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Quantifying key variables of damage to wheat and barley by *Syringopais temperatella* (Lepidoptera: Scythrididae)

Cuantificación de variables clave en los daños al trigo y cebada por *Syringopais temperatella* (Lepidoptera: Scythrididae)

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Abstract: Wheat and barley are the principal food crops for millions of people in the predominantly mixed crop-livestock farming systems. The cereal leafminer, *Syringopais temperatella* (Lepidoptera, Scythrididae) is a major biotic constraint to wheat and barley production in Jordan and the region. Three variables of yield components were used to quantify the loss of wheat and barley including the grain yield, straw dry mass and leaf area consumed. Forty-two (in the field experiment) and one hundred eighteen (in the laboratory experiment) accessions of wheat and barley were used to access the average damage; representing different levels of susceptibility to *S. temperatella*. Equations of three negative correlations of percentage of infestation versus both grain yield and straw dry mass, and the number of larvae versus the straw dry mass were produced. Results indicated that the average grain yield reduction for both crops due to pest infestation was estimated at 36.1% for wheat and 50% for barley, but the individual reductions ranged 17.4-73.3%. The straw dry mass reduction was estimated at 29.9% for wheat and 16.5% for barley with individual reductions ranging between 8.4 and 44.8%. In addition, one positive correlation for the number of leafminer larvae versus the leaf area consumed was found. The estimated leaf area consumed per one larva was 0.30 cm² and 0.38 cm² for wheat and barley, respectively.

Key words: Cereal leafminer. Grain and straw damage. Leaf area consumed.

Resumen: El trigo y la cebada son los principales cultivos alimenticios para millones de personas en los sistemas de producción de cultivos y ganadería predominantemente mixtas. El minador de cereales, *Syringopais temperatella* (Lepidoptera: Scythrididae) es una importante limitación biótica de producción de trigo y cebada en Jordania y la región. Tres parámetros de daño fueron utilizados para cuantificar la pérdida en trigo y cebada: el rendimiento de grano, masa seca de paja y área foliar consumida. Cuarenta y dos (en experimentos de campo) y ciento dieciocho (en experimentos de laboratorio) accesiones de trigo y cebada se utilizaron para estimar el daño promedio, que representan diferentes niveles de susceptibilidad a *S. temperatella*. Se construyeron las ecuaciones de tres correlaciones negativas para porcentaje de infestación en comparación con el rendimiento de grano y materias seca de paja, y la del número de larvas en comparación con la masa seca de paja. Los resultados indicaron una reducción promedio de rendimiento de grano para los dos cultivos debido a la infestación de plaga estimada en 36,1% para el trigo y 50% para la cebada, pero las reducciones individuales oscilaron entre 17,4-73,3%. La reducción de la masa seca de paja se estimó en 29,9% para el trigo y 16,5% para la cebada con reducciones individuales que variaron entre 8,4 y 44,8%. Además, se encontró un aumento, con correlación positiva, en el número de larvas de minador frente a la zona consumida de hoja. El área foliar estimada consumida por una larva es de 0,30 cm² y 0,38 cm² para trigo y cebada, respectivamente.

Palabras clave: Minador de cereales. Daños grano y paja. Área foliar consumida.

Introduction

Wheat and barley are the most planted cereal crops in Jordan with cultivated area of 27,856 and 41,264 hectares in 2011, respectively. However, Jordan is not self-sufficient in these crop productions and depends on imports to cover the national needs. In 2010, Jordan produced 26,659 and 26,711 tons and imported 1,076,000 and 447,000 tons of wheat and barley, respectively (Jordan Statistical Yearbook 2011). Both crops are classified as low-input crops to farmers; hence they cannot accept yield loss due to pest attack. One of the most important insect pests on wheat and barley in Jordan is the cereal leafminer, *Syringopais temperatella* Lederer (Lepidoptera, Scythrididae). In the Middle East, *S. temperatella* is a major pest of wheat and barley, and it causes quantitative and qualitative damages through feeding on plant leaf tissues (Jemsi *et al.* 2002; Jemsi and Rajabi 2003; Gozuüacik *et al.* 2008; Al-Zyoud 2012, 2013). Duran *et al*. (1979) found that the insect damage in Turkey reached 22%, while Kaya (1976) estimated the damage to be around 40-60%. In Iraq, crop losses caused by the pest on wheat and barley ranged between 10 and 20% (Abu-Yaman 1971). In Jordan, the pest was reported since more than 50 years ago (Klapperich 1968). It was considered as a non-serious pest on wheat and barley, but since 2001 the insect has become a destructive pest in the south of the country, especially in Karak District (Al-Zyoud 2008; Al-Zyoud *et al.* 2011) with infestation reaching up to 70% (Al-Zyoud 2013).

