Thiamethoxam seed treatment controls Hessian fly (*Mayetiola destructor* (Say)) on wheat in Morocco

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Abstract

Hessian fly (*Mayetiola destructor* (Say); Diptera: *Cecidomyidae*) is by far the critical insect pest of wheat (*Triticum sp*.) in Morocco. Damage caused by the insect can result in total loss of the crop if high infestations occur on the young stages of the crop. The most commonly practiced and effective management technique to control Hessian fly infestations is through planting of resistant wheat cultivars. However, such means is hindered by the rapid breakdown of resistance, as long as such resistance is controlled by a gene for gene relationship. In order to ensure a good protection of wheat and a long lasting resistance of a given cultivar, a wise and efficient use of agrochemicals is to be furthered. To do so, thiamethoxam seed treatment was evaluated under natural pest infestation in Morocco. The results indicated that thiamethoxam as seed treatment is effective in controlling the infestation of Hessian fly. It reduced the infestation by 78% compared to untreated plots. That is, thiamethoxam seed treatment is a simple, accurate, efficient, and low-cost control technology of of Hessian fly on wheat in Morocco and then should be scaled out and adopted. However, Hessian fly control tactics are more effective and sustainable when used in an integrated pest management (IPM) program.

Key words: Morocco, Wheat, Hessian fly, seed treatment, Thiamethoxam

Le traitement des semences au thiaméthoxame contrôle la mouche de Hesse (*Mayetiola destructor* (Say)) sur le blé au Maroc

Résumé

La mouche de Hesse (*Mayetiola destructor* (Say) ; Diptera : *Cecidomyidae*) est de loin le principal insecte ravageur du blé (*Triticum sp*.) au Maroc. Les dommages causés par l'insecte peuvent entraîner la perte totale de la culture si de fortes infestations se produisent sur les jeunes stades de la culture. La technique de gestion la plus couramment pratiquée et la plus efficace pour contrôler les infestations par la mouche de Hesse est l'utilisation de variétés résistantes. Cependant, de tels moyens sont entravés par la dégradation rapide de la résistance, sachant que cette résistance est contrôlée par une relation gène pour gène. Afin d'assurer une bonne protection du blé et une résistance durable d'une variété donnée, une utilisation judicieuse et efficace des produits agrochimiques doit être encouragée. Pour ce faire, le traitement des semences au thiaméthoxame a été évalué sous infestation naturelle du blé par les ravageurs au Maroc. Les résultats ont indiqué que le thiaméthoxame en tant que traitement des semences est très efficace pour contrôler l'infestation de la mouche de Hesse. Il a réduit l'infestation de 78% par rapport aux parcelles non traitées. Autrement dit, le traitement des semences au thiaméthoxame est une technologie de contrôle simple, durable, précise, efficace, peu coûteuse et respectueuse de l'environnement et devrait donc être vulgarisée et adoptée. Cependant, les tactiques de lutte contre la mouche de Hesse sont plus efficaces et durables lorsqu'elles sont utilisées dans un programme de lutte intégrée contre les ravageurs (IPM).

Mots clés : Maroc, Blé, Mouche de Hesse, traitement des semences, thiaméthoxame.

تتحكم معالجة البذور بمبيد تيامطوكسام (Thiamethoxam) في ذبابة هسه (*Mayetiola Destroyor* (Say)) على القمح في المغرب

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ملخص

ذبابة هسه هي إلى حد بعيد الآفة الحشرية الرئيسية للقمح في المغرب. يمكن أن يؤدي الضرر الذي تسببه الحشرة إلى خسارة كاملة للمحصول في حالة حدوث إصابات عالية في المراحل الصغيرة من المحصول. إن أسلوب الإدارة الأكثر شيوعًا والأكثر فاعلية للسيطرة على تفشي ذبابة هس هو استخدام أصناف قمح مقاومة. لكن هذه الوسائل يعيقها الانهيار السريع للمقاومة، طالما أن هذه المقاومة يتحكم فيها العلاقة الجينية جين من أجل جين. لضمان حماية جيدة للقمح ومقاومة طويلة الأمد لصنف معين، يجب تعزيز الاستخدام الحكيم والفعال للكيماويات الزراعية. للقيام بذلك، تم تقييم فعالية الثيامثوكسام كمعالج لبذورالقمح في ظل الإصابة الطبيعية بالآفات في المغرب. أشارت النتائج إلى أن الثيامثوكسام كمعالجة للبذور فعال للغاية في السيطرة على انتشار ذبابة هس. خفضت الإصابة بنسبة 78٪ مقارنة بالشاهد الغير المعالج. هذا يعني أن معالجة بذورالقمح بالثيامثوكسام هي تقنية بسيطة، مستدامة، دقيقة، فعالة، منخفضة التكلفة وصديقة للبيئة في محاربة ذبابة هسه على القمح في المغرب، ومن ثم يجب توسيع نطاقها واعتمادها. لكن أساليب مكافحة ذبابة هس تكون أكثر فعالية عند استخدامها في برنامج الإدارة المتكاملة للآفات

