol, a hydrophobic compound, constitutes the major monoterpene in *O. compactum*; it can penetrate the compartment membrane, which diminishes its impermeability, this mechanism stimulates the entry of other components into the cytoplasm [35,36]. There is also evidence in the literature that thymol and eugenol have a neurotoxic effect on arthropods, with different mechanisms of action. Thymol can bind to GABA receptors located in the membrane of post-synaptic neurons and disrupt the functioning of synapses [37], under laboratory conditions. A study shows that the essential oils of *O. compactum* is often toxic against *R. dominica* and *Sitophilus oryzae* Linnaeus, 1763 [38]. This was confirmed in our study against *T. urticae* and *E. orientalis. O. compactum* significantly inhibited oviposition of *T. urticae;* it was also toxic to females of this pest. Inhibition of fecundity exceeding 80% [39]. The essential oil of *M. pulegium* was very toxic against the strawberry spider mite *Tetranychus turkestani* Ugarov and Nikolskii, 1937 (Acari: Tetranychidae) [19]. The same results in another study were observed on *T. urticae*, a serious pest of many agricultural crops. The phytotoxicity of *M. pulegium* was significant against this pest after 24 hours [40,41].

The statistical analysis (first PCA) permed to conclude that the acaricidal activity depends to the major compounds of the essential oils tested. A strong correlation was identified between the LD50, dihydrocarvone and carvone. Thus, when the quantity of dihydrocarvone and carvone increased, the acaricidal activity increased. Several studies reported that the principal compound present in the essential oils of thyme and oregano increase (thujone 65.78% and carvone 59.35%) the acaricidal activities against spider mite *Tetranychus cinnabarinus* Boisd is more important [42]. Other study Twenty eight monoterpenes including monoterpene

hydrocarbons and oxygenated monoterpenes (camphor, 3-carene, carvone, 1,8-cineole, citronellal, β-citronellene, dihydrocarvone, α-terpineol) of essential oils obtained from different plant species were tested against adults of *Sitophilus zeamais* Motschulsky under laboratory conditions. The results show that most of the monoterpenes with high concentration have significantly insecticidal and acaricidal effect on the tested pests [43,44].

The second PCA showed that *M. pulegium* was found to be more effective, followed by *O. compactum* EO and *L. stoechas*. EOs acquired from multiple plants have already been tested for their potential fumigant toward pests species (Choi et al., 2006) [42]. As an example, [45] examined the fumigant toxicity of *L. stoechas* EOs against three spider mites pests attacking stored products (*Lasioderma serricorne* Fabricius 1792, *Rhyzopertha dominica* Fabricius 1792, and *Tribolium castaneum* Herbst, 1797), the findings of this analysis showed that this EO had strong acaricidal properties with the high rates of mortality were obtained after 24 h and 48h of fumigation. *L. stoechas* was also tested for its acaricidal action against *Tetranychus cinnabarinus* Koch, 1836, one of the most important pests, the registered LC50 and LC90 values were in the range of 2.92 µg/ ml and 13.0 µg/ml, respectively [42]. [35] Also recorded an effective acaricidal effect of *L. stoechas* against *Orgyia trigotephras* Boisduval, 1828 (Lepidoptera, Lymantriidae).

The third PCA and HCA illustrated that the activity of *O. compactum* EO has been ameliorated when it mixed with the acaricide (synergetic effect). The *R. officinalis and M. pulegium* remains has the same activity when they mixed with the acaricide. However, the activity of *L. stoechas* reduced when it mixed with the acaricide (antagonistic effect). Several studies confirm that the mixture of several products often triggers an antagonistic effect or a synergistic effect and all depends on the obtained combination [39,46,47]

Moreover, the fumigant toxicity for Eos mixtures with the chemical acaricides revealed encouraging results where the mortality reached more than 95% for both spider mites. The search for synergistic mixtures aims to reduce the concentrations needed by increasing the biological activity against the target organism. This reduction of concentration may also result in decreased toxicological and environmental risks, and lower production cost [48,49].