Little is known about the association of *S. temperatella* infestation to the grain and straw yield of wheat and barley. Al-Zyoud (2012) provided results on the leaf area consumed by the cereal leafminer larvae for only six local cultivars of

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wheat and barley in an attempt to sort out the preferred ones. Unfortunately, his study did not provide information on the number of larvae that consumed that leaf areas.

Pest management is an intensive decision making system requiring efficient decision tools. Decisions require information on crop losses due to pest for control intervention and research prioritization. Traditionally, the crop losses have been determined through empirical yield-infestation relations. Therefore, the current study is undertaken to provide formulas for predicting the grain yield, straw dry mass and plant-leaf area consumed of wheat and barley crops due to the cereal leafminer at a certain infestation level and number of larval attack.

Materials and methods

Field experiment. Seeds of twenty-seven wheat and fifteen barley accessions used in this study were obtained from the National Centre of Agriculture Research and Extension/ Jordan (Table 1). The accessions were separately sown in three replicates distributed randomly in three blocks in a field in Al-Qasr-Karak (31º11"N and 35º42"E, altitude of 980 m). A randomized complete block design with three replications of each of the 42 wheat and barley accessions were used. Each replicate represented by a row of 2 m in length and was sown with 30 g of seeds at a depth of 5 cm. Spacing between rows was 0.5 m and 2 m between blocks. Normal cultural practices were followed as practiced by farmers usually do except for no pesticide usage. The field site is characterized by semi-arid conditions with warm weather. The temperature increases gradually during the spring months while the pest larvae are active. A rainfall of 300 mm as long-term annual average was recorded from Al-Rabeh Metrological Station (5 km south of the experimental site). At the end of March, three researchers independently estimated the percentage of infestation for all the accessions for the two successive cropping seasons; 2011/12 and 2012/13. At the same time, number of larvae per plant was recorded for each accession. In addition, yield grain and straw dry mass of all accessions were separately recorded at the harvesting time. Three correlations were linearly plotted; the first two were between the infestation level versus both of yield grain and straw dry mass, and the third one was between larval population size and straw dry mass.

Laboratory experiment. A laboratory experiment was conducted to quantify the fourth relationship between the larval population size and leaf area consumed by such size. Eighty wheat and thirty-eight barley accessions were used in the experiment (Table 2). Seeds of each wheat and barley accession were sown in pots of 50 cm in height and 30 cm in diameter. The pots were kept under a normal field conditions at the Faculty of Agriculture, Mutah' University, Al-Rabeh-Karak. For the experiment, four trays (100 cm in length and 40 cm in width) were used; representing four replicates; where layer of cotton was spread in the tray bottom and wetted as needed. A piece of leaf cut of 10 cm^2 area of each of 80 wheat accessions and 38 of barley accessions were made

Table 1. Wheat and barley cultivars and accessions used in the field experiments to link *Syringopais temperatella* infestation with grain yield and straw dry mass in the 2011/12 and 2012/13 cropping seasons.

No.	Crop	Cultivar/accession name	No.	Crop	Cultivar/accession name
1	Wheat	Acsad 1273	1	Barley	1212
2	Wheat	Acsad 1275	2	Barley	1614
3	Wheat	Umkais	3	Barley	Tadmor
4	Wheat	Acsad 1245	4	Barley	Anta
5	Wheat	Horani	5	Barley	Yarmouk
6	Wheat	Acsad 357	6	Barley	Rum
7	Wheat	Irbid Norsieh	7	Barley	Nabawi
8	Wheat	SafraMaan	8	Barley	Wi 2269
9	Wheat	1103	9	Barley	Mutah
10	Wheat	HoraniNawawi	10	Barley	Stepter
11	Wheat	DeirAlla	11	Barley	Eyl
12	Wheat	885	12	Barley	Wi 2291
13	Wheat	Acsad 65	13	Barley	Gp
14	Wheat	Acsad 1105	14	Barley	Athroh
15	Wheat	Tari 885	15	Barley	Morex
16	Wheat	899			
17	Wheat	1315			
18	Wheat	Sham 1			
19	Wheat	Acsad 1187			
20	Wheat	Petra			
21	Wheat	981			
22	Wheat	Tari 889			
23	Wheat	Amoon			
24	Wheat	1110			
25	Wheat	969			
26	Wheat	1131			
27	Wheat	1069			

Table 2. Wheat and barley cultivars and accessions used in the laboratory (tray experiment) to correlate the larval population density with the consumed leaf area by *Syringopais temperatella* larvae.

Wheat				Barley	
No	Cultivar/accessin	No.	Cultivar/accessin	No.	Cultivar/accession
1	Sham	41	3549	1	510
2	Safra Moan	42	3560	2	Jo 473
3	Petra	43	3550	3	Jo 535
4	969	44	3541	4	Jo 465
5	Irbid Nowsieh	45	3553	5	981
6	Jo 2127	46	3540	6	1115
7	Jo 2124	47	Jo 3583	7	Jo 469
8	Jo 3567	48	3542	8	Jo 460
9	3552	49	3539	9	538
10	Jo 2123	50	3562	10	510
11	3561	51	3543	11	Jo 541
12	Jo 2134	52	3559	12	Jo 514
13	Jo 2126	53	3537	13	526
14	Jo 3570	54	Um-Kies	14	1212
15	899	55	Jo 3568	15	451
16	Acsad 245	56	Jo 2135	16	308
17	Acsad 1237	57	3555	17	Jo 470
18	1275	58	3546	18	499
19	357	59	2121	19	Jo 464
20	Rabeh	60	Jo 2125	20	307
21	Horani	61	3538	21	531
22	Jo 3576	62	Jo 3575	22	Jo 471
23	3564	63	Jo 2138	23	Mutah
24	Jo 3566	64	Jo 3569	24	1614
25	3554	65	3544	25	Jo 502
26	3545	66	Jo 2129	26	Jo 466
27	3519	67	Jo 3584	27	Jo 525
28	3563	68	Jo 3572	28	527
29	899	69	1275	29	Jo 462
30	1315	70	1105	30	302
31	1131	71	Acsad 65	31	Jo 472
32	3589	72	Sham1	32	Jo 524
33	3547	73	Horani Nawawi	33	Jo 474
34	3551	74	1187	34	Jo 529
35	Jo 3580	75	Jo 3571	35	Jo 532
36	3557	76	3558	36	Jo 463
37	885	77	3556	37	Rum
38	1169	78	3565	38	Tadmur
39	1103	79	3548		
40	Jo 3579	80	3582		

when plants were about 15 cm in length was laid down into each tray. Hereafter, a total of 200 *S. temperatella* in the third larval instars were introduced per tray. The trays were kept under laboratory conditions of 20 ± 5 °C temperature, 50 ± 10% relative humidity and 12:12 (L: D) h photoperiod. After 3-day-period, the number of larvae attacked each accession leaf-strip and their associated leaf areas consumed were recorded. Data obtained for both variables (number of larvae and leaf area consumed) were plotted for both crops.

Statistical analysis. The statistical analysis was performed using the proc GLM of the statistical package SigmaStat version 16.0 (SPSS 1997). Regressions' analysis between the infestation level versus both of yield grain and straw dry mass, as well as between larval population size versus both of straw dry mass and leaf area consumed was conducted using Spearman's correlation method (Zar 1999).

Results

The results showed that none of the cultivars and/or accessions tested of wheat and barley was immune to *S. temperatella* attack. The linear regression between percentage of infestation and grain yield was a negative function; this means that at high percentages of infestation, the grain yield is low (Fig. 1A and B). This correlation was significant

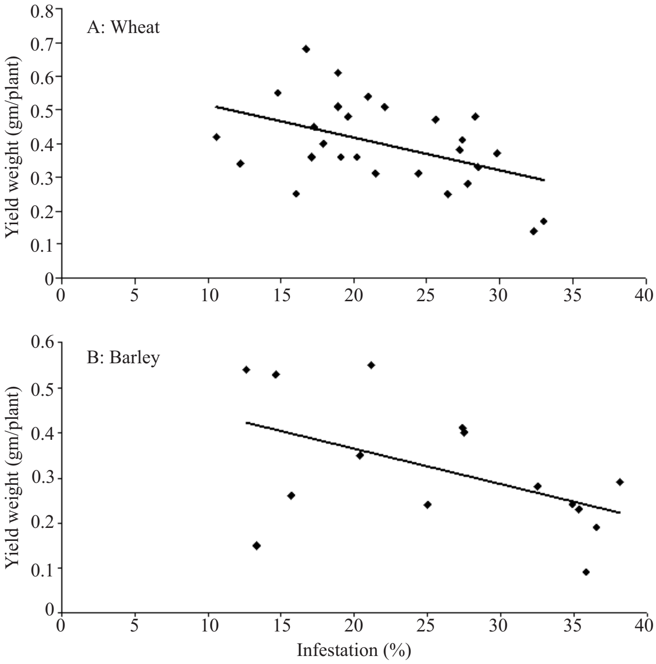

Figure 1. Scatter diagram with a line of best fit curve of obtained grain yield values as a function of infestation percentages of 27 accessions of wheat **(A)** and 15 accessions of barley **(B)** in a field experiment.

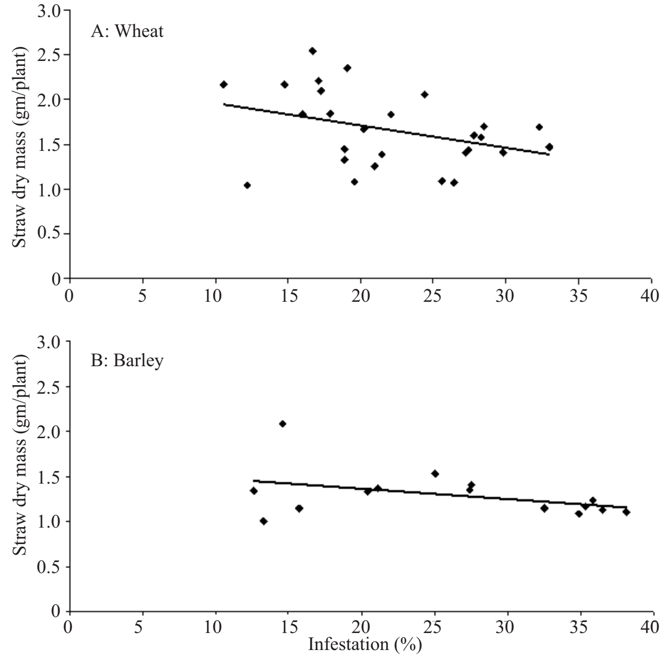

Figure 2. Scatter diagram with a line of best fit curve of obtained straw biomass values as a function of infestation percentages of 27 accessions of wheat **(A)** and 15 accessions of barley **(B)** in a field experiment.

for both of wheat (r = -0.405, P = 0.036) and barley (r = -0.503, P = 0.050) (Table 3). The minimum percentages of infestation for wheat and barley were 10.6 and 13.3%, in which accessions produced 0.21 and 0.15 g of seeds/plant, respectively, while the maximum percentages of infestation were 33.0 and 38.1% producing 0.44 and 0.29 g of seeds/plant for both crops, respectively.

The correlation of infestation percentage versus straw dry mass is also of negative function for both crops (Figs. 2A and B); in which the higher foliage infestation by larvae reduced the straw dry mass much more than the lower infestation. The maximum percentages of infestation for wheat and barley resulted in straw production of 2.03 and 1.10 g/plant as compared to 1.56 and 1.00 g of straw/plant that obtained at the minimum infestation percentages, respectively. Slight negative functions were appeared between the number of larvae that attack plant foliage and the straw dry mass (Figs. 3A and B), in which the larval feeding is slightly reduced plant foliage. This inverse correlation is not significant for wheat (r = -0.212, P = 0.288) and also barley (r = -0.304, P = 0.271) as shown in Table 3.

A positive function was found, that is between the number of larvae and leaf area consumed by the pest larvae (Figs. 4 A and B); in which the increasing number of larvae the increased leaf area consumed. This function was highly significant for both of wheat (r = 0.965, P = 0.000) and barley (r = 0.974, P = 0.000) (Table 3). By using the models obtained, one 3rd instar larva consumed during 3 days about 0.30 cm^2 leaf area of wheat and about 0.38 cm^2 of barley; representing 3.0-3.8% of the leaf area provided, respectively.

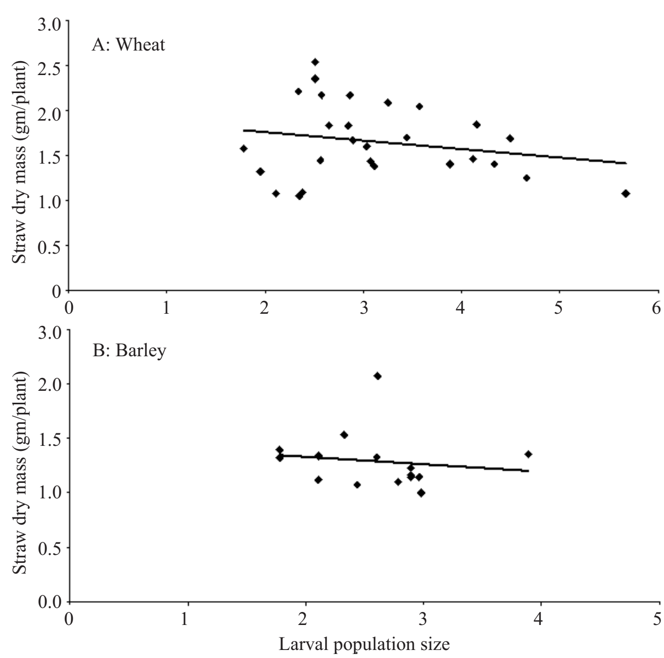

Figure 3. Scatter diagram with a line of best fit curve of obtained straw yield values as a function of larval population infesting 27 accessions of wheat **(A)** and 15 accessions of barley **(B)** in a field experiment.

Discussion

Due to the importance of wheat and barley crops in food security and also due to the increasing demand for their products as food for humans and animals because of the large increase in the world population, it was necessary to investigate and predict the damage caused by any pest threatening such crops. Therefore, this study is found dealing with constructing equations representing damage caused by *S. temperatella* to hundreds of wheat and barley accessions including the most common cultivars grown

Table 3. Correlation analysis of wheat and barley infestation by *Syringopais temperatella* with grain yield and straw dry mass, and larval population size with leaf area consumed during the 2011/2012 and 2012/2013 cropping seasons.

Correlated variables	Crop	R value	Sig.	Model	Notes
Infestation vs. yield weight	Wheat	-0.405*	0.036	y = -0.01x + 0.61	Fig. 1A
	Barley	-0.503*	0.050	y = -0.01x + 0.52	Fig. 1B
Infestation vs. straw dry mass	Wheat	-0.339	0.083	y = -0.03x + 2.21	Fig. 2A
	Barley	-0.399	0.141	y = -0.01x + 1.58	Fig. 2B
Straw dry mass vs. larval population size	Wheat	-0.212	0.288	y = -0.09x + 1.95	Fig. 3A
	Barley	-0.304	0.271	y = -0.07x + 1.47	Fig. 3B
Leaf area consumed vs. larval population size	Wheat	0.965**	0.000	y = 0.1734x + 0.12	Fig. 4A
	Barley	0.974**	0.000	y = 0.1647x + 0.21	Fig. 4B

*Correlation is significant at the 0.05 probability level. **Correlation is significant at the 0.01 probability level.

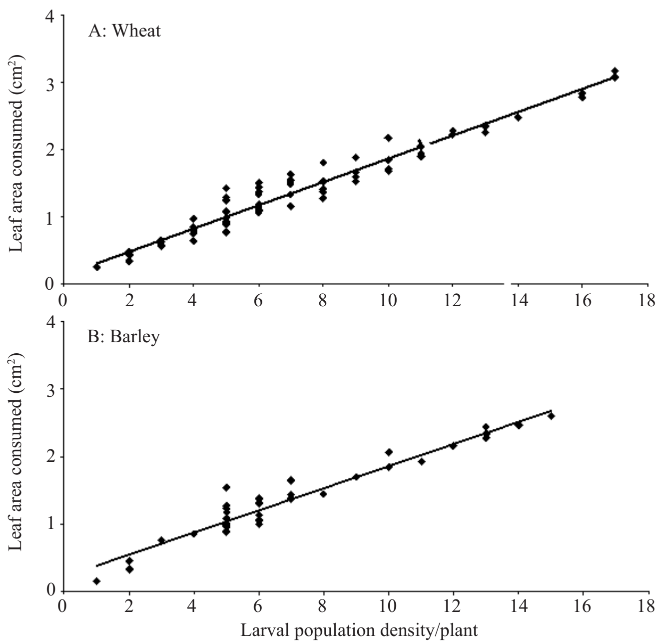

Figure 4. Scatter diagram with a line of best fit curve of obtained leaf area consumed as a function of larval population infesting 80 accessions of wheat **(A)** and 38 accessions of barley **(B)** in a lab experiment.

locally and regionally; where these cultivars vary in their susceptibility (Al-Zyoud *et al.* 2009). Larvae of this pest feed strictly on the leaf tissues, which affects plant growth and thereby, the production of grain yield and straw biomass. Therefore, it was a priority to link the pest injury level with yield reduction (Stansly *et al.* 1996). However, the current study indicated that the average percentage of infestation for the 27 wheat and 15 barley accessions was 22 and 26%, respectively. By applying these infestation percentages on the obtained models that correlated the infestation with the grain yield, the grain yield will be 0.39 and 0.26 g/plant for wheat and barley, respectively. At zero infestation, the yield is estimated at 0.61 and 0.52 g/plant, for wheat and barley, respectively. So that, the overall yield reduction due to the leafminer will be around 36.1% for wheat and 50% for barley, but the individual reduction ranged from 17.4% (in the most resistant wheat accession at the 10.6% infestation) to 73.3% (in the most susceptible barley accession at the 38.1% infestation).

At the average percentage of infestation for wheat (22%) and barley (26%) accessions, and by applying the obtained models that correlated the infestation with straw dry mass, at these averages, the straw yield will be 1.55 and 1.32 g/plant for wheat and barley, respectively. At zero infestation, the straw yield is estimated at 2.21 and 1.58 g/plant, for wheat and barley, respectively. Therefore, the average straw biomass reduction due to the leafminer will be 29.9% for wheat and 16.5% for barley, while the individual reduction was between 8.4% (in the most resistant barley accession at the 13.3% infestation) and 44.8% (in the most susceptible wheat accession at the 33% infestation). The capacity of the cereal leafminer to reduce yield has been documented by many researchers. In Turkey, it was estimated to be 40-60% reduction (Kaya 1976) and later, Duran *et al*. (1979) estimated the reduction in the field to be around 22%. In Iraq, crop loses caused by the pest on wheat ranged between 10% and 20% (Abu-Yaman 1971). However, several factors may explain the variation of the current study as compared to the previous findings. The most important is that the results of the other researchers representing specific wheat and barley cultivars, while we provide representative numbers for more than 40 accessions and cultivars. Other factors can explain such variation is the differences in the environmental conditions, mainly rainfall which is scarce in our experimental location and maximized the pest infestation. Highly significant leafminer injury to wheat and barley in Jordan allows grouping the pest with the leaf-mass consumer injury guilds as proposed by Peterson (2001).

Models obtained for the number of larvae versus the leaf area consumed showed that one third larval instar of *S. temperatella* consumed during 3 days an average of 0.3 cm² (3%) of the leaf area of wheat and 0.38 cm² (3.8%) of the barley of the offered leaves. Here, leaf area consumed was considered as a criterion to measure the larval damage and not the number of mines, as often number of mines does not give a clear indication of the damage. Peiia and Schaffer (unpublished data) found a poor correlation between the number of mines and the percentage of leaf damage; this was presumably due to the large variability in larval size and instars in a single leaf. Leaf area consumed by other leafminers is found by Knapp *et al.* (1995), in which one citrus leafminer larva could consume a leaf area between 1-7 cm² during the period of the entire larval stage (10-19 days). Our finding of the leaf area consumed/larva in 3 days is in agreement with the finding of Knapp *et al.* (1995), and contrasts that one reported by Sugiura and Yamazaki (2003), in which on average, one larva of the sawfly leafminer *Profenusa japonica* consumed 71% of the total area of a leaflet. At the average number of larvae/plant of the 27 wheat (3.15) and the 15 barley (2.60) accessions, and also by applying the models that correlated the number of larvae with straw dry mass, the straw biomass is estimated at 1.66 and 1.29 g/plant for wheat and barley, respectively. At the average number of larvae/ plant of the 27 wheat accessions (3.15) and of the 15 barley accessions (2.6), these larvae caused 14.9 and 12.3% reductions in the straw biomass, respectively.

In conclusion, the current study provides equations for predicting the loss due to leaf damage caused by *S. temperatella* larvae representing 27 wheat and 15 barley accessions. The models quantifying the grain yield loss at (x) percentage of infestation is ($y = -0.01x + 0.61$) for wheat and is ($y = -0.01x + 0.52$) for barley. The models quantifying the straw yield loss at (x) percentage of infestation is ($y = -0.03x + 2.21$) for wheat and is ($y = -0.01x + 1.58$) for barley. The average percentage of infestation of 22% (wheat) and 26% (barley) reduced the grain yield by 36.1% and 50%, respectively, and reduced the straw dry mass by 29.9% for wheat and 16.5% for barley. The leafminer damage for more than 40 accessions and/or cultivars of wheat and barley is larger for the grain yield than for the straw yield; which clarify the economic importance of the pest.

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