Ozberk F (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 2, Article number 13535
DOI:10.15835/nbha52213535
Research Article

Reaction of some hollow stem bread and durum wheat cultivars to wheat stem sawfly (*Cephus pygmaeus* L., Hymenoptera: Cephidae) infestation in Southeastern Anatolia

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Abstract

Wheat stem saw fly (WSS) (*Cephus pygmaeus* L.) is a notorious pest causing significant yield reductions in wheat crop. The use of tolerant cultivars is the most important management tactic against WSS. However, the reactions of frequently cultivated hollow-stemmed bread (*Triticum aestivum* L.) and durum (*Triticum durum* Desf.) wheat cultivars to WSS in southeastern Anatolia region of Türkiye are unknown. This study investigated the reactions of hollow-stemmed bread and durum wheat cultivars (twelve each) to WSS in Diyarbakir and Adiyaman provinces in southeastern Anatolia region during 2021-22. The cultivars were tested under field conditions and data relating to number of infested stalks (NIS), infestation ratio (IR), stalk wall thickness (SWT), spike length (SL), number of grains spike^{-1} (NGS), grain weight spike^{-1} (GWS), grain yield (GY) and grain yield loss were recorded. The tested wheat cultivars significantly differed for the NIS and GY at both locations. Similarly, SWT, NGS, SL, and GWS significantly differed among cultivars and higher values of these traits were recorded for healthy stalks than infested stalks. Overall, bread wheat cultivars i.e., 'Kale' (7127 and 5642 kg ha^{-1}), 'Dinç' (6788 and 5628 kg ha^{-1} and 'Hazar' (6249 and 5821 kg ha^{-1}) and durum wheat cultivars i.e., 'Zühre' (6261 and 5272 kg ha^{-1}) and 'Hasanbey' (6038 and 5141 kg ha^{-1}) with higher SWT recorded the highest grain yield at Diyarbakir and Adiyaman locations. Yield losses varied from 2.5% to 5.3% for bread wheat and 1.57% to 8.39% for durum wheat cultivars at Adiyaman and Diyarbakir, respectively. It is recommended that wheat cultivars with high GY and SWT should be planted to lower WSS infestation and yield losses in the region and breeding solid stem cultivars.

Keywords: bread and durum wheat cultivars; Saw fly damage; southeastern Anatolia; stalk wall thickness; yield losses

Introduction

Wheat stem sawflies (WSS) [*Cephus pigmeus* L., *Cephus cinthus*, *Trachelus tabidus* (F)] are common pests in the wheat growing areas of Europe, Mediterranean, West Asia and North Africa (Ozberk *et al.*, 2005). The WSS is an underestimated pest of wheat in Türkiye since its first report in 1906 (Altınayar, 1975; Özberk *et al.,* 2005; Mutlu, 2019). *Cephus pygmaeus* L. and *Trachelus tabidus* are the sawfly species infesting wheat in different wheat-growing regions of the country (Ozberk *et al.*, 2005; Korkmaz *et al.*, 2010; Tülek *et al.,* 2011).

Received: 24 Dec 2023. Received in revised form: 29 Apr 2024. Accepted: 15 May 2024. Published online: 21 May 2024.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Southeastern Anatolia (SEA) is known as durum wheat belt of the country and wheat is cultivated on ~1 million ha in the region with 2.60 million tons of wheat production including 1.46 million tons durum wheat production annually (TUIK, 2022). The SEA region has a mild winter, dry and hot summer with inadequate and irregular rainfall distribution. Wheat is grown under dryland condition in the region and significant outbreak of sunn pest (*Eurygaster integriceps* Puton) and WSS are recorded during dry seasons (Ozberk *et al.*, 2005). The WSS (*C. pygmaeus* and *C. tabidus*) have been reported as widespread pests of wheat in SEA and the Middle East (Altınayar, 1975; Raswani, 1981; Tulek, 2013; Mutlu, 2019).

The WSS adults emerge from the residues of previous crop in mid-May and remain active until mid-June in SEA (Mutlu *et al.*, 2019). They can feed on wild mustard (*Sinapis arvensis* L.) in early spring growing on the edge of wheat fields. The WSS looks for a convenient host plant for oviposition after mating. Wheat plants in the adjacent fields serve as the most convenient host plants for the female flies. A healthy female can lay ~50 eggs; therefore, population can increase exponentially. Larvae hatch within a week, commence boring the culm of wheat stem, which continues till physiological maturity. The moisture contents of the plant decrease at ripening, which gives an indication to the larvae to prepare for the winter. The larvae move into the base of stem, make a 'v shape' groove, fill around with frass, and hide itself in a thinly cocoon under the groove until next growing season (Criddle, 1922; 1923; Holmes, 1979; Mutlu, 2019; İnce *et al*., 2022a). The groove weakens the stem and results in toppling to ground. This makes the harvest recovery difficult (Ainslie, 1929). Furthermore, grain quality traits such as protein content and seed weight of WSS-damaged kernels are negatively affected (Seman *et al*., 1994; Morrill *et al*., 1992; Mutlu, 2019).

Stem boring-induced injury reduces the photosynthesis rate (Macedo *et al*., 2007). The injury also affects the nutrient and water flow into the developing spike resulting in fewer number of grains spike^{-1} and lower grain weight. Non-harvested toppled stalks result in an additional yield loss (Altınayar, 1975; Morrill *et al.,* 1992; Shanower, 2004; Beres *et al.,* 2007; Tulek *et al.,* 2013; Ince *et al*., 2022b). Hence, the overall yield reduction in wheat infested by WSS can reach ~25% (Beres *et al*., 2011). The infestation ratios ranging from 0.28% to 26.61% reduced yield by 0.9 % to 2.52% (Altınayar, 1975). The annual yield loss in Saskatchewan, Canada ranged from 1.4% to 10.3% between 1926-58 (Anonymous, 2002). Ozberk *et al.* (2005) reported 2.23 % yield loss in durum wheat (288 kg ha^{-1}) and 3.32% in bread wheat (297 kg ha^{-1}) in SEA.

The use of solid stem (SS) cultivars can mitigate crop losses and decrease WSS infestation (Bathini *et al.,* 2023). The SS cultivars can develop a pitch in the stem and prevent larva development (Holmes and Peterson, 1961; Bathini *et al.,* 2023). The recessive nature of stem solidness might result in some difficulties in variety improvement (Hayat *et al*., 1995). The SS cultivars are resistant to WSS and have higher concentrations of cellulose and lignin in the stem due to thicker cell walls compared to hollow stemmed (HS) cultivars. Kong *et al.* (2013) and Lavergne *et al.* (2020) suggested that mechanical changes and composition of HS cultivars are responsible for their susceptibility to WSS infestation. The WSS infestation in SS cultivars is hindered by several ways. Eggs may be destroyed by mechanical interference as well as antibiosis (Beres *et al.,* 2012; Holmes and Peterson, 1960, 1961). Furthermore, higher moisture content in pith may accelerate the hatching of WSS eggs and increase neonatal mortality (Holmes and Peterson, 1964). Furthermore, small larvae hardly chew through dense layers of pith in SS as the pith matures and becomes dry. Therefore, it acts as a physical barrier to larval nutrition and causes motility (Kemp, 1934). Unfortunately, no SS cultivars are currently available for cultivation in Türkiye. Therefore, selection of the tolerant HS cultivars could help to lower WSS infestation.

Agronomic and cultural strategies are effective for the management of WSS. Row spacing and sowing density can influence WSS infestation. Field mixtures of SS and HS cultivars with compatible maturity and marketing class attributes may be a feasible approach for WSS management (Luginbill and Mc Neal, 1958; Bowden *et al*., 2001; Beres *et al.,* 2011a; Beres *et al*., 2011b). The primary parasites of WSS are *Collyria calcitrator* Grav., *Bracon terebella* Wesm., *Pyroscytoides masi*, *Tetrastrchus* sp. and *Eurytoma* sp. in Central Anatolia (Altınayar, 1975; Korkmaz *et al.,* 2010). Although being less effective in keeping the WSS population

at lower levels, they recognize and attack the WSS larva of infested plants while the larva is proceeding to bottom of stem. The response of both bread and durum wheat cultivars to WSS infestation has seldom been investigated in Türkiye (Kılıc *et al*., 2017; İnce *et al*., 2022a, 2002b). Nevertheless, bread wheat seemed more susceptible to WSS in SEA region (Ozberk *et al.,* 2005).