Conclusions

This scientific investigation highlighted the acaricidal effect of four essential oils against two important spider mites involved in agriculture damage. The obtained results proved the acaricidal potential of the tested oils and showed the efficacy of the binary mixtures with an acaricidal product reaching the mortality to 100%. These plant-based natural products can be

applied in large field application using low concentrations (based on the LD_{50} values) and minimizing the production cost; they since could be involved in pest management programs as a new tool that could solve pest problems reducing risks to humans and the environment. Their inclusion in an integrated pest management program can contribute greatly to the achievement of the acaricide reduction objectives set by several countries and organizations. In this context, responsible agricultural organizations should actively support the development and implementation of essential in integrated pest protection programs. Further studies are needed to test the toxicity of these natural products.

Acknowledgments: Authors are thankful to Researchers Supporting Project Number (RSP/2021/45), at King Saud University Riyadh, Saudi Arabia for financial support.

Data Availability Statement: All related data are within the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Assouguem, A.; Kara, M.; Mechchate, H.; Korkmaz, Y.B.; Benmessaoud, S.; Ramzi, A.; Abdullah, K.R.; Noman, O.M.; Farah, A.; Lazraq, A. Current Situation of *Tetranychus urticae* (Acari: Tetranychidae) in Northern Africa: The Sustainable Control Methods and Priorities for Future Research. *Sustainability* **2022**, *14*, 2395, doi:10.3390/su14042395.

2. Afzal, M.; Ullah, M.I.; Bashir, M.H.; Mukhtar, S.N.; Arshad, M.; Altaf, N. Diversity and Abundance of Mite Species in Citrus Orchards of Sargodha, Pakistan. *Punjab Univ. J. Zool.* **2021**, *36*, 37–46, doi:10.17582/JOURNAL.PUJZ/2021.36.1.37.46.

3. Ferragut, F.; Navia, D.; Ochoa, R. New mite invasions in citrus in the early years of the 21st century. *Exp. Appl. Acarol.* **2013**, *59*, 145–164, doi:10.1007/s10493-012-9635-9.

4. Mazih, A. Status of citrus IPM in the southern mediterranean basin Morocco, North Africa. *Acta Hortic.* **2015**, *1065*, 1097–1104, doi:10.17660/ActaHortic.2015.1065.138.

5. Smaili, M.C.; Boutaleb-Joutei, A.; Blenzar, A. Beneficial insect community of Moroccan citrus groves: assessment of their potential to enhance biocontrol services. *Egypt. J. Biol. Pest Control* 2020, *30*.

6. Assouguem, A.; Farah, A.; Ullah, R.; Korkmaz, Y.B.; Almeer, R.; Sayed, A.A.; Najda, A.; Lazraq, A. Evaluation of the Varietal Impact of Two Citrus Species on Fluctuations of *Tetranychus urticae* (Acari : Tetranychidae) and Beneficial Phytoseiid Mites. **2022**.

7. Assouguem, A.; Kara, M.; Mechchate, H.; Al-Mekhlafi, F.A.; Nasr, F.; Farah, A.; Lazraq, A. Evaluation of the Impact of Different Management Methods on *Tetranychus urticae* (Acari: Tetranychidae) and Their Predators in Citrus Orchards. *Plants* **2022**, *11*, 623, doi:10.3390/PLANTS11050623.

8. Sato, M.E.; Silva, M.Z. da; Raga, A.; Souza Filho, M.F. de Abamectin resistance in *Tetranychus urticae* Koch (Acari: Tetranychidae): selection, cross-resistance and stability of resistance. *Neotrop. Entomol.* **2005**, *34*, 991–998, doi:10.1590/s1519-566x2005000600016.

9. Xue, W.; Snoeck, S.; Njiru, C.; Inak, E.; Dermauw, W.; Van Leeuwen, T. Geographical distribution and molecular insights into abamectin and milbemectin cross-resistance in European field populations of *Tetranychus urticae*. *Pest Manag. Sci.* **2020**, *76*, 2569–2581, doi:10.1002/ps.5831.

10. Smaili, Mc Current pest status and the integrated... - Google Scholar Available online: https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Smaili+MC+%282017%29+Current+pest+status+and+

the+integrated+pest+management+strategy+in+the+citrus+groves+in+Morocco.+In%3A+Abstracts+of+the+IOBC+citrus+working+group+meeting+on+citrus+pests%2C+disea (accessed on Jul 10, 2021).

