SUPPRESSION OF HESSIAN FLY (DIPTERA : CECIDOMYIIDAE) POPULATIONS IN MOROCCO BY THE USE OF RESISTANT WHEAT CULTIVARS

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INTRODUCTION

The Hessian fly, **Mayetiola destructor** (Say) is one of the major limiting factors of wheat (**Triticum aestivum** L. and **T. turgidum** L. var. **durum**) production in Morocco. Damage up to total crop failure has been observed in the high infestation zones of the country (LHALOUI 1986, AMRI 1990). The National Agricultural Research Institute (INRA) and the MidAmerica International Agricultural Consortium (MIAC) concentrated on the development of resistant wheat cultivars as a means of reducing losses. Plant resistance has been used succeessfully to control the Hessian fly in the U.S.A., and numerous resistant cultivars have been deployed against the pest for more than 30 years. Twenty resistance genes have been identified in the U.S.A. (AMRI et al. 1990 for review). The mechanism of resistance is antibiosis, i.e., first instars die after feeding for two to three days on resistant plants.

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In Morocco, seven sources of resistance have been identified, **H5, H11,** and **H13** genes (EL BOUHSSINI et al. 1985; GALLAGHER et al. 1987, EL BOUHSSINI et al. 1988), two unnamed genes derived from **Triticum tauschii** (Coss.) (Amri 1990), and two unnamed genes derived from rye (**Secale cereale** L. (Friebe et al. 1990; HATCHETT, unpublished data). It was only in 1989 that the first bread wheat cultivar carrying the Hessian fly resistance gene **H5** was deployed in Morocco. This line, SD 8036 (PI 491571), a hard red spring wheat (**Triticum aestivum** L.), was developed cooperatively by the South Dakota Agricultural Experiment Station and the USDA-ARS for resistance to Hessian fly (Cholick et al. 1987). Because of its satisfactory agronomic performance in Morocco, SD8036 was released for commercial production under the name of 'Saada'. Saada is targeted for regions of the country where the Hessian fly is more damaging to wheat.

The objectives of this study were to assess the effect of deploying wheat resistance genes **H5, H11, H13** in reducing Hessian fly populations and the effect of wheat growth habit (spring vs winter) on the expression of resistance.

MATERIALS AND METHODS

Two experiments were conducted to quantify the effect of resistance genes on reducing Hessian fly populations, one at Sidi El Aidi in 1985-86, and the other at Sidi El Aidi, Jemaa Shaim, and Dar Bouazza in 1987-88. Three resistance wheat genes were evaluated, **H11** and **H13** in winter wheats and **H5** in a spring wheat. The experimental design was a randomized complete block with four replications, and four rows, each 1 m long for each cultivar. Rows were spaced 30 cm apart. 'Newton' was used as a susceptible check cultivar. In 1985-86, only two evaluations were made, one in January (first generation) and the other in April (second generation) because only two full Hessian fly generations developed. A total of 30 plants (10 successive plants from each end of the row and 10 from the middle) were sampled. All plants (120) of the same cultivar were combined and a subsample of 50 plants from each replicate was randomly selected and examined for presence of larvae.

In 1987-88, an experiment similar to the 1985-86 experiment was repeated, except that three evaluations were made because three full Hessian fly generations developed. Also in the 1987-88 experiment, the **H5** resistance gene was evaluated in two wheat backgrounds, spring wheat Saada and the winter wheat 'Arthur 71', to assess the effect of wheat growth habit on the expression of resistance to Hessian fly.

Analyses of variance using the general linear models procedures of SAS (SAS Institute, 1982) were made to test whether there is an effect on the build-up of the Hessian fly populations from the first to the second or third generation as measured by two variables: 1) the number of larvae per susceptible plant, and 2) percentage of susceptible plants. Paired comparisons were made using the least significant difference (LSD) procedure (P<0.05).

RESULTS AND DISCUSSION

Table 1 summarizes the 1985-86 data of two Hessian fly evaluations, one for the first generation (G1) at the end of January and the other for the second generation (G2) during the first week of April. There were highly significant (P<0.01) differences between increases in the number of larvae per susceptible plant and percentage of susceptible plants from G1 to G2 for the susceptible cultivar Newton. The number of larvae increased from 3.0 per plant at G1 to 19.4 per plant at G2, while the percentage of susceptible plants increased from 69.7 to 84.5. There were also significant increases (P<0.05) in the number of larvae per susceptible plant of **H11** and **H13** plants, but the numbers were still much lower than those on susceptible Newton at G2. Saada (**H5** gene) was highly resistant and showed no increase in either the number of larvae per plant or percentage of susceptible plants from G1 to G2.