الكلمات المفتاحية: المغرب، قمح، ذبابة هسه، معالجة البذور، ثيامثوكسام

Introduction

Wheat, one of the most important cereal and commercial crops in Morocco, is attacked by various diseases and insect pests during the growing season. Among these, Hessian fly (HF), *Mayetiola destructor* (Say) (Diptera: *Cecidomyiidae*), is the most serious insect pest and obligate parasite of wheat which threaten the production early in the season, particularly in North Africa, North of Kazakhstan, South Europe and North America (El Bouhssini et al. 2012; Shmid et al., 2018; Bassi et al., 2019). The pest is widely distributed across wheat growing zones of Morocco (Hatchettet al., 1984; Naber et al., 2000; Lhaloui et al., 1992a, 2014 ; Chandrashekhar et al., 2014). Damage caused by the insect can result in total loss of the crop if high infestations occur on the young stages of the crop. In Morocco, grain yield losses have been estimated to 42 and 36% in bread wheat using an insecticide control method, and near isogenic resistant and susceptible lines respectively (Lhaloui et al., 1992a; Amri et al., 1992). Moreover, mean percent grain yield loss due to Hessian fly infestations on mid-season plantings estimated over 3 years in three different regions was 42, 32 and 45% respectively for bread wheat, durum wheat and barley. Economic levels of infestations (20% of tillers infested; Lafever et al., 1980) were observed in 65, 55, and 55% of bread wheat, durum wheat and barley fields, respectively (Lhaloui et al., 1992b). Severe infestations (over 50% tillers infested) were observed in 27, 22 and 23% of bread wheat, durum wheat and barley fields, respectively (Lhaloui et al., 1992b).

The most commonly practiced and effective management technique to control insect and Hessian fly infestations is the use of resistant wheat cultivars (Smith, 2021). However, such means is hindered by the rapid breakdown of resistance as long as it is controlled by a gene for gene relationship (Hatchett and Gallun 1970; Shmid et al., 2018; Lhaloui et al., 2000; Ferrahi, 2004).

To date, 35 HF resistance genes have been characterized and named in wheat and its wild relatives (Li et al. 2015; Tang et al. 2018). Out of the 35 HF resistance genes identified so far, only 11 (H5, H11, H13, H14, H15, H21, H22, H23, H25, H26, and H34) are effective against the Moroccan fly populations (El Bouhssini et al. 2009).
Sixteen Hessian fly biotypes are known to occur in the United States (Ferrahi, 2004; Gaylon et al., 2005). Knowing which biotypes are present in an area can help growers select wheat varieties known to be resistant to those specific biotypes. However, no recent extensive survey has been conducted to determine the biotypes present in Morocco.

The resistance that was identified is of the antibiosis type; plants were not stunted, had normal growth with light green color, and contained dead first instars of Hessian fly at the bases of their stems, which indicates that these larvae died when they started feeding on the plants (antibiosis reaction). Antibiosis is the most desirable form of resistance in the case of host plant resistance to Hessian fly as it is controlled by a gene for gene relationship (Lhaloui et al. 2000; Sadeghi et al., 2021). Injury to susceptible wheat caused by larvae feeding manifests itself in the form of a darker, almost blue-green, foliage color and stunted growth (Whitworth et al. 2009).

Because of the nature of Hessian fly genetics and its ability to develop new more virulent biotypes in wheat (Kosma et al., 2010), we need to stay continuously alerted and ahead of biotype development. In fact, the speed of the rise of new more virulent biotypes depends on the size of the pest population, the number of generations, and acreage on which the resistant cultivar carrying a specific gene has been deployed. The development of these biotypes is even faster if the cultivar carrying the resistance is grown over a large acreage (Lhaloui et al. 2000). Thus, Hessian flies can overcome resistance in wheat just as rust fungi can develop new races to overcome rust resistance in wheat.