11. Wang, Z.; Cang, T.; Wu, S.; Wang, X.; Qi, P.; Wang, X.; Zhao, X. Screening for suitable chemical acaricides against two-spotted spider mites, *Tetranychus urticae*, on greenhouse strawberries in China. *Ecotoxicol. Environ. Saf.* **2018**, *163*, 63–68, doi:10.1016/j.ecoenv.2018.07.058.

12. İçli, N.; Tahmas Kahyaoğlu, D. Investigation of pesticide residues in fresh sultani grapes and antioxidant properties of fresh/sun-dried/oven-dried grapes. *Turkish J. Agric. For.* **2020**, *44*, 350–360, doi:10.3906/tar-1904-49.

13. Takafuji, A.; Ozawa, A.; Nemoto, H.; Gotoh, T. Spider mites of Japan: Their biology and control. *Exp. Appl. Acarol.* **2000**, *24*, 319–335, doi:10.1023/a:1006453209154.

14. Lynn, D.; Data, R.U.S.A.; Robinson, P.E.J. Miticidal and aphicidal method utilizing 2-higher alkyl-3-hydroxy-1,4-naphthoqui none carboxylc acd esters. **1977**, 2–9.

15. Salman, S.Y.; Sarıtaş, E. Acequinocyl resistance in *Tetranychus urticae* Koch (Acari: Tetranychidae): inheritance, synergists, cross-resistance and biochemical resistance mechanisms. *http://dx.doi.org/10.1080/01647954.2014.944932* **2014**, *40*, 428–435, doi:10.1080/01647954.2014.944932.

16. Koura, Y.; Kinoshita, S.; Takasuka, K.; Koura, S.; Osaki, N.; Matsumoto, S.; Miyoshi, H. Respiratory inhibition of acaricide AKD-2023 and its deacetyl metabolite. *J. Pestic. Sci.* **1998**, *23*, 18–21, doi:10.1584/jpestics.23.18.

17. Raut, J.S.; Karuppayil, S.M. A status review on the medicinal properties of essential oils. *Ind. Crops Prod.* **2014**, *62*, 250–264, doi:10.1016/J.INDCROP.2014.05.055.

18. Faria, J.M.S.; Rodrigues, A.M. Essential Oils as Potential Biopesticides in the Control of the Genus Meloidogyne: A Review †. **2021**, doi:10.3390/IECAG2021-09687.

19. Zandi-Sohani, N.; Ramezani, L. Evaluation of five essential oils as botanical acaricides against the strawberry spider mite *Tetranychus turkestani* Ugarov and Nikolskii. *Int. Biodeterior. Biodegradation* **2015**, *98*, 101–106, doi:10.1016/J.IBIOD.2014.12.007.

20. Attia, S.; Grissa, K.L.; Lognay, G.; Bitume, E.; Hance, T.; Mailleux, A.C. A review of the major biological approaches to control the worldwide pest *Tetranychus urticae* (Acari: Tetranychidae) with special reference to natural pesticides: Biological approaches to control Tetranychus urticae. *J. Pest Sci. (2004).* **2013**, *86*, 361–386, doi:10.1007/s10340-013-0503-0.

21. Aziz, M.A., Adnan, M., Khan, A.H., Shahat, A.A., Al-Said, M.S. and Ullah, R., 2018. Traditional uses of medicinal plants practiced by the indigenous communities at Mohmand Agency, FATA, Pakistan. *Journal of ethnobiology and ethnomedicine*, *14*(1), pp.1-16.

22 Ullah, R., Alqahtani, A.S., Noman, O.M., Alqahtani, A.M., Ibenmoussa, S. and Bourhia, M., 2020. A review on ethno-medicinal plants used in traditional medicine in the Kingdom of Saudi Arabia. *Saudi Journal of Biological Sciences*, *27*(10), pp.2706-2718.

23. Mohammadhosseini, M.; Venditti, A.; Mahdavi, B. Characterization of essential oils and volatiles from the aerial parts of *Mentha pulegium* L. (Lamiaceae) using microwave-assisted hydrodistillation (MAHD) and headspace solid phase microextraction (HS-SPME) in combination with GC-MS. *https://doi.org/10.1080/14786419.2021.1960523* **2021**, doi:10.1080/14786419.2021.1960523.