This study investigated the reaction of different HS bread and durum wheat cultivars to WSS under natural conditions. It was hypothesized that the tested cultivars will differ in their susceptibility to WSS infestation. The results would help to identify the HS bread and durum wheat cultivars tolerant to WSS infestation.

Materials and Methods

Field trails were conducted at two different locations, i.e., Diyarbakir (DYB) 37.56°N, 43.15°E, 630 m asl, and Adiyaman (ADM) 37.50°N, 38.0°E, 650 m asl, with common WSS infestation. Experimental soil in DYB had reddish brown color and clay-loam texture (Ozkan *et al*., 2020), whereas ADM soil had brown color and sandy-loam texture. Wheat-food legume rotation is followed under rainfed condition in both locations. Twelve (12) durum and 12 bread wheat HS cultivars developed and released recently by the regional agricultural research institutes were cultivated under rainfed conditions. The names, pedigrees and traits of the tested bread and durum wheat cultivars are given in Table 1 and Table 2, respectively.

Table 1. Hollow-stemmed bread wheat cultivars used in the current study, their characteristics and pedigrees

Name	Pedigree	Traits
Ceyhan-99	BLUEJAY(SIB)/JUPATECO-73[144]BLUEJAY(SIB) COCORAQUE75[2400][2850]	Plant height = 75-85 cm, no lodging, medium tolerance to drought and cold, medium-late maturing type, Tolerance to yellow rust, average yield = 6320 kg/ha
Cemre	2Ca542C/Skorospelka/ Neuzuct/3/nac76	Medium plant height, no lodging, spring growing habit, tolerance to yellow rust, yield potential = 8500 kg/ha
Tekin	WBLL1*2/TUKURU	Plant height = medium, tall, (>110 cm), white spike color and awned, tolerance to yellow rust, yield potential = 800 kg/ha
Hilar	SAUAL/YANAC//SAUA	Plant height = medium, strong stem, long and white spike with awn, spring type, yield potential: 900 kg/da
Dinc	KAUZ/PASTÖR	Short plant height (<80 cm), strong stem, short spike, and white color with awn, tolerant to yellow rust
Cendere	No access	Plant height = 95-105 cm, strong stem, tolerance to drought, good tillering ability, no lodging, tolerance to yellow rust, yield potential = 7680 kg/dh
Amida	TUKURU//BAV92/RAYON/6/ NG8201/KAUZ/4/SHA7//PRL/ VEE#6/3/FASAN/5/MILAN/ KAUZ/7/TRCH/SRTU//KACHU CMSS10Y00314S-099Y-099M-099NJ-099NJ-27WGY-0B	Plant height = long (>110cm), spring growing habit, medium early heading, yield potential = 9700 kg/ha
Adana-99	PFAU/SERI-82//(SIB)BOBWHITE[2400][2850]	Plant height = 95-110 cm, strong stem, no lodging, white dense and awned spike, white semi hard grain, spring growing habit, susceptible to yellow rust,
Nurkent	Neelkant's'	Plant height = 100-1005 cm, spring growing habit and early maturing type, medium tolerance to cold, good tolerance to drought
Kale	KAUZ//STAR/LUCOM/5/ BOW/CROW//BUC/BUN/3/ VEE#10/4/TRAP#1	Plant height = dwarf, short dense spike, awned, waxy type, spring growing habit, tolerance to yellow rust, yield potential = 6340 kg/ha
Karacadag-98	Kop 's'	Plant height = 90-110 cm, medium long spike, red grain color, Alternative growing habit, susceptible to yellow rust, yield potential = 7360 kg/ha
Hazar	KAPKA-I.P./BILINMIYEN96.55 TCI061091 -0SE-0E-050E-050E-7YM-0E	Plant height = medium long, alternative growing habit, yield potential = 600 kg/ha, medium late maturing type

Weather data

Average annual precipitation of the experimental duration was ~30% lower than long-term average in DYB [348 mm in 2022-23 and long-term average: 496 mm (Kılıç *et al*., 2017) and 710.6 mm in ADM]. Although the total amount of precipitation was low, seasonal distribution was favorable for crop development in DYB. Adequate amount of rainfall was received during critical growth stages of wheat in DYB. Although ADM received twice of the precipitation in DYB, distribution was irregular and drought stress was experienced during grain filling stage, resulting in relatively lower grain yield. Excessive rainfall during October 2022 and March and April in 2023 resulted in surface run off or floats in some areas. Trends in annual precipitation and temperature were similar at both locations.

Table 2. Hollow-stemmed durum wheat cultivars used in the current study, their characteristics and pedigrees

Name	Pedigree	Traits
Artuklu	LAHN//GANSO/STORK	Spring type growing habit, medium plant height, waxy, spike highly waxy, cylindrical with white awns
Hasanbey	No access	Moderate plant height, waxy leaf sheet, waxy, white spike, light brown awns
Guney Yildizi	RASCON-39/TILD-1	Medium plant height (85-95 cm), no flag leaf rolling, waxy leaf sheet, spike short with white color, light brown awns
Eyyubi	MORUS//ALTAR 84/ALONDRA	Tall, alternative growing habit, white spike, waxy, brown awns, dense spike, medium length
Firat-93	AA"S"/VOL"S"//FG"S"/3/SHWA'S'	Dark grey or black spike color, plant height = 90-95 cm, lodging resistant, spring type, medium –early maturing, medium susceptible to cold, tolerant to drought and heat
Şahinbey	TOPDY-4-CD84785-3B-030YRL-040-PAP-1Y-0PAP	Grain yield = average 7000 kg/ha, moderate tolerance to yellow rust
Perre	Stn/Altar 84/3/Gs//Cndo	Plant height = 90-100 cm, shiny green color, white spike, semi erect, dense and 7-10 cm in length, no shattering
Saricanak-98	DAKI 'S'	Plant height = 80-90 cm, lodging resistant, spring type, medium-early maturing
Zuhre	SNTURK M183-84 375/NIGRİS S//TANTLO-1	Plant height = 85-95 cm, low flag leaf rolling, waxy leaf sheet, high yellow pigmentation
Diyarbakir-81	LL393//Bel116E/2*TC/3/CİT71	Plant height = 90-110 cm, tolerant to cold and lodging, medium maturing type, tolerance to rust diseases
Aydin-93	OMRABIA"S"	Plant height = 110-120 cm, lodging under supplementary irrigation, equal length tillers, erect type –medium spike with brown colored awns, small medium size kernel
Altıntoprak-98	Aconchi 89= Altar 84/Aos	Medium plant height, strong stem, no lodging, white spike color and awns, susceptible to leaf rust

Field trials were set up according to randomized complete block design with three replications in both locations. Seeds were sown on 16 November 2022 by a plot drill keeping seed rate of 500 grains m^{-2}. The plot size was 6 m × 6 rows (7.2 m^2) at planting and 5 m × 6 rows (6 m^2) at harvest. At sowing, 300 kg ha^{-1} of 20-20-0 N-P-K fertilizer was applied, and 150 kg ha^{-1} of urea was supplied at the late joining and early stem elongation stage. All necessary measures were taken for healthy and reliable results. Chemical control for weeds was done by appropriate chemicals (i.e., Tribenuron-methyl (12 g ha^{-1}) for broad leaves and Phenoxiprop-P-ethyl 500 cc ha^{-1}) for narrow leaf weeds. Agronomic and insect-related traits such as number of infested stalk $plot^{-1}$ (NIS) infestation ratio (IR), stalk wall thickness (SWT), number of grain $spike^{-1}$ (NGS), spike length (SL), grain weight $spike^{-1}$ (GWS), yield loss (YL) and grain yield (GY) were recorded. The GY and NIS were scored at plot level and the rest traits were scored from sampling in the plot by 0.25 m^2 quadrat.