In most cases, resistance is based on a single gene present in the variety that must match a gene in the Hessian fly (a gene for gene relationship). Unfortunately, the Hessian fly can overcome host plant resistance mechanisms, resulting in the formation of new strains called biotypes (Kathy et al., 2013). Plant breeders try to stay ahead of the biotypes by producing wheat varieties with different resistance genes. To be effective, wheat varieties must be specifically resistant to the local Hessian fly genotype. In areas with severe Hessian fly problems, the use of resistant and tolerant varieties may not be sufficient to prevent infestations from occurring (Kathy et al., 2013).

However, the most effective approach remains host plant resistance, which is the most practical, environmentally sound, and economical option for HF management. However, the deployment of wheat cultivars with high level of antibiosis to first instars exerts a strong selection pressure on Hessian fly populations, which favors selection of biotypes capable of surviving on resistant wheat (Naber et al. 2003; Ferrahi, 2004; El Bouhssini et al. 2009 and 2021, Kathy et al., 2013; Bassi et al., 2019; Smith, 2021).

Outbreaks of the Hessian fly can cause extensive crop losses. When or where economic infestations may appear is not always predictable and methods for managing the pest should be preventive rather than remedial. Consequently, an Integrated Pest Management program is to be adopted. The two main pillars of such program are the use of resistant cultivars and chemical seed dressing. The IPM may also include anticipated planting dates; destruction of volunteer wheat or ‘green bridges’; plowing or burning of stubble, variety diversification or mixture, crop rotations; sex pheromone traps, biological control and beneficial insects (Berzonsky et al. 2003; Gaylon et al., 2005; Harris et al. 2015).

The most popular choices for seed treatments are neonicotinoids, which are favored due to their long-lasting residuals and low application rates. Neonicotinoid seed treatment options include clothianidin, imidacloprid, and thiamethoxam. When applied at the correct rates, use of systemic insecticidal seed treatments (neonicotinoid treatments) can reduce populations of Hessian flies in early growing season. Clothianidin, Thiamethoxam, or Imidacloprid provide fair to good control of Hessian fly (Kathy et al., 2013). Moreover, Wilde et. (2001) tested the efficacy of three insecticides as seed treatments for control of insect pests on wheat and found that Imidacloprid (Gaucho®) and thiamethoxam (Adage®) were effective in controlling early season (fall) infestations of the greenbug, *Schizaphis graminum* (Rondani), and the Russian wheat aphid, *Diuraphis noxia* (Mordvilko), whilst Fipronil (Regent®) was not effective against these two aphid species (*Schizaphis graminum* and *Diuraphis noxia*). However, they

found that these three compounds effectively controlled fall infestations of Hessian fly, *Mayetiola destructor* (Say).

According to Peng Zhang et al. (2016), wheat seeds treated with Imidacloprid and Clothianidin were effective against wheat aphids throughout the winter wheat growing season and reduced the yield loss under field conditions. Their active ingredients were detected in winter wheat leaves up to 200 days after the sowing. Peng Zhang et al. (2016) concluded that Imidacloprid and Clothianidin seed treatments can be an important component of the integrated management of wheat aphids on winter wheat.

If 20 % of the tillers are infested with Hessian fly maggots or pupae, significant yield losses can be expected. It is the economic level of infestations according to Lafever et al. (1980). For areas that have a history of high Hessian fly populations, or when other management techniques are not optional, for example, use of resistant varieties or delayed planting dates, a seed treatment consisting of Gaucho 600F (imidacloprid) or Cruiser 5FS (thiamethoxam) is recommended (Whaley, 2019). Seed treatments typically provide a 30-day period of control and can be effective against HF (Whaley, 2019). On the whole, seed treatments protect against feeding insects for 1-2 months after planting (Schmid et al., 2018).

According to Gaylon et al. (2005), insecticide seed-treatments control fall infestations of Hessian fly and can be effective against greenbugs in seedling wheat. They reported also that Imidacloprid (Gaucho®) or thiamethoxam (Cruiser®) seed-treatments are both effective at controlling the first fall generation of Hessian fly in early planted wheat.

Hessian fly management tactics such as delayed planting, destruction of volunteer wheat, and insecticides, should be integrated with wheat production practices notably no-till and additional pest management programs to reduce risk of other economically important wheat pests (McCornack et al. 2017; Ryan et al., 2018).

In order to ensure a good protection of wheat and a long lasting resistance of a given cultivar, a wise and efficient use of agrochemicals is to be used. In this regard, thiamethoxam seed treatment was evaluated under natural pest infestation in Morocco.