24. Hassanpour, H.; Khavari-Nejad, R.A.; Niknam, V.; Razavi, K.; Najafi, F. Effect of penconazole and drought stress on the essential oil composition and gene expression of *Mentha pulegium* L. (Lamiaceae) at flowering stage. *Acta Physiol. Plant. 2014 365* **2014**, *36*, 1167–1175, doi:10.1007/S11738-014-1492-1.

25. Hanana, M.; Mansour, B.; Algabr, M.; Amri, I.; Gargouri, S.; Romane, A.; Jamoussi, B.; Hamrouni, L. Potential Use of Essential oils from Four Tunisian Species of Lamiaceae: Biological Alternative for Fungal and Weed Control. *Nat. Prod* **2017**, *11*, 258–269.

26. Bourhia, M., Laasri, F.E., Aourik, H., Boukhris, A., Ullah, R., Bari, A., Ali, S.S., El Mzibri, M., Benbacer, L. and Gmouh, S., 2019. Antioxidant and antiproliferative activities of bioactive compounds contained in Rosmarinus officinalis used in the Mediterranean diet. *Evidence-Based Complementary and Alternative Medicine*, *2019*.

27. Assouguem, A.; Kara, M.; Mechchate., H.; Alzain, M.N.; Noman, O.M.; Imtara, H.; Hano, C.; Ibrahim, M.N.; Benmessaoud, S.; Farah, A.; et al. Evaluation of the Effect of Different Concentrations of Spirotetramat on the Diaspine Scale Parlatoria ziziphi in Citrus Orchards. *Agronomy* **2021**, *11*, 1–11, doi:10.3390/agronomy11081562.

28. Vicente, C.; Boutaleb, A.; Lebrun, P. Quelles stratégies de lutte contre les acariens ravageurs du pommier au Maroc.

Parasitica **2003**, *59*, 25–41.

29. Isman, M.B.; Wan, A.J.; Passreiter, C.M. Insecticidal activity of essential oils to the tobacco cutworm, *Spodoptera litura*. *Fitoterapia* **2001**, *72*, 65–68, doi:10.1016/S0367-326X(00)00253-7.

30. Abdelgaleil, S.A.M.; Badawy, M.E.I.; Mahmoud, N.F.; Marei, A.E.S.M. Acaricidal activity, biochemical effects and molecular docking of some monoterpenes against two-spotted spider mite (Tetranychus urticae Koch). *Pestic. Biochem. Physiol.* **2019**, *156*, 105–115, doi:10.1016/j.pestbp.2019.02.006.

31. Negahban, M. ; Moharramipour, S. ; Zandi, M. ; Hashemi, S.A. Efficiency of nanoencapsulated essential oil of Artemisia sieberi Besser on nutritional indices of *Plutella xylostella.* Available online: https://www.cabdirect.org/cabdirect/abstract/20143373422 (accessed on Jul 17, 2022).

32. Taban, A.; Saharkhiz, M.J.; Khorram, M. Formulation and assessment of nano-encapsulated bioherbicides based on biopolymers and essential oil. *Ind. Crops Prod.* **2020**, *149*, 112348, doi:10.1016/J.INDCROP.2020.112348.

33. Jahanian, H.; Kahkeshani, N.; Sanei-Dehkordi, A.; Isman, M.B.; Saeedi, M.; Khanavi, M. secticidRosmarinus officinalis as a natural ine: a review. *https://doi.org/10.1080/09670874.2022.2046889* **2022**, 1–46, doi:10.1080/09670874.2022.2046889.

34. Miresmailli, S.; Bradbury, R.; Isman, M.B. Comparative toxicity of Rosmarinus officinalis L. essential oil and blends of its major constituents against Tetranychus urticae Koch (Acari: Tetranychidae) on two different host plants. *Pest Manag. Sci.* **2006**, *62*, 366–371, doi:10.1002/ps.1157.

35. Akkari, H.; Ezzine, O.; Dhahri, S.; B'chir, F.; Rekik, M.; Hajaji, S.; Darghouth, M.A.; Jamâa, M.L. Ben; Gharbi, M. Chemical composition, insecticidal and in vitro anthelmintic activities of Ruta chalepensis (Rutaceae) essential oil. *Ind. Crops Prod.* **2015**, *74*, 745–751, doi:10.1016/J.INDCROP.2015.06.008.