Results of the 1987-88 experiment at Dar Bouazza, Sidi El Aidi, and Jemâa Shaim are summarized in Tables 2, 3, and 4, respectively. There was a highly significant increase (P<0.05) in the number of larvae per susceptible plant of Newton from G2 to G3 at all three locations. **H11** plants were almost free of larvae at Dar Bouazza (Table 2), but at Jemaa Shaim, which had the highest Hessian fly infestation, there was a slight but significant increase (P<0.05) of susceptible plants infested from G1 to G3 (Table 4). Again the increase from 0 to 2.5% was low compared to the increase from 23.6 to 98.2% of susceptible Newton plants. There was a significant increase (P<.05) in the percentage of **H13** susceptible plants from G1 to G3 at Dar Bouazza and Jemaa Shaim, increasing from 0 to 12.5% and from 0 to 18%, respectively. However, these increases were still relatively low compared to those of susceptible Newton, in which susceptible plants increased from 20.5 to 95% and from 23.6 to 98.2% at the two locations, respectively. There also was a significant increase (P<0.05) in the number of larvae per susceptible H13 from G1 to G3 at Dar Bouazza and Sidi El Aidi. These numbers increased from 0 to 4.3 and from 1.5 to 8.8 at the two locations, respectively, whereas the number of larvae on Newton susceptible plants increased from 1.3 to 12.8 at Dar Bouazza and from 2.1 to 19.9 at Sidi El Aidi.

Table 1: **Effect of resistance genes H5 in 'Saada' spring wheat and H11 and H13 in winter wheats on population suppression of two generations of Hessian fly at Sidi El Aidi, 1985-1986.**

	Resistance genes and No. larvae/ susceptible plant				Resistance genes and % plants susceptible			
Generation	Newton (susc. ck)	Saada H5	H11	H13	Newton (susc. ck)	Saada H5	H11	H13
G1	3.0 a	1.0 a	1.0 a	2.2 a	69.7 a	0.7 a	0.7 a	7.0 a
G2	19.4 b	0.0 a	3.2 b	7.0 b	84.5 b	0.0 a	2.2 b	13.7 b

Means followed by the same letter within a column do not differ significantly ($P>.05$; least significant differences [SAS INSTITUTE 1982]).

Table 2: **Effect of resistance genes H5, H11, and H13 in winter wheats on population suppression of three generations of Hessian fly at Dar Bouazza.**

Resistance genes	No. larvae/ susceptible plant				% plants susceptible			
Generation	Newton (susc. ck)	Arth 71 H5	H11	H13	Newton (susc. ck)	Arth 71 H5	H11	H13
G1	1.3 a	1.0 a	0.0 a	0.0 a	20.5 a	1.0 a	0.0 a	0.0a
G2	6.0 b	2.4 ab	1.0 a	4.0 ab	92.0 b	8.5 a	1.0 a	5.5 ab
G3	12.8 c	6.6 b	0.0 a	4.3 b	95.0 b	5.5 ab	0.0 a	12.5 b

Means followed by the same letter within a column do not differ significantly (P>.05; least significant differences [SAS INSTITUTE 1982]).

Table 3: **Evaluation of resistance genes H5, in spring wheat Saada and winter wheat Arthur, and H11 and H13 in winter wheat on population supression of three generations of Hessian fly at Sidi El Aidi, 1987-88.**

Resistance genes	No. larvae/ susceptible plant					% plants susceptible				
	Newton	H5		H11	H13	Newton	H5		H11	H13
Generations	(susc. ck)	Arth 71	Saada			(susc. ck)	Arth 71	Saada		
G1	2.1a	1.9 a	0.0 a	0.0 a	1.5 a	47.9 a	6.7 a	0.0 a	0.0 a	4.0 a
G2	11.6 b	6.1 ab	3.5 a	5.0 a	5.1 ab	93.9 b	12.5 a	0.7 a	0.5 a	7.5 a
G3	19.9 c	9.3 b	0.0 a	1.5 a	8.8 b	97.1 b	9.5 a	0.0 a	1.5 a	7.5 a

Means followed by the same letter within a column do not differ significantly (P>.05; least significant differences [SAS INSTITUTE 1982]).

Saada (**H5** gene) showed no increase in susceptible plants from G1 to G3 at Sidi El Aidi and Jemaa Shaim (Tables 4 and 5). Saada plants were free of larvae at Jemâa Shaim. However, there, there was a significant increase ($P<.05$) in the number of larvae from G1 to G3 on the winter wheat Arthur 71 (**H5** gene) at both locations. These increases in number of larvae were about half of those on Newton plants. There was also a significant ($P<.05$) increase in the percentage of susceptible Arthur 71 plants at Jemâa Shaim from G1 to G2, which was about one-fifth of that of the susceptible Newton plants.