Materials and Methods

The experiment was carried out at INRA-Meknes experimental station (latitude 33°53' W, longitude 05°33'N, altitude 532 m above sea level) during 2021-2022 cropping season in order to investigate the effect of wheat seed dressing on Hessian fly infestations. The bread wheat cultivar used was Faiza seeded at a rate of 165 kg/ha. A total of five seed treatments were investigated including an untreated control, three fungicide seed treatments and one fungicide-insecticide seed treatment mixture (Celest Top) (Table 1).

Table 1. List of agrochemicals used as seed treatments

Label	Treatment (Trade name)	Active ingredients
T0	Untreated control	Untreated control
T1	Celest Extra	Difénoconazole (25 g/l) + Fludioxonil (25 g/l)
T2	Celest Top	Difénoconazole (25 g/l) + Fludioxonil (25 g/l) + **Thiamethoxam** (262,5 g/l)
T3	Vibrance Duo	Sedaxane (25 g/litre) + Fludioxonil (25 g/l)
T4	Spectro Extreme	Difénoconazole (92 g/l) + Métalaxyl-M (23 g/l)

The rate used was 200 cc/100 kg of seeds

Plots were arranged in a randomized complete block design with eight replications seeking reliability and replicability. Individual plots were 2 rows of 0.5 m each, with a 30 cm row spacing. Planting date was 31st January 2022. It is on purpose to delay the planting to favor HF infestations. The trial was frequently irrigated to avoid subsequent drought during the growing season.

Visual assessment of the severity of Hessian fly infestation was performed using a scale ranging from zero (no visible symptoms, plants having normal growth, with a light green color) to 5 (20% or more of stunted tillers with dark-green foliage color). It is to remind that 20% of infested tillers are considered by Lafever et al. (1980) as the economic level of infestations. The assessment was performed on 15th February 2022 corresponding to the end of tillering growth stage of wheat (Figures 1 & 2).

Figure 1. Field evaluation of the magnitude of Hessian fly wheat infestation

Figure 2. Plant exhibited symptoms of Hessian fly infestation (Stunting and dark green coloration of infested wheat tillers)

Standard analysis of variance was performed using the SAS software package to analyze the data obtained and means were compared by Duncan's multiple range test at 5% probability level.

Results and discussion

The analysis of variance of data of Hessian fly infestation of wheat (cv. Faiza) in Meknes during 2021-22 cropping season showed a highly significant difference between treatments. The treatment effect captured 46% of the variability (Table 2).

Table 2. Analysis of variance (RCBD) of data of Hessian fly infestation of wheat (Faiza) in Meknès during 2021-22 cropping season

Source of variation	Degree of freedom	Sum of squares	Mean squares
Treatment	4	23.4	5.85***
Replication	7	6.4	0.91 ns
Error	28	21.0	0.75
Total	39	50.8	

*** *Significant difference at P<0.001 probability level*

The Duncan's multiple range test at 5% probability level showed no significant difference between treatments including the untreated control except the fungicide-insecticide seed treatment mixture (T2, Celest Top) that exhibited a highly significant difference (Table 3).

Table 3. Mean values of the magnitude of Hessian fly infestation of bread wheat (cv Faiza) in Meknès during 2021-22 cropping season for each seed dressing treatment

Label	Treatment (Trade name)	Active ingredients	Magnitude of Hessian fly infestation
T0	Untreated control	Untreated control	2.87 a
T1	Celest Extra	Difénoconazole (25 g/l) + Fludioxonil (25 g/l)	2.12 a
T2	Celest Top	Difénoconazole (25 g/l) + Fludioxonil (25 g/l) + **Thiamethoxam** (262,5 g/l)	**0.62 b**
T3	Vibrance Duo	Sedaxane (25 g/litre) et Fludioxonil (25 g/l)	2.37 a
T4	Spectro Extreme	Difénoconazole (92 g/l) + Métalaxyl-M (23 g/l)	2.37 a

Means within columns with the same letter are not significantly different at 5% probability level according to Duncan's test

This experiment showed that Celest Top (that contains 262.5 g/l of Thiamethoxam) as seed treatment is highly effective for managing Hessian fly in wheat under Moroccan conditions (Figure 3).