36. Ahmad, M.; Benjakul, S.; Prodpran, T.; Agustini, T.W. Physico-mechanical and antimicrobial properties of gelatin film from the skin of unicorn leatherjacket incorporated with essential oils. *Food Hydrocoll.* **2012**, *28*, 189–199, doi:10.1016/J.FOODHYD.2011.12.003.

37. Priestley, C.M.; Williamson, E.M.; Wafford, K.A.; Sattelle, D.B. Thymol, a constituent of thyme essential oil, is a positive allosteric modulator of human GABAA receptors and a homo-oligomeric GABA receptor from Drosophila melanogaster. *Br. J. Pharmacol.* **2003**, *140*, 1363–1372, doi:10.1038/SJ.BJP.0705542.

38. Bounoua-Fraoucene, S.; Kellouche, A.; Debras, J.F. Toxicity of Four Essential Oils against Two Insect Pests of Stored Grains, *Rhyzopertha Dominica* (Coleoptera: Bostrychidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae). *African Entomol.* **2019**, *27*, 344–359, doi:10.4001/003.027.0344.

39. Ramzi, A., El Ouali Lalami, A., Assouguem, A., Almeer, R., Najda, A., Ullah, R., Ercisli, S. and Farah, A., 2022. Insecticidal effect of wild-grown Mentha pulegium and rosmarinus officinalis essential oils and their main monoterpenes against Culex pipiens (Diptera: Culicidae). *Plants*, *11*(9), p.1193.

40. Mozaffari, F.; Abbasipour, H.; Garjan, A.S.; Saboori, A.R.; Mahmoudvand, M. Various effects of ethanolic extract of Mentha pulegium on the two-spotted spider mite, *Tetranychus urticae* (Tetranychidae). *http://dx.doi.org/10.1080/03235408.2012.674708* **2012**, *45*, 1347–1355, doi:10.1080/03235408.2012.674708.

41. Mozaffari, F.; Abbasipour, H.; Garjan, A.S.; Saboori, A.; Mahmoudvand, M. Toxicity and Oviposition Deterrence and Repellency of *Mentha pulegium* (Lamiacaeae) Essential Oils against *Tetranychus urticae* Koch (Teteranychidae). *http://dx.doi.org/10.1080/0972060X.2013.854500* **2013**, *16*, 575–581, doi:10.1080/0972060X.2013.854500.

42. Sertkaya, E.; Kaya, K.; Soylu, S. Acaricidal activities of the essential oils from several medicinal plants against the carmine spider mite (*Tetranychus cinnabarinus* Boisd.) (Acari: Tetranychidae). *Ind. Crops Prod.* **2010**, *31*, 107–112, doi:10.1016/j.indcrop.2009.09.009.

43. Yildirim, E.; Emsen, B.; Kordali, S. Insecticidal effects of monoterpenes on *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *J. Appl. Bot. Food Qual.* **2013**, *86*, 198–204, doi:10.5073/JABFQ.2013.086.027.

44. Yang, X.; Han, H.; Li, B.; Zhang, D.; Zhang, Z.; Xie, Y. Fumigant toxicity and physiological effects of spearmint (Mentha spicata, Lamiaceae) essential oil and its major constituents against Reticulitermes dabieshanensis. *Ind. Crops Prod.* **2021**, *171*, 113894, doi:10.1016/J.INDCROP.2021.113894.

45. Ebadollahi, A.; Safaralizadeh, M.; Pourmirza, A. Fumigant toxicity of lavandula stoechas L. Oil against three insect pests attacking stored products. *J. Plant Prot. Res.* **2010**, *50*, 56–60, doi:10.2478/v10045-010-0010-8.

46. Shezryna, S.; Anisah, N.; Saleh, I.; Syamsa, R.A. Acaricidal activity of the essential oils from citrus hystrix (Rutaceae) and cymbopogon citratus (poaceae) on the cattle tick rhipicephalus (boophilus) microplus larvae (acari: Ixodidae).

Trop. Biomed. **2020**, *37*, 433–442.