Table 5 summarizes the effect of wheat growth habit (spring vs. winter) on the expression of resistance. For both the percentage of susceptible plants and the number of larvae per susceptible plant, there were highly significant differences ($P<.05$) between the **H5** resistance gene in Arthur 71 and in Saada at the two locations. In general, increases occurred only in the number of larvae and not in the percentage of plants susceptible from G2 to G3. This could be due to the rapid physiological maturation of plants toward the end of the growing season, so even if the number of ovipositing females of the first generation were high, there would be fewer preferred sites (younger and greener leaves) for oviposition. However, for infested plants that remain attractive, a greater number of females would find more of the preferred sites to oviposit. This would increase the probability of a higher number of larvae per plant, but would not necessarily increase the number of susceptible plants.

An important point to consider is the comparative increase or decrease of larval populations on susceptible versus resistant cultivars. For example, at Sidi El Aidi in 1985-86 (Table 1), the susceptible Newton wheat had a mean plant density of 66 plants per linear meter of row. Since the spacing between rows was 0.3m, plant density was 66 plants per $0.3m^2$, of which 69.7% were infested. thus, there were 46 infested plants per $0.3m^2$, or about 1.5 million infested plants per ha. So, for the first generation there were 1.5 million infested plants x 3.0 larvae per plant or about 4.6 million larvae per ha. Using similar calculations for the second generation, there were about 1.9 million infested plants x 19.4 larvae per plant or 36.1 million larvae per ha. This constitutes almost a nine-fold increase in the population on the susceptible cultivar from the first to the second generation.

In comparing the population increase on susceptible Newton wheat with that of resistant wheats, we can see that the resistance genes were highly effective in suppressing Hessian fly populations. For example, for the **H11** gene, only 0.7% of the plants were susceptible in the first generation and 2.2% in the second generation.

Table 4: **Evaluation of resistance genes H5, in spring wheat Saada and winter wheat Arthur 71 and H11 and H13 in winter wheats on population supression of three generations of Hessian fly at Jemaa Shaim, 1987-88.**

Resistance genes	No. larvae/ susceptible plant					% plants susceptible				
	Newton	H5		H11	H13	Newton	H5		H11	H13
Generations	(susc. ck)	Arth 71	Saada			(susc. ck)	Arth 71	Saada		
G1	1.7 a	2.7 a	0.0 a	0.0 a	0.0 a	23.6 a	2.2 a	0.0 a	0.0 a	0.0 a
G2	17.4b	11.3 b	0.0 a	1.0 a	7.9 a	97.7 b	20.0 b	0.0 a	1.0 ab	21.0 b
G3	31.1 c	16.2 b	0.0 a	3.4 a	10.1 a	98.2 b	13.5 ab	0.0 a	2.5 b	18.0 b

Means followed by the same letter within a column do not differ significantly (P>.05; least significant differences [SAS INSTITUTE 1982]).

Table 5: **Effect of wheat growth habit background (spring vs. winter) on the level of expression of resistance of H5 gene against Hessian fly, 1987-88.**

Source of resistance	Sidi El Aidi		Jemaa Shaim	
	% plants susceptible	No. larvae/ plant	% plants susceptible	No larvae/ plant
Arthur 71 (winter wheat)	9.6 a	5.5 a	13.0 a	10.1 a
Saada (spring wheat)	0.25 b	0.6 b	0.0 b	0.0 b

Means followed by the same letter within a column do not differ significantly (P>.05; least significant differences [SAS INSTITUTE 1982]).

Following the same method of calculation, but using plant density of **H11** gene wheat, 1.6 plants were infested per 0.3 m2 or about 0.54 million susceptible plants per ha. Based on the mean number of larvae per plant (Table 1), the total larval population is about 0.17 million per ha. Therefore, compared to the estimated larval population on susceptible Newton wheat, the **H11** gene reduced the potential population by 35.9 million larvae per ha or more than 99.5%. Considering the resistance gene **H13** at the same location, larval population was reduced only by about 29.6 million larvae per ha (80%) bacause of the increase in the number of susceptible plants and numbers of larvae per plot. The resistance gene **H5** in Saada reduced the larval population by 100%, since there were no plants infested by the second generation. However, this would be unlikely to occur in a large field where some susceptible plants would be expected.