Traits and scoring methods

The NIS was scored by counting the WSS-damaged and toppled stalks in plot by pulling out stems firmly from the whole plot. The GY was scored by weighing cleaned grain obtained from a 6 m^2 plot harvested by plot combined harvester. The rest of the traits were scored by sampling randomly selected 5 healthy and 5 infested stems derived from 0.25 m^2 quadrat. Infested spikes were detected by dissecting. The IR (%) was determined by the formula given below Mutlu *et al.* (2019).

$$\text{IR (\%)} = \frac{\text{Total number of infested stems}}{\text{Total number of examined stems}} \times 100$$

The SWT was measured from the third internode by manual caliper for healthy and infested stalks. The NGS were counted from five randomly selected healthy and infested spikes, and averaged. The SL was noted by measuring the length of spike excluding awns by a meter rod. The GWS was recorded by weighting the grains obtained from each spike. Similarly, YL was scored by the formula given by Altinayar (1975).

$$\text{YL (\%)} = \frac{\text{Infested stems (\%)} \times \text{ Grain weight reduction (\%)}}{100}$$

Statistical analysis

Data relating to measured traits were analyzed by analysis of variance (ANOVA) fulfilling the normality assumptions (Steel *et al.,* 1997). Means of the statistically significant cultivars were grouped by least significant difference (LSD) test at 95% probability. Paired t test was used to infer the differences between healthy vs infested stems for the measured traits. All analyses were executed on JMP11 statistical software.

Results

Number of infested stalks, infestation ratio and grain yield

The bread wheat (BW) and durum wheat (DW) cultivars significantly differed for NIS at both locations ($p \leq 0.01$). The NIS ranged from 12.66 to 48.05 in DYB and 9.33 to 30.33 in ADM. The 'Dinç', 'Ceyhan-99' and 'Nurkent' were the least affected cultivars, whereas 'Tekin' and 'Amida' were the most affected BW cultivars at both locations. The NIS ranged from 7.66 to 40.66 in DYB and from 6.33 to 18.33 in ADM for DW cultivars. The 'Sariçanak-98' and 'Hasanbey' were the least affected DW cultivars by WSS infestation at both locations (Table 3).

The BW cultivars significantly differed from each other for IR ($F= 2.83$ $p \leq 0.05$) at DYB, and ADM ($F=2.49$, $p \leq 0.054$). The IR ranged from 11.53% to 32.56% in DYB, and the cultivars 'Cendere' (11.53%), 'Dinc' (13.01%), and 'Kale' (14.64%) were the most infested at DYB. The IR ranged from 2.77% to 9.72% at ADM and the least affected cultivars were 'Hilar' (2.77%), 'Hazar' (2.95%), and 'Ceyhan-99' (3.04%).

The DW cultivars significantly differed for IR at DYB ($p<0.049$) and ADM ($p<0.05$). The 'Sarıcanak-98' (12.8%), 'Sahinbey' (14.66%), and 'Firat-93' (14.71%) were the most infested DW cultivars at DYB, whereas 'Artuklu' (1.41%), 'Sahinbey' (1.48%), and 'Firat-93' (1.64%) were the most infested DW cultivars at ADM (Table 4).

The BW cultivars significantly differed for GY at both locations ($F=2.83$, $p \leq 0.05$ and $F=3.55$, $p \leq 0.05$). The 'Kale' (7127 kg ha^{-1}), 'Dinç' (6788 kg ha^{-1}), 'Amida' (6578 kg ha^{-1}), 'Hazar' (6249 kg ha^{-1}) and 'Ceyhan-99' (6177 kg ha^{-1}) at DYB, and 'Hazar' (5821 kg ha^{-1}), 'Kale' (5642 kg ha^{-1}), 'Dinç' (5628 kg ha^{-1}), 'Hilar' (5555 kg ha^{-1}) and 'Nurkent' (5437 kg ha^{-1}) BW cultivars at ADM recorded the highest GY. Overall, DYB location had 15% higher mean yield than ADM.

The DW cultivars significantly differed ($F=2.09$, $P \leq 0.07$) for GY at DYB and ADM. The 'Saricanak-98', 'Zuhre' and 'Sahinbey' produced the highest GY, i.e., 6383 kg ha^{-1}, 6261 kg ha^{-1}, and 6250 kg ha^{-1},

respectively at DYB. Similarly, 'Guney yildizi', 'Perre', and 'Altıntoprak-98' produced the highest GY, i.e., 5546 kg ha^{-1}, 5368 kg ha^{-1}, and 5323 kg ha^{-1}, respectively at ADM (Table 3).

Table 3. The impact of different bread and durum wheat cultivars on of number of infested stalks (NIS), infestation ratio (IR) and grain yield (GY) under natural infestation of wheat stems sawfly in Diyarbakir and Adiyaman province of southeastern Anatolia

Cultivars	Diyarbakır			Adıyaman		
	NIS	GY (kg ha^{-1})	IR (%)	NIS	GY (kg ha^{-1})	IR (%)
Bread wheat						
Adana-99	30.66 a-c	4955.50 d	26.60 d	9.33 d	3357.97 d	9.72 c
Amida	38.05 ab	6578.28 a-c	21.80 b-d	30.33 a	5153.10 a-c	3.22 ab
Cemre	24.33 b-d	5766.66 cd	32.56 d	11.33 d	4423.30 c	7.18 bc
Cendere	26.00 c-d	6088.86 bc	11.53 a	16.0 cd	5135.50 a-c	6.22 a-c
Ceyhan-99	18.66 cd	6177.73 a-c	21.74 b-d	13.0 cd	5212.20 a-c	3.04 a
Dinc	12.66 d	6788.86 ab	13.01 ab	12.0 cd	5628.83 ab	3.96 ab
Hazar	32.00 a-c	6249.96 a-c	24.84 b-d	27.33 ab	5821.06 a	2.95 a
Hilar	20.00 b-d	5761.10 cd	22.99 b-d	20.33 bc	5555.50 ab	2.77 a
Kale	22.00 b-d	7127.76 a	14.64 a-c	18.0 cd	5642.20 ab	5.33 ab
Karacadag-98	46.33 a	5605.5 0cd	26.03 cd	19.0 b-d	5391.10 ab	6.21 a-c
Nurkent	13.33 d	6077.7 6bc	24.18 b-d	16.0 cd	5437.73 ab	6.15 a-c
Tekin	48.05 a	5428.28 cd	28.54 d	29.33 a	4855.53 bc	6.02 a-c
Durum wheat						
Altıntoprak-98	30.66 ab	5511.10 bc	21.43 a-c	12.33 ab	5323.20 a-c	7.57 b
Artuklu	20.33 a-c	5416.63 c	23.88 a-c	7.00 b	4788.83 a-c	1.41 a
Aydin-93	7.66 c	5483.40 c	23.16 a-c	13.66 ab	4643.26 a-c	1.80 a
Diyarbakir-81	24.75 a-c	5616.61 a-c	20.24 a-c	14.66 ab	4507.73 bc	6.80 ab
Eyyubi	16.33 bc	5466.66 c	33.80 bc	18.33 a	4396.63 c	5.45 ab
Firat-93	40.66 a	5405.50 c	14.71 a-c	16.00 ab	4811.10 a-c	1.64 a
Guney Yildizi	28.00 a-c	6011.06 a-c	21.34 a-c	8.84 ab	5546.90 a	6.39 ab
Hasanbey	11.33 bc	6038.86 a-c	18.79 a-c	7.00 b	5141.06 a-c	2.14 ab
Perre	12.33 bc	6072.20 a-c	35.68 c	9.50 ab	5368.64 a-c	4.04 ab
Şahinbey	14.66 bc	6250.00 ab	14.66 ab	11.66 ab	4828.86 a-c	1.49 a
Saricanak-98	8.66 c	6383.33 a	12.80 a	6.33 b	4768.83 a-c	3.06 ab
Zuhre	28.66 a-c	6261.06 ab	18.59 a-c	9.00 ab	5272.16 a-c	3.04 ab