47. Jyoti; Singh, N.K.; Singh, H.; Mehta, N.; Rath, S.S. In vitro assessment of synergistic combinations of essential oils against Rhipicephalus (Boophilus) microplus (Acari: Ixodidae). *Exp. Parasitol.* **2019**, *201*, 42–48, doi:10.1016/J.EXPPARA.2019.04.007.

48. Belhoussaine, O., El Kourchi, C., Harhar, H., Bouyahya, A., El Yadini, A., Fozia, F., Alotaibi, A., Ullah, R. and Tabyaoui, M., 2022. Chemical Composition, Antioxidant, Insecticidal Activity, and Comparative Analysis of Essential Oils of Leaves and Fruits of Schinus molle and Schinus terebinthifolius. *Evidence-Based Complementary and Alternative Medicine*, *2022*.

49. Maestre, F.T.; Quero, J.L.; Gotelli, N.J.; Escudero, A.; Ochoa, V.; Delgado-Baquerizo, M.; García-Gómez, M.; Bowker, M.A.; Soliveres, S.; Escolar, C.; et al. Plant species richness and ecosystem multifunctionality in global drylands. *Science (80-.).* **2012**, *335*, 214–218, doi:10.1126/SCIENCE.1215442/SUPPL_FILE/MAESTRE.SOM.PDF.

CONCLUSION ET PERSPECTIVES

La gestion intégrée des ravageurs par le biais d'un prédateur et/ou par les huiles essentielles peut constituer une stratégie alternative à la lutte chimique contre les ravageurs.

Ce travail met en évidence les connaissances actuelles et les perspectives des approches de lutte contre certains insectes ravageurs des agrumes, afin de clarifier la situation actuelle de ces ravageurs et d'inspirer les spécialistes d'autres pays à les combattre. En outre, elle sert de feuille de route aux scientifiques pour développer leurs recherches. En termes de protection des plantes, il ressort des discussions, développées, que la lutte intégrée reste la méthode durable la plus appropriée pour une meilleure protection des cultures.

Pratiquée par la majorité des pays africains, la lutte chimique est la méthode la plus utilisée dans l'agriculture commerciale. Ceci est essentiellement dû à des raisons économiques et techniques. Désormais, les méthodes de lutte doivent être basées sur l'utilisation de bio pesticides, la lutte génétique et la lutte physique dans un programme intégré et durable à long terme. Le développement de la lutte physique offre des possibilités intéressantes comme la lutte mécanique, la lutte thermique, la lutte électromagnétique et la lutte pneumatique. Leur inclusion dans un programme de lutte intégrée contre les ravageurs peut contribuer grandement à l'atteinte des objectifs de réduction des pesticides fixés par plusieurs pays et organisations. Dans ce contexte, les organisations agricoles responsables devraient soutenir activement le développement et la mise en œuvre de méthodes de lutte physique dans les programmes de gestion intégrée des parasites et des plantes. Des modifications génétiques des plantes et des insectes pourraient être effectuées pour améliorer les mécanismes moléculaires qui contrôlent l'interaction plante-insectes, car la compréhension avancée de l'interaction plante-insectes sera un outil de protection efficace. Des avancées sont également attendues en matière de lutte contre les ravageurs grâce à ces développements technologiques en matière d'éclairage.

Par ailleurs, la tendance actuelle est de combiner toutes ces méthodes dans une stratégie de lutte intégrée contre les ravageurs. Ces programmes doivent prendre en compte les conditions climatiques, la phénologie des ravageurs, les taux d'infestation et la vitesse de propagation des ravageurs dans chaque pays. Tous ces éléments sont proposés pour contrôler les nuisibles, respecter l'environnement et la santé publique.

Toute l'étude conduite dans le cadre de ce doctorat a porté sur l'évaluation de l'effet de différentes méthodes de luttes contre certains ravageurs des agrumes. Nos résultats mettent en évidence plusieurs informations clées :

1) Les données indiquent que les doses faibles du produit chimique à base de Spirotétramate étaient efficaces sur différents stades larvaires et femelles des cochenilles diaspines et avaient de même un faible impact sur le parasitoïde A. hispanicus des cochenilles diaspines dans la région du Gharb ;