Using the same method of calculation for estimating larval density in the 1987-88 experiment, the number of larvae at Dar Bouazza increased from about 0.47 million per ha the first generation to 9.8 million the second and 21.6 the third generation on susceptible Newton (Table 2). The **H11** gene reduced the larval population by almost 21.6 million larvae ha, since it was nearly free of larvae by the third generation. The **H5** gene in Arthur 71 and the **H13** wheat gene, even though they showed some increase in susceptibility, reduced the potential larval population by 21.3 million larvae (98.3%) and 21.1 million larvae (97.6%), respectively.

A higher population buildup was observed at Sidi El Aidi (Table 3). The Hessian fly larval density on susceptible Newton wheat increased from about 2.0 million larvae per ha the first generation to 21.2 million the second and to 37.6 million the third. Calculations show that the **H5** gene in Saada and the **H11** gene reduced the fly population tremendously by about 37.6 and 37.5 million larvae per ha, respectively, since few or no larvae survived on the plants. The **H5** gene in Arthur 71 and **H13** gene reduced the larval population by 35.5 million (94.3%) and 36.2 million (96.2%), respectively.

At Jemâa Shaim, the second and third genrations were extremely high with infestation levels of 97.7 and 98.2% of the Newton plants susceptible, respectively (Table 4). The Hessian fly larval density went from 0.55 million per ha at the first generation to 35.3 million the second generation to 52.5 million the third. The **H5** in Saada had no infested plants and thus reduced the potential population by 100%. The **H11** gene had some infested plants, but still reduced the larval population by 52.4 larvae per ha or 99.8%. The **H5** gene in Arthur 71 and **H13** gene wheat showed more infested plants at this location. They reduced the population by 49.9 million (95.2%) and 50.6 million (96.7%) larvae per ha, respectively.

Several explanations could be given for the increases in infestation levels from the first to the third generations on the resistant plants. Perhaps the most logical explanation is that the high larval populations may have simply overpowered the resistant plants, allowing more larvae to survive and stunt plants. Also, in the subsequent generations of the fly, virulent genotypes may have resulted from the mating of heterozygous genotypes. Although heterozygous genotypes are avirulent, because virulence is conditioned by recessive alleles (HATCHETT and GALLUN, 1970), some of the progenies of such matings would be virulent. If the latter is the case, then selecttion and development of virulent biotypes may be rapid in Morocco, because population densities are very high and in most years three generations may develop. In the USA, eight biotypes have already been identified from field populations and have increased in populations as a result of selection pressure by resistance genes (GALLUN, 1977, for review; SOSA, 1981). Another plausible explanation for the increase of infestations during the third generation is that susceptible plants of resistant genotypes may have been affected by high temperature, which is normally much higher after February. Thus, more precise tests should be conducted in growth chambers to determine the temperature sensitivity of these resistance genes to the Moroccan Hessian fly. Temperature sensitivity of Hessian fly resistance genes has been shown to be biotype dependent. The **H5** resistance gene in Arthur 71 was susceptible to biotype B and D at 27°C (SOSA and FOSTER, 1976). The resistance of the **H13** gene was only significantly reduced at 31°C against biotype D (TYLER and HATCHETT, 1983).

It appears that millions of Hessian flies can be eliminated each year by growing resistant cultivars. Therefore, wheat production could be stabilized for some time by properly deploying different or new resistance genes when virulent biotypes appear to be increasing as a result of selection by a resistance gene. Conversely, when populations are extremely high, thousands of flies may survive and reproduce on wheats having these resistance genes. Therefore, while hastening to deploy these useful genes, they should not be relied on alone for long-term protection, since they will likely be rendered ineffective by virulent biotypes at some time in the future. It might be a prudent strategy, once several resistance genes are available, to identify and deploy genes that allow for high larval survival on resistant plants or those that are not highly antibiotic. For example, some genes such as **H1H2** and **H7H8** allow for high larval survival on resistant plants when tested against avirulent heterogeneous Hessian flies (EL BOUHSSINI, unpublished data). These types of genes would not put as much selection pressure on biotype development as would those that condition high levels of antibiosis. Also, there may be little genetic variability for virulence against resistance genes originating from the relatives of wheat such as rye (HATCHETT, unpublished data). The use of exotic genes could increase the life span of a resistant cultivar if virulence against such genes are extremely low in populations.

In 1987-88, the effect of wheat growth habit, spring vs. winter, was assessed in two locations, Sidi El Aidi and Jemâa Shaim (Table 5). In both locations there was a highly significant increase ($p<.05$) of both the percentage of susceptible plants and the larval density on Arthur 71 as compared to Saada. The results indicate that **H5** resistance gene in a winter wheat may be more temperature sensitive to the Moroccan Hessian fly than in the spring wheat Saada. These results also support the conclusion of SOSA and FOSTER (1976) that temperature sensitivity of wheat resistance genes is biotype dependent. Arthur 71 was resistant to the Great Plains biotype in the U.S.A. at 27°C (EL BOUHSSINI, unpublished data), but was more susceptible to the Moroccan Hessian fly. Only spring wheat is grown in Morocco, but if both spring and winter wheats are grown in a country, it would be beneficial to test which of them is susceptible at higher temperatures. Resistance genes should be incorporated in the wheat type in which resistance is expressed at a wider range of temperatures. In Morocco, the temperature goes as high or higher than 27°C starting in March when wheat is usually in the jointing stage and when the third generation is developing.

ACKNOWLEDGMENT

We thank Ken Starks for his advice on conducting the experiments and El Hossaini Khalid, and Chakir Abdel Kader for their technical assistance. This study was a cooperative investigation by : the National Institute for Agricultural Research (INRA), Rabat, Morocco ; the MidAmerican International Agricultural Consortium (MIAC), University of Nebraska; the Moroccan Dryland Farming Projetct; USAID Project No. 608-0136; INRA, the U.S. Department of Agriculture, Agricultural Research Service, and the Dept. of Entomology, Kansas State University, Manhattan, KS 66506-4008.

ABSTRACT

The effect of wheat resistance genes, **H5, H11**, and **H13**, on suppressing populations of the Hessian fly in Morocco was studied in 1985-1986 and 1987-1988. Experiments conducted at Sidi El Aidi, Jemaa Shaim, and Dar Bouazza showed that all three genes were highly effective in reducing three generations of larval populations during a single growing season. All three genes condition antibiosis which results in high mortality of first instars. Based on estimated larval densities on resistant and susceptible cultivars, the resistance genes reduced larval populations by more than 94.0% in most tests. Although infestation levels increased from the first to the third generation on resistant wheats in some tests, the **H5** and **H11** genes were generally more effective than the **H13** gene in reducing populations at all locations. Increases in infestation levels of resistant wheats may have been caused by high larval populations that simply overpowered the resistant plants, by high temperature that reduced the expression of resistance, or by virulent biotypes that survived and increased on resistant plants in subsequent generations.

KEY WORDS : Insecta, **Mayetiola destructor**, **Triticum**,
Antibiosis, Suppression.

RESUME

L'effet des gênes de résistance de blé, **H5, H11, H13,** dans la suppression des populations de la mouche de Hesse au Maroc a été étudié en 1985-1986 et 1987-1988. Les essais conduits à Sidi El Aidi, Jemaa Shaim et Dar Bouazza ont montré que les trois gênes étaient efficaces dans la réduction des populations larvaires des trois générations de la saison agricole. Tous les trois gênes conditionnent l'antiboisis qui se traduit par une forte mortalité de larves de premier stade. En se basant sur l'estimation des densités larvaires sur les variétés résistantes et sensibles, les gênes de résistance ont réduit les populations larvaires, dans la majorité des essais, de plus de 94%. Bien que les niveaux d'infestation ont augmenté de la première à la troisième génération sur les blés résistants dans quelques essais, les gênes **H5, H11,** étaient généralement plus éfficaces que le gêne **H13** dans la réduction des populations, et ce dans toutes les stations. Les augmentations des niveaux d'infestation des blés résistants seraient causées par de fortes populations larvaires qui auraient, tout simplement, accablé les plantes résistantes, ou par des températures élevées qui auraient réduit l'expression de la résistance, ou par des biotypes virulents qui auraient survécu et qui seraient multiplié sur les plantes résistantes à travers les générations.

MOTS CLES : Insecte, **Mayetiola destructor**, **Triticum**, Antibiosis, Suppression.

ملخص

لقد تمت دراسة تأثير جينات المقاومة، H5، H11 و H13 على الحد من تكاثر دودة هس بالمغرب في سنتي 1986 و 1988 .وقد أظهرت التجارب بمحطة سيدي العايدي وجمعة سحيم أن الجينات الثلاثة كانت مقاومتها عالية بحيث تسببت في نقص كبير لعدد يرقات الأجيال الثلاث .

الجينات الثلاثة عندها مايسمى با " Antibiosis " أي أنها تعمل على قتل اليرقات الأولى لدودة هس وقد تسببت في نقص عدد يرقات هذه الحشرة بما يزيد على 94 ٪. على العموم ، كانت الجينات H5 و H11 أكثر فعالية في الحد من تكاثر دودة هس من الجين H13 ، وكان هذا بجميع محطات التجارب .

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