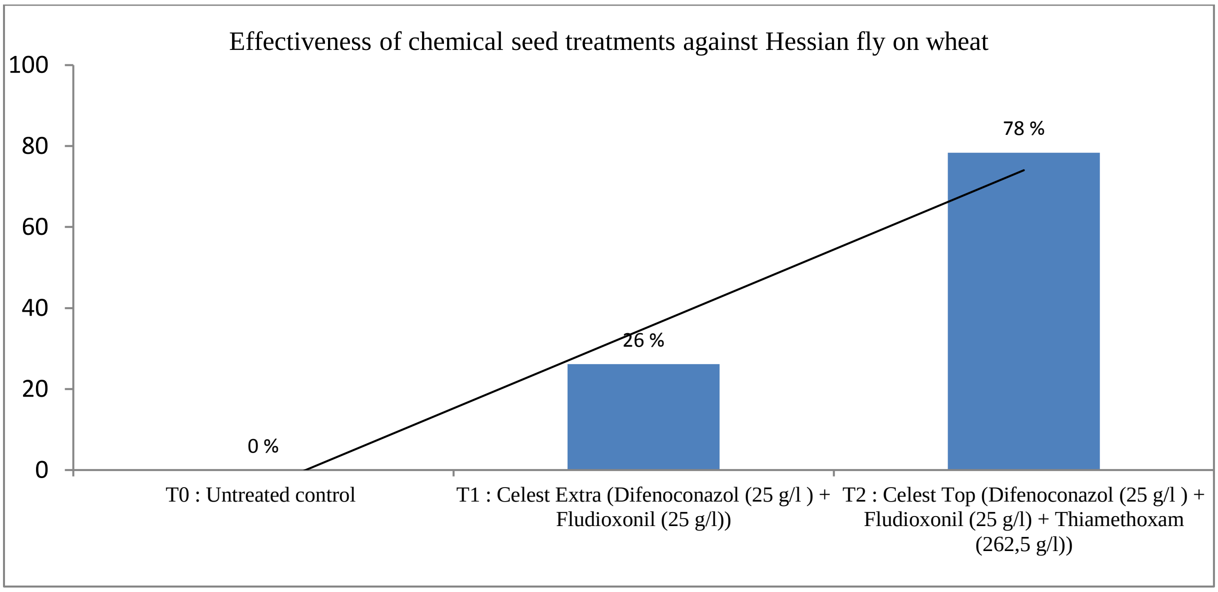

Figure 3. Effectiveness of Thiamethoxam seed treatment for managing Hessian fly in wheat under Moroccan conditions (control percentage)

This finding corroborates what has been reported by many authors such as Wilde et al. (2001) who found that Imidacloprid (Gaucho®) and thiamethoxam (Adage®) were effective in controlling early season (fall) infestations of the greenbug, *Schizaphis graminum* (Rondani), and the Russian wheat aphid, *Diuraphis noxia* (Mordvilko), whilst Fipronil (Regent®) was not effective against these two aphid species. However, they found that these three compounds effectively controlled fall infestations of Hessian fly, *Mayetiola destructor* (Say).

Kathy et al. (2013) reported that Clothianidin, thiamethoxam, or imidacloprid provide fair to good control of Hessian fly. Schmid et al. (2018) stated that seed treatments protect against feeding insects for 1-2 months after planting; and Whaley (2019) from his side stated that seed treatments typically provide a 30-day period of control and can be effective against Hessian fly and that seed treatment consisting of Gaucho 600F (imidacloprid) or Cruiser 5FS (thiamethoxam) is recommended.

When applied at the correct rates, use of systemic insecticidal seed treatments (neonicotinoid treatments) can reduce populations of Hessian flies. However, Hessian fly control tactics are more effective when used in an integrated pest management (IPM) program.

A shortcoming of the Hessian fly IPM program is the absence of reliable sampling methods for estimating the risk of Hessian fly damage and economic treatment thresholds. Instead management practices are used as either a preventative measure or in response to damage from the previous season (Ryan et al., 2018). To ensure the use of the management practices is justified, pest detection surveillance strategies need to be advanced and/or developed in conjunction with economic thresholds, to help producers implement Hessian fly IPM programs.

Conclusion and recommendations

The results indicated that thiamethoxam as seed treatment is effective in controlling the infestation of Hessian fly in Morocco. It reduced the infestation by 78% compared to untreated control. Therefore, treating wheat seeds with thiamethoxam can provide effective protection against early-season HF and hence reduce yield losses under field conditions. Thus (latitude 33°53' W, longitude 05°33'N, altitude 532 m above sea level) early control of HF insect populations using seed treatment is essential for cost-effective crop production. In other terms, thiamethoxam seed treatment is a simple, accurate, efficient, low-cost and ecofriendly control technology of Hessian fly on wheat in Morocco and should be scaled out and widely adopted by wheat growers. However, Hessian fly control tactics are more effective and sustainable when used in an integrated pest management (IPM) program.

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Conflict of interest

The authors declare that they have no conflict of interest.

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