Aux stades larvaires, l'efficacité des concentrations était variable. T2 (0,755 L/Ha) était efficace contre la larve 1, et T1 (0,625 L/Ha) était efficace sur la larve 2. L'augmentation de la quantité de pesticide appliquée n'a pas augmenté de manière significative le taux d'inhibition observé. De plus, l'objectif principal était d'utiliser la concentration minimale de pesticide nécessaire pour obtenir un contrôle efficace des cochenilles diaspines avec un impact inférieur sur les prédateurs. Cette approche permettra d'utiliser moins de pesticides et d'éviter le développement de la résistance aux pesticides. Par conséquent, moins de résidus devraient rester sur les fruits et dans le sol. En revanche, T1 (0,625 L/Ha) a assuré le plus haut taux de parasitisme pour les trois stades femelles. Par conséquent, la dose de 0,625 L/Ha est suggérée comme étant moins nocive pour l'environnement et les ennemis naturels et la dose la plus adéquate pour inhiber ces cochenilles diaspines

2) la combinaison appropriée de mesures chimiques et d'ennemis naturels réduira la population de cochenilles diaspines ;

3) l'utilisation de petites doses du pesticide réduira l'impact sur l'environnement et la résistance de l'insecte. Étant donné que le Spirotétramate est un pesticide efficace et largement utilisé, d'autres études sur ses effets sur d'autres populations d'ennemis naturels et sur les résidus restant sur les fruits sont nécessaires pour établir des stratégies de gestion adéquate.

4) le savon noir et les deux détergents utilisés peuvent remplacer les pesticides et restent des outils importants de la lutte contre les ravageurs d'agrume s'ils sont utilisés correctement.

5) La pulvérisation répétée de produits écologiques comme le savon noir peut assurer la réduction des niveaux de parasites à long terme,

6) La libération des ennemis naturels peut être assurée après 5 semaines après le traitement avec ces produits puisque leur persistance ne dépasse pas 4 semaines selon nos résultats.

Une autre recherche scientifique réalisée dans les laboratoires a mis en évidence l'effet acaricide de quatre huiles essentielles contre deux importants acariens tetranyques impliqués dans les dommages agricoles *(Tetranychus urticae* et *Eutetranychus orientalis*). Les résultats obtenus ont prouvé le potentiel acaricide des huiles testées et ont montré l'efficacité des mélanges binaires avec un produit acaricide atteignant la mortalité à 100%.

Pour les perspectives, ces produits naturels à base de plantes seront étudiés et appliqués à grande échelle en utilisant les faibles concentrations (basées sur les valeurs de la DL50) que nous avons trouvé dans les études preliminaire dans le chapitre 6, ce qui va nous permettre de minimiser le coût de production, des études approfondues sur les diferentes techniques d'encapsulation des huiles essentielles ont été déjà initiées.

L'incorporation de la nanotechnologie comme moyen de nano-biopesticides va nous permettre de délivrer les huilles essentielles de manière appropriée, c'est-à-dire de manière ciblée, en réduisant l'utilisation indiscriminée des pesticides conventionnels et aussi de les protéger contre les aléats climatiques sévères tels que la lixiviation, l'évaporation, l'hydrolyse photolytique et la dégradation microbienne. Les atouts d'une formulation de biopesticide nanoencapsulé sont des propriétés de libération contrôlées avec une solubilité, une spécificité, une perméabilité et une stabilité accrues. Elles vont nous fournissent des interrupteurs intégrés pour contrôler la libération et la disponibilité ultérieure des huiles essentielles et vont nous permettre de les utiliser efficacement sur une période donnée. Si les esais quand va entamer sur le terrain donnent des résultas interesants, ces Eos pourraient donc être impliquées dans des programmes de gestion des nuisibles comme un nouvel outil qui pourrait résoudre les problèmes de pullulations en réduisant les risques pour les humains et l'environnement. Alors que leur inclusion dans un programme de lutte intégrée peut contribuer grandement à la réalisation des objectifs de réduction des acaricides fixés par plusieurs pays et organisations. Dans ce contexte, les organisations agricoles responsables devraient soutenir activement le développement et la mise en œuvre des huiles essentielles dans les programmes de protection intégrée contre les ravageurs. Ces différentes perspectives pourraient constituer une source d'information particulièrement utile pour améliorer l'aptitude des méthodes de luttes contre les nuisibles dans le futur.