The means followed by different letters are statistically different from each other ($p \leq 0.01$)

Stem wall thickness, spike length, number of grains per spike, and grain weight per spike of healthy and infested stalks of bread and durum wheat cultivars

The STW significantly differed among BW cultivars at DYB ($F= 2.42$, $p \leq 0.001$, CV = 11%). Overall, SWT for infested stems was lower than healthy stems. Infested stalks of BW cultivar 'Kale', and healthy stalks of BW cultivars 'Hilar', 'Cemre' and 'Amida' recorded the highest (0.38, 0.37, 0.37 and 0.36 mm, respectively) SWT at DYB (Table 4). The SWT of healthy and infested stems of same cultivar was further tested by paired t test (Table 5). The overall SWT of healthy stems was 0.346 mm, whereas it was 0.335 for infested stems with a non-significant t value ($t= -2{,}07^{ns}$, df:11). The BW cultivars grown at ADM also exhibited significant differences for SWT ($F= 3.63$, $p \leq 0.001$, CV = 10%). Infested 'Tekin', infested 'Hilar', healthy 'Tekin', and healthy and infested 'Amida' recorded the highest SWT at ADM (0.36, 0.35, 0.348, 0.344, and 0.341 mm, respectively) (Table 4).

Table 4. Stalk wall thickness (SWT, mm), number of grains per spike (NGS), spike length (DL, cm) and grain weight per spike (GWS, g) obtained from healthy and infested plants of different bread wheat cultivars grown under natural infestation of wheat stem sawfly in southeastern Anatolia

Cultivars	Diyarbakır				Adiyaman			
	SWT (mm)	NGS	SL (cm)	GWS (g)	SWT (mm)	NGS	SL (cm)	GWS (g)
Healthy								
Adana 99	0.339 c-f	45.00 e-j	9.58 a-d	1.666 fg	0.317 e-g	46.4	8.34 e-h	1.826 d-g
Amida	0.358 a-c	55.33 a-c	9.20 a-e	2.246 a-c	0.344 a-c	44.53	9.65 b	1.900 b-f
Cemre	0.369 ab	41.46 h-k	10.0 2ab	1.586 fg	0.305 fg	45.86	6.76 jk	1.900 b-f
Cendere	0.332 c-f	40.33 ı-k	8.96 b-f	1.766 e-g	0.337 a-e	54.32	8.56 c-f	2.324 a
Ceyhan 99	0.338 c-f	49.13 c-h	8.84 c-f	1.800 c-f	0.327 b-f	44.73	8.59 c-f	1.793 e-g
Dinç	0.348 b-e	59.13 ab	9.47 a-d	2.493 a	0.308 fg	46.93	7.86 f-ı	2.073 a-e
Hazar	0.342 b-f	55.6 1a-c	8.79 c-f	2.249 a-c	0.322 c-g	50	8.46 d-g	2.200 a-c
Hilar	0.369 ab	61.72 a	8.46 d-g	2.47 2a	0.336 b-e	52.78	8.34 e-h	2.099 a-e
Kale	0.345 b-f	50.61 c-g	9.33 a-e	2.237 a-d	0.319 d-g	48.53	8.08 f-h	1.840 d-g
Karacadağ 98	0.338 c-f	50.46 c-g	8.57 c-f	2.273 ab	0.324 c-g	50.36	8.13 f-h	2.143 a-d
Nurkent	0.332 c-f	54.48 a-d	8.15 eg	2.315 ab	0.317 e-g	50.66	7.49 h-j	1.933 b-f
Tekin	0.349 b-e	45.26 e-j	9.33 a-e	1.733 e-g	0.348 ab	51.6	9.19 b-e	2.233 ab
Infested								
Adana 99	0.316 f	46.40 d-j	9.68 a-c	1.620 fg	0.312 f-g	40.86	8.13 f-h	1.533 g-ı
Amida	0.334 c-f	51.33 b-f	8.74 c-f	1.986 b-f	0.341 a-d	32.66	9.25 b-d	1.360 h-j
Cemre	0.336 c-f	33.8 6k	9.33 a-e	1.346 g	0.302 g	42.53	6.42 k	1.680 f-h
Cendere	0.339 c-f	38.40 jk	8.60 c-f	1.726 e-g	0.329 b-f	41	9.82 b	1.353 h-j
Ceyhan 99	0.322 ef	43.66 f-j	8.54 c-f	1.593 fg	0.307 fg	32.32	9.16 b-e	1.113 j
Dinç	0.326 d-f	47.26 c-ı	8.48 d-f	1.786 d-g	0.316 e-g	41.46	7.07 ı-k	1.893 b-f
Hazar	0.343 b-f	52.68 b-e	8.21 e-g	2.230 a-d	0.309 fg	43.46	8.06 f-h	1.866 c-g
Hilar	0.354 a-d	53.73 a-d	8.63 c-f	2.126 a-e	0.349 ab	59.2	9.38 bc	2.241 ab
Kale	0.380 a	48.93 c-h	10.29 a	1.993 b-f	0.306 fg	43.13	7.64 g-ı	1.653 f-ı
Karacadağ 98	0.317 f	42.46 g-j	7.90 fg	1.880 b-f	0.311 fg	40.17	8.05 f-h	1.298 ıj
Nurkent	0.323 ef	48.66 c-ı	7.29 g	2.126 a-e	0.305 fg	39.26	7.55 h-j	1.380 h-j
Tekin	0.338 c-f	52.40 b-e	8.96 b-f	1.733 e-g	0.361 a	55.58	11.72 a	1.845 d-g

SWT = stem wall thickness, NGS = number of grains per spike, SL = spike length, GWS = grain weight per spike, the means followed by different letters are significantly different from each other ($p \leq 0.01$).

The NGS ranged from 33.86 to 61.72 and healthy stalks of 'Hilar', 'Dinc', 'Hazar', 'Amida', and 'Nurkent' produced the highest NGS (61.72, 59.13, 55.61, 55.33 and 54.48, respectively) at DYB (Table 4). Overall NGS for healthy and infested stems of BW cultivars was 50.71 and 46.64, respectively at DYB, and paired t test indicated significant differences among healthy and infested stems ($t= -2.80$, $p \leq 0.017$) (Table 5). Significant differences were recorded among the tested BW cultivars for NGS at ADM ($F=6.44$, $p \leq 0.0001$). The NGS ranged from 32.32 to 59.20 with infested stems of 'Hilar' and 'Tekin', and healthy stems of 'Cendere', 'Hilar', and 'Tekin' produced the highest NGS (59.20, 55.58, 54.32, 52.78, and 51.6, respectively) at ADM (Table 4). Overall healthy and infested stems was 48.89, and 46.63, respectively and paired t test indicated that these differences were significant ($t = -3.43$, $p=0.0055$) (Table 5).

Table 5. Paired t test for yield-related traits of health and infested plants of bread and durum wheat cultivars grown under natural infestation of wheat stem sawfly in southeastern Anatolia

Traits	Bread wheat				Durum wheat			
	Diyarbakir		Adiyaman		Diyarbakir		Adiyaman	
	Healthy	Infested	Healthy	Infested	Healthy	Infested	Healthy	Infested
SWT (mm)	0.346	0.335	0.325	0.320	0.342	0.337	0.335	0.326
T statistics	-2.07		-1.487		-1.49		0.38	
P value	0.062ns		0.164ns		0.164ns		0.19ns	
NGS^{-1}	50.71	46.64	48.89	42.63	56.4	50.72	49.0	41.27
T statistics	-2.80		-3.43		-4.78		-3.43	
P value	0.017		0.0055		0.0006		0.0064	
SL (cm)	9.05	8.72	8.28	8.52	8.47	8.75	9.62	9.44
T statistics	-2.187		0.845		2.091		-0.82	
P value	0.0512ns		0.4158ns		0.0605ns		0.42ns	
GWS^{-1} (g)	2.06	1.83	2.06	1.83	2.36	2.01	1.92	1.43
T statistics	-4.22		-4.22		-4.38		-5.65	
P value	0.0014		0.0014		0.0011		0.0002	

ns = non-significant

The BW cultivars grown at DYB significantly differed from each other for SL (CV = 18%, F = 2.64, p≤ 0.001). The SL ranged from 7.29 to 10.29 cm, and healthy plants of 'Kale', 'Cemre', 'Adana-99', and 'Dinc', and infested plants of 'Adana-99' cultivar recorded the highest SL at DYB (10.29, 10.02, 9.58, 9.47, 9.68, cm, respectively) (Table 4). Overall SL of healthy and infested plants was 9.05 and 8.72 cm, respectively, which was statistically non-significant (t = -2.187, p=0.0512ns) (Table 5). Similarly, BW cultivars sown in ADM significantly differed from each other for SL (CV = 14%, F = 12.83, p≤0.0001). The SL ranged between 6.42 and 11.72 with the longest spikes were produced by infested 'Tekin', healthy 'Cendere', healthy and infested 'Amida', and healthy 'Tekin' cultivars (11.72, 9.82, 9.65, 9.38 and 9.25 cm, respectively) (Table 4). Overall SL of healthy and infested plants of BW cultivars at ADM was 8.28 and 8.52 cm, respectively, which was statistically non-significant (t = 0.845, p = 0.4158ns) (Table 5).

The BW cultivars grown at DYB significantly differed for GWS (CV = 31%, F = 3.72, p≤ 0.001). The GWS of BW cultivars at DYB ranged from 1.34 to 2.49 g and healthy plants of 'Dinc', 'Hilar', 'Nurkent', 'Karacadag-98', and 'Hazar' cultivars resulted in the highest GWS (2.29, 2.47, 2.31, 2.27, and 2.24 g, respectively) (Table 4). Overall, healthy, and infested plants of BW cultivars recorded 2.06 and 1.83 g GWS, respectively which was statistically significant (t = -4.22, p=0.0014) (Table 5). Similarly, BW cultivars sown at ADM significantly differed from each other for GWS (CV = 25%, F = 6.84, p≤0.0001). The GWS ranged from 1.11 to 2.32 g and healthy plants of 'Cendere', 'Tekin', 'Hazar', and 'Karacadag-98' cultivars, and infested plants of 'Hilar' cultivars resulted in the highest GWS (2.32, 2.23, 2.20, 2.14, and 2.24 g, respectively) at ADM (Table 4). Overall GWS of healthy and infested plants of BW cultivars at ADM was 2.04 and 1.64 g, respectively and statistically significant differences were recorded among healthy and infested plants (t = -4.634, p = 0.0007) (Table 5).

The DW cultivars significantly differed for SWT (F=4.89, p≤0.001). Infested stems had lower SWT compared with healthy stems. Healthy and infested stems of 'Eyyubi', healthy stems of 'Zuhre', and 'Aydin-93', and infested stems of 'Saricanak-98' recorded the highest SWT at DYB (0.38, 0.37, 0.369, 0.362 and 0.36 mm, respectively) (Table 6). The paired t test between SWT of healthy and infested stems revealed non-significant differences (t= -1,49ns, df = 11) (Table 5). The DW cultivars grown in ADM significantly differed for SWT (F= 4.58, p≤0.001). The highest SWT was recorded for healthy stems of 'Hasanbey', 'Firat-93', 'Saricanak-98', and infested stems of 'Firat-93' (0.366, 0.358, 0.355 and 0.355 mm, respectively) (Table 6). Paired t test indicated non-significant differences among healthy and infested stems of DW cultivars grown at ADM (t= -1,38ns, df = 10). Overall SWT of healthy and infested stems was 0.335, and 0.326 mm, respectively (Table 5).

The DW cultivars grown at DYB significantly differed from each other for NGS (F=3.13, p ≤0.0001). The NGS produced by DW cultivars at DYB ranged from 44.4 to 64.57, and healthy stems of 'Eyyubi', 'Aydin-

93', 'Zuhre', 'Perre', and infested stems of 'Eyyubi' resulted in the highest NGS (64.57, 59.8, 58.33, 58.20, and 58.26, respectively) at DYB (Table 6). Paired t test indicated significant differences among healthy and infested stems of DW cultivars at DYB (t = -4.78, p =0.0006) (Table 5). Significant differences were recorded among DW cultivars grown at ADM for NGS (CV = 23%, F = 4.59, p≤ 0.0001). The NGS produced by DW cultivars at ADM varied between 34.6 and 53.73. Healthy stems of 'Eyyubi', 'Saricanak-98', 'Guney yildizi', and 'Diyarbakir-81' and infested stems of 'Saricanak-98' recorded the highest NGS (53.73, 51.46, 51.0, 50.86, and 51.93, respectively) at ADM (Table 6). The overall NGS produced by healthy and infested stems of DW cultivars at ADM was 49.0 and 41.27, respectively which was statistically significant (Table 5).

The DW cultivars grown at DYB significantly differed for SL (F = 7.21, p ≤0.0001). The longest spikes at DYB were produced by infested and healthy plants of 'Zuhre', and infested plants of 'Firat-93', 'Saricanak-98', and 'Altintoprak-98' (10.62, 10.12, 9.94, 9.86, and 9.84, respectively) (Table 6). The overall SL of healthy and infested plants of DW cultivars at DYB was 8.47 and 8.75 cm, respectively, which was statistically non-significant (t = 2.091, p = 0.0605ns) (Table 5). The DW cultivars sown in ADM significantly differed from each other for SL (F = 9.03, p≤ 0.0001). The SL varied from 6.58 to 11.53 cm at ADM. Healthy and infested plants of 'Hasanbey' and 'Sahinbey', and infested plants of 'Firat-93' produced the longest spikes at ADM (11.53, 11.18, 11.13, 10.62 and 10.46 cm, respectively) (Table 6). The overall SL mean of DW cultivars at ADM was 9.62 and 9.44 cm, respectively, which was non-significant (t = -0.82, p = 0.42ns) (Table 5).

The DW cultivars grown at DYB significantly differed for GWS (F=3.91, p =0.0001). The GWS of DW cultivars at DYB ranged from 1.76 to 2.92 g and healthy plants of 'Eyyubi', 'Şahinbey', 'Diyarbakir-81', 'Hasanbey' and 'Altıntoprak-98' cultivars resulted in the highest GWS (2.92, 2.62, 2.52, 2.46, and 2.42 g, respectively) (Table 6). Overall, healthy, and infested plants of all DW cultivars recorded 2.36 and 2.01 g GWS, respectively which was statistically significant (t = -4.38, p = 0.0011) (Table 5). Similarly, DW cultivars sown at ADM significantly differed from each other for GWS (F = 7.07, p≤ 0,0001). The GWS ranged from 1.13 to 2.37 g and healthy plants of 'Artuklu', 'Firat-93', 'Hasanbey', 'Eyyubi', and 'Perre' cultivars resulted in the highest GWS (2.27, 2.13, 2.07, 2.02, and 2.00 g, respectively) at ADM (Table 6). The grand mean of healthy and infested plants of DW cultivars at ADM was 1.92 and 1.43 g, respectively and statistically significant differences were recorded among healthy and infested plants for GWS (t = -5.65, p = 0.0002) (Table 5).

Table 6. Stalk wall thickness (SWT, mm), number of grains per spike (NGS), spike length (SL, cm) and grain weight per spike (GWS, g) obtained from healthy and infested plants of different durum wheat cultivars grown under natural infestation of wheat stem sawfly in southeastern Anatolia

Cultivars	Diyarbakır				Adiyaman			
	SWT (mm)	NGS	SL (cm)	GWS (g)	SWT (mm)	NGS	SL (cm)	GWS (g)
Healthy								
Altıntoprak 98	0.340 c-f	56.60 a-e	8.83 d-g	2.426 b-e	0.342 a-d	48.73 a-d	10.38 a-e	1.813 b-e
Artuklu	0.288 h	44.78 fg	6.68 j	2.205 c-ı	0.335 b-f	50.26 a-c	8.86 g	2.273 a
Aydın 93	0.362 a-c	59.80 ab	8.44 e-h	2.426 b-e	0.338 b-e	41.26 d-h	10.1 6b-f	1.593 d-h
Diyarbakır 81	0.328 e-g	57.53 a-d	7.60 h-j	2.526 a-c	0.330 c-f	50.86 ab	9.24 e-g	1.926 b-d
Eyyubi	0.382 a	64.57 a	8.62 e-h	2.926 a	0.344 a-d	53.73 a	10.02 c-f	2.026 a-c
Fırat 93	0.324 f-g	45.33 fg	8.92 c-f	1.793 jk	0.355 a-c	48.13 a-d	8.97 fg	2.131 ab
Güneyyıldızı	0.326 e-g	58.00 a-d	7.56 h-j	2.380 b-g	0.312 f-h	51.00 ab	7.71 hı	1.840 b-e
Hasanbey	0.349 b-f	58.13 a-c	9.04 b-f	2.466 b-d	0.366 a	50.74 a-c	11.5 3a	2.079 ab
Perre	0.335 c-f	58.20 a-c	8.62 e-h	2.206 c-ı	0.328 d-f	45.60 b-e	8.33 gh	2.000 a-c
Şahinbey	0.358 a-d	57.53 a-d	8.03 f-ı	2.626 ab	0.324 d-g	43.33 c-f	11.18 ab	1.633 d-g
Sarıçanak 98	0.353 b-e	50.93 c-g	9.27 b-e	2.073 d-k	0.338 b-e	51.46 ab	9.46 d-g	1.933 a-d
Zühre	0.369 ab	58.33 a-c	10.12 ab	2.420 b-f	Na	na	na	na
Infested								
Altıntoprak 98	0.347 b-f	54.86 b-d	9.84 a-d	1.886 ı-k	0.345 a-d	42.33 d-g	10.23 b-e	1.373 f-ı
Artuklu	0.302 gh	44.40g	6.79 j	2.000 g-k	0.298 h	41.86 d-h	8.55 gh	1.446 f-ı
Aydın 93	0.348 b-f	51.46 c-g	8.56 e-h	2.053 e-k	0.332 b-f	42.39 d-g	10.38 a-e	1.311 ı
Diyarbakır 81	0.303 gh	49.80 d-g	7.10 ıj	2.066 e-k	0.336 b-f	39.97 e-h	8.55 gh	1.257 hı

Eyyubi	0.370 ab	58.26 a-c	9.10 b-f	2.293 b-h	0.342 a-d	34.60 h	10.14 b-f	1.260 hı
Fırat 93	0.332 d-f	52.46 b-g	9.94 a-c	2.026 f-k	0.358 ab	47.86 a-d	10.46 a-d	1.686 c-f
Güneyyıldızı	0.324 f-g	52.86 b-f	7.65 h-j	2.173 c-j	0.292 h	38.00 f-h	6.58 ı	1.353 f-ı
Hasanbey	0.341 c-f	50.80 c-g	9.17 b-e	2.013 g-k	0.316 e-h	37.76 f-h	10.62 a-d	1.135 ı
Perre	0.333 d-f	49.00 e-g	8.64 e-h	1.766 k	0.340 a-e	35.13 gh	8.50 gh	1.553 e-h
Şahinbey	0.340 c-f	48.66 e-g	7.79 g-j	1.913 h-k	0.299 gh	42.20 d-g	11.13 a-c	1.426 f-ı
Sarıçanak 98	0.360 a-d	54.60 b-d	9.86 a-d	2.133 c-k	0.355 a-c	51.93 ab	8.73 gh	1.980 a-c
Zuhre	0.348 b-f	48.66 e-g	10.6 2a	1.953 h-k	Na	na	na	na

SWT = stem wall thickness, NGS = number of grains per spike, SL = spike length, GWS = grain weight per spike, the means followed by different letters are significantly different from each other ($p \leq 0.01$).

Yield loss (%)

The yield loss (YL) ranged from 0 to 4.92 % in BW cultivars grown at DYB with an average loss of 2.46±0.459. The cultivar 'Tekin' observed no loss in grain weight and yield DYB. The YL in BW cultivars grown at ADM ranged between 0 and 2.60% with an average YL of 1.237±0.232. The 'Hilar' cultivar recorded no grain weight and YL at ADM. The YL in DW cultivars sown at DYB ranged between 0 and 7.267% with an average YL of 1.14%±0.57. The DW cultivars 'Saricanak-98' and 'Firat-93' recorded no grain weight and YL at DYB. Similarly, the YL in DW cultivars sown at ADM varied from 0 to 2.40% with an average YL of 1.231%±0.21. The DW cultivar 'Saricanak-98' recorded no grain weight and YL at ADM (Table 7).

Table 7. Infestation ratio (IR, %), grain weight loss (GWL, %) and yield loss (YL, %) for durum and bread wheat cultivars grown under natural infestation of wheat stem sawfly

Cultivars	BW in DYB			BW in ADM		
	IR (%)	GWL (%)	YL (%)	IR (%)	GWL (%)	YL (%)
Ceyhan-99	21.74	11.66	2.53	3.049	37.98	1.15
Cemre.	32.56	15.13	4.92	7.179	11.57	0.83
Tekin	28.54	0	0	6.024	17.04	1.02
Hilar	22.99	13.76	3.16	2.773	0	0
Dinc	13.01	28.51	3.70	3.964	8.69	0.344
Cendere	11.53	9.62	1.10	6.219	41.81	2.60
Amida	21.80	11.57	2.52	3.225	28.42	0.916
Adana-99	26.60	2.40	0.638	9.72	15.93	1.54
Nurkent	24.18	7.79	1.88	6.15	28.49	1.75
Kale	14.64	14.75	2.15	5.33	10.32	0.55
K.dag-98	26.03	17.18	4.47	6.214	39.71	2.46
Hazar	24.84	0.44	0.10	2.955	15.45	0.456
Grand mean± SE	2.46±0.459			1.237±0.232		
	DW in DYB			DW in ADM		
Artuklu	23.88	9.09	2.17	1.415	36.56	0.517
Hasanbey	18.79	18.44	3.46	3.049	45.19	1.37
G.Yildizi	21.34	8.82	1.88	6.802	26.63	1.81
Eyyubi	33.80	21.5	7.267	6.396	37.62	2.40
Firat-93	14.71	0	0	1.641	21.12	0.346
Sahinbey	14.66	27.00	3.958	1.488	1226	1.82
Perre	35.68	20.00	7.136	5.451	22.5	1.22
Saricanak-98	12.80	0	0	2.144	0	0
Zuhre	18.59	19.42	3.61	4.047	n.a	0
Diyarbakir-81	20.24	18.25	3.69	3.069	34.63	1.06
Aydin-93	23.16	15.28	3.53	7.576	17.61	1.33
Altintoprak-98	21.43	22.31	4.78	1.804	24.30	0.438
Grand mean± SE	4.14±0.57			1.231±0.21		

DYB = Diyarbakir, ADM = Adiyaman, BW = bread wheat, DW = durum wheat, the means followed by different letters are significantly different from each other ($p \leq 0.01$).

Discussion

A regular rainfall distribution in spring is vital for successful wheat production in SEA. Excessive precipitation during spring at ADM was not utilized by the crop, resulting in lesser grain yield than DYB. The BW cultivars produced higher yield than DW cultivars at both locations. The yield gap between these two wheat species can be attributed to their genetic yield potential as genetic yield potential of DW is a little lower than BW in SEA (Bagcı and Ekiz, 1993).

Field trials had a lower CV showing reliability of study results; therefore, BW and DW cultivars expressed their yield potential under natural WSS infestation. The IR was higher in DYB than ADM for both wheat classes. This was also confirmed by NIS. The differences in the IR at different experimental sites can be owed to differential parasitism rate at the locations (Mutlu *et al*., 2019). A drought episode was experienced at DYB during wheat growing season which could also be responsible for higher WSS infestation and reduced GY. The DW and BW cultivars suffered from WSS infestation at both experimental sites. A higher IR in BW than DW has been reported from neighboring province of the experimental sites earlier (Ozberk *et al*., 2005). Replications were significant in the current study, which is evidence of higher WSS infestation in the blocks close to edge of experimental field with high wild mustard abundance. Similar findings have been reported earlier (Runyon *et al.,* 2002; Weaver *et al.,* 2005; Nansen *et al*., 2005; Knodel *et al.,* 2010).

Sampling-based paired t test indicated that SWT of WSS-damaged stems was significantly lower than healthy ones. The cultivars with higher SWT resulted in higher yield. The protective effect of higher SWT from WSS has been reported by a project finding in Lincoln, Nebraska in 2022 (*https://projects.sare.org/project-reports/lnc21-451/*). This might be used as a selection criterion in breeding programs.

The results for NGS and GWS were reliable with acceptable CV. The overall mean NGS and GWS of healthy stems were higher than infested confirming findings of Kılıç *et al.* (2017), Peterson *et al.* (2016), and Tulek *et al*. (2011). A strong correlation between NGS and GWS indicated these as major yield-related traits which should be utilized in breeding programs (Yagbasanlar, 1996; Sozen and Yagdı, 2005; Bilgin *et al*., 2008; Kınacı *et al.,* 2008).

The YL was the most important trait, which was higher in DYB than ADM for both wheat classes. Average YL for BW varied from 1.23 to 2.46% in ADM and DYB, respectively. The YL in DW varied from 1.23 to 4.14% at ADM and DYB, respectively. Kılıç *et al*. (2017) reported similar YL in the region. Ozberk *et al*. (2005) also indicated that a YL of 3.32 and 2.23 % for BW and DW, respectively resulting in a loss of 68 $ ha^{-1}. This indicates that nearly the same amount of yield and economic loss are inevitable for this study. Although the solid stem varieties can be used as a management option against WSS, grain yield loss should not be neglected (McNeal *et al.,* 1965).

The HS BW cultivars 'Kale', 'Dinc' and 'Hazar', and HS DW cultivars 'Perre', 'Zuhre' and 'Hasanbey' observed the highest values for yield-related traits under natural WSS infestation. Therefore, these are promising cultivars for future breeding programs. Although BW cultivars 'Tekin' and 'Hilar' and DW cultivars 'Saricanak-98' and 'Firat-93' were not high-yielding, these did not suffer from YL under natural WSS infestation. Therefore, these cultivars could also be used for breeding purposes. Apart from agronomic practices such as optimizing plant density for lower WSS infestation, field mixtures of compatible two or three hollow and semi solid stem BW cultivars with high SWT (Beres *et al.,* 2011) and yield should be planted in the region considering the climate change evidence in the region (Ozberk *et al*., 2022).

Conclusions

The bread wheat cultivars 'Kale', 'Dinç', and 'Hazar' and durum wheat cultivars 'Zühre' and 'Hasanbey' produced higher yield under natural WSS compared to the rest of the hollow stem bread and durum wheat

cultivars. The WSS-induced yield losses ranged from 2.5% to 5.3% for bread wheat and 1.57% to 8.39% for durum wheat cultivars. Therefore, it is advisable to consider planting wheat cultivars that exhibit high resistance to WSS for mitigating infestation and subsequent production losses. The bread wheat cultivars 'Kale', 'Dinç', and 'Hazar' and durum wheat cultivars 'Zühre' and 'Hasan bey' can be used for improving WSS tolerance and breeding of tolerant varieties.

Authors' Contributions

The author read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 120O412. The author thanks to TUBITAK for their supports.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Ainslie CN (1929). The western grass-stem sawfly: A pest of small grains. USDA Tech. Bull. 157. USDA, Washington, DC.

Altınayar G (1975). Ekin Sap Arıları [*Cephus pygmaeus* (L.) ve *Trachelus tabidus* (F.) Hymenoptera: Cephidae)]'nın Konya İlinde Biyo-Ekolojileri, Sebep Oldukları Ürün Kayıpları ve Savaş Yolları Üzerinde Araştırmalar. [Research on the bio-ecology of wheat stem sawflies [*Cephus pygmaeus* (L.) and *Trachelus tabidus* (F.) Hymenoptera: Cephidae)] in Konya province, crop losses and their management]. Ankara Bölge Zirai Mücadele Araştırma Enstitüsü Müdürlüğü Yayınları Araştırma Eserleri Serisi No: 36, 135.

Anonymous (2002). Wheat stem sawfly. Agriculture, Food and Rural Development, Alberta, Canada. *http://www1.agric.gov.ab.ca/department/deptdocs.nsf*

Bağcı SA, Ekiz H (1993). Makarnalık buğdayın verim potansiyeli ve problemleri. Makarnalık Buğday ve Mamülleri Sempozyumu, 30 Kasım- 3 Aralık, Ankara, Turkey. [Yield potential and problems of durum wheat. Durum Wheat and Products Symposium, 30 November - 3 December, Ankara, Turkey].

Bathini A, Mendu L, Singh NP, Cook J, Weaver D, Sherman J, Mendu V (2023). A "solid" solution for wheat stem sawfly (Hymenoptera: Cephidae) resistance: Genetics, breeding and development of solid stem wheat. Crop Science 63(4):1934-1948. *https://doi.org/10.1002/csc2.20998*

Beres B, Cárcamo HA, Byers JR (2007). Effect of wheat stem sawfly damage on yield and quality of selected Canadian spring wheat. Journal of Economic Entomology 100:79-87. *https://doi.org/10.1603/0022-0493(2007)100[79:EOWSSD]2.0.CO;2*

Beres BL, Cárcamo HA, Weaver DK, Dosdall LM, Evenden ML, Hill BD, McKenzie RH, Yang RC, Spaner DM (2011a). Integrating the building blocks of agronomy and biocontrol into an IPM strategy for wheat stem sawfly. Prairie Soils and Crops 4:54-65.

Beres BL, Dosdall LM, Weaver DK, Spaner DM, Cárcamo HA (2011b). The biology and integrated management of wheat stem sawfly, *Cephus cinctus* (Hymenoptera: Cephidae), and the need for continuing research. The Canadian Entomologist 143:105-125. *https://doi.org/10.4039/n10-056*

Beres BL, McKenzie RH, Cárcamo HA, Dosdall LM, Evenden ML, Yang RC, Spaner DM (2012). Influence of seeding rate, nitrogen management, and micronutrient blend applications on pith expression in solid-stemmed Spring wheat. Crop Science 52(3):1316-1329. *https://doi.org/10.2135/cropsci2011.05.0239*

Bilgin O, Korkut KZ, Başer I, Dağlıoğlu O, Öztürk I, Kahraman T (2008). Determination of variability between grain yield components of durum wheat varieties (*Triticum durum* L.) in Thrace Region. Journal of Tekirdağ Agricultural Faculty 5(2):101-109.

Bowden R, Shroyer J, Roozeboom K, Claassen M, Evans P, Gordon B, ... Witt M (2001). Performance of wheat variety blends in Kansas. Kansas State University Agricultural Experiment Station and Cooperative Extension Service Manhattan, Kansas, USA.

Boz DP (2020). Kızıltepe'de bazı ekmeklik buğday tarla paçallarının incelenmesi. YL Tezi. Fen Bil. Ens. Harran Üniversitesi, Şanlıurfa. [Examination of some bread wheat field blends in Kızıltepe. Master's Thesis. Institute of Science, Harran University, Şanlıurfa].

Cereal Sector Report (2020). Retrieved 2023 July 23 from: *https://www.tmo.gov.tr/Upload/Document/sektorraporlari/hububat2020.pdf*

Criddle N (1922). The western wheat stem sawfly and its control. Dominion of Canada, Department of Agriculture Pamphlet No. 6, New Series 1-8.

Criddle N (1923). The life habits of *Cephus cinctus* Nort. in Manitoba. The Canadian Entomologist 55:1-4. *https://doi.org/10.4039/Ent551-1*

Dinc M (2018). Diyarbakır bölgesi için bazı ekmeklik buğday tarla paçallarının incelenmesi. YL Tezi. Fen Bil. Ens. Harran Üniversitesi, Şanlıurfa. [Examination of some bread wheat field blends for the Diyarbakır region. Master's Thesis. Institute of Science, Harran University, Şanlıurfa].

Freedman D, Pisani R, Purves R (2007). Statistics (international student edition). In: Pisani R (Ed). Purves, 4th edn. WW Norton & Company, New York.

Hayat MA, Martin JM, Lanning SP, McGuire CF, Talbert LE (1995). Variation for stem solidness and its association with agronomic traits in spring wheat. Canadian Journal of Plant Science 75:775-780. *https://doi.org/10.4141/cjps95-131*

Holmes N, Peterson L (1960). The influence of the host on oviposition by the wheat stem sawfly, *Cephus cinctus* Nort. (Hymenoptera: Cephidae). Canadian Journal of Plant Science 40(1):29-46. ttps://doi.org/10.4141/cjps60-004

Holmes ND (1979). The wheat stem sawfly. In: Philip HG (Ed). Proc. of the 26th Annual Meet. of the Entomological Soc. of Alberta, Lethbridge, AB. 19–21 Oct. 1979. Vol. 26. Entomol. Soc. of Alberta, Lethbridge, pp 2-13.

Holmes ND, Peterson LK (1961). Resistance of spring wheats to the wheat stem saw fly, *Cephus cinctus* Nort. (Hymenoptera: Cephidae) I. Resistance to the egg. The Canadian Entomologist 93:250-260. *https://doi.org/10.4039/Ent93250-4*

Holmes ND, Peterson LK (1964). Resistance to the wheat stem sawfly, *Cephus cinctus* Nort. The Canadian Entomologist 96(1-2):120. *https://doi.org/10.4039/Ent96120-1*

İnce HU, Canhilal R, Mutlu C (2022a). Distribution and density of wheat stem sawflies (Hymenoptera: Cephidae) at wheat fields in Yozgat province, Turkey. Harran Journal of Agriculture and Food Science 26(1):40-49. *https://doi.org/10.29050/harranziraat.1026052*

İnce HU, Canhilal R, Mutlu C (2022b). Infestation and damage caused by wheat stem sawfly, [*Cephus pygmeus* (Hymenoptera: Cephidae)], at wheat fields in Yozgat Province, Turkey. International Journal of Agriculture and Wildlife Science 8(1):44-52. *https://doi.org/10.24180/ijaws.1059376*

Ipeksever F (2019). Şanlıurfa'da bazı ekmeklik buğday tarla paçallarının incelenmesi. YL Tezi. Fen Bil. Ens. Harran Üniversitesi, Şanlıurfa. [Examination of some bread wheat field blends in Şanlıurfa. Master's Thesis. Institute of Science, Harran University, Şanlıurfa].

Kemp H (1934). Studies of solid stem wheat varieties in relation to wheat stem sawfly control. Scientific Agriculture 15(1):30-38. *https://doi.org/10.4141/sa-1934-0076*

Kılıç H, Bayram Y, Tektal S (2017). Evaluation in terms of resistance to wheat stem sawfly [*Cephus pygmaeus* L. (Hymenoptera: Cephidae)] damage of bread wheat cultivars with different phenological characters. Yuzuncu Yil University Journal of Agricultural Sciences 27:65-76. *https://doi.org/10.29133/yyutbd.305101*

Kınacı G, Budak Z, Kutlu I, Tavas N, Tarhan P, Bozkuş C, Gündüz F, Gıcı BN, Kınacı E (2008). Kışlık Makarnalık Buğday Çeşitlerinde Hasat İndeksi İle Başak Özellikleri Arasındaki İlişkiler. Ülkesel Tahıl Sempozyumu, 2-5 Haziran 2008, Konya (Relationships Between Harvest Index and Ear Characteristics in Winter Durum Wheat Varieties. National Grain Symposium, 2-5 June 2008, Konya).

Knodel J, Shanower TG, Beauzay P (2010). Integrated Pest Management of Wheat Stem Sawfly in North Dakota. Retrieved 2019 January 12 from: *https://www.ag.ndsu.edu/publications/crops/integrated-pest-managementof-wheat-stem-sawfly-in-north-Dakota*

Kong E, Liu D, Guo X, Yang W, Sun J, Li X, Zhan K, Cui D, Lin J, Zhang A (2013). Anatomical and chemical characteristics associated with lodging resistance in wheat. The Crop Journal 1(1):43-49. *https://doi.org/10.1016/j.cj.2013.07.012*

Korkmaz E, Hastaoğlu M, Örgen HS, Gencer L, Ülgentürk S, Başıbüyük HH (2010). Determination of some wheat pests and their parasitoids in wheat fields of Central Anatolia Region. Turkish Journal of Entomology 34(3):361-377.

Lavergne FD, Broeckling CD, Brown KJ, Cockrell DM, Haley SD, Peairs FB, Pearce S, Wolfe LM, Jahn CE, Heuberger AL (2020). Differential stem proteomics and metabolomics profiles for four wheat cultivars in response to the insect pest wheat stem sawfly. Journal of Proteome Research 19(3):1037-1051. *https://doi.org/10.1021/acs.jproteome.9b0056*

Luginbill P, McNeal FH (1958). Influence of seeding density and row spacings on the resistance of spring wheats to the wheat stem sawfly. Journal of Economic Entomology 51:804-808. *https://doi.org/10.1093/jee/51.6.804*

Macedo TB, Weaver DK, Peterson RKD (2007). Photosynthesis in wheat at the grain filling stage is altered by larval wheat stem sawfly (Hymenoptera: Cephidae) injury and reduced water availability. Journal of Entomological Science 42:228-238. *https://doi.org/10.18474/0749-8004-42.2.228*

McNeal FH, Watson CA, Berg MA, Wallace LE (1965). Relationship of stem solidness to yield and lignin content in wheat selections. Agronomy Journal 57:20-21. *https://doi.org/10.2134/agronj1965.00021962005700010007x*

Morrill WL, Gabor JW, Kushnak GD (1992). Wheat stem sawfly (Hymnoptera: Cephidae) damage and detection. Journal of Economic Entomology 85:2413-2417. *http://dx.doi.org/10.1093/jee/85.6.2413*

Mutlu C (2019). Wheat stem sawflies in the southeast Anatolia region of Turkey. Entomological News 128(3):267-283. *https://doi.org/10.3157/021.128.0307*

Mutlu C, Karaca V, Tonğa A, Erol S, Mamay M (2019). Infestation and damage caused by wheat stem sawflies (Hymenoptera). Journal of the Kansas Entomological Society 92(1). *https://doi.org/10.2307/26856843*

Nansen C, Weaver DK, Sing SE, Runyon JB, Morrill WL, Grieshop MJ, Shannon CL, Johnson ML (2005). Within-field spatial distribution of *Cephus cinctus* (Hymenoptera: Cephidae) larvae in Montana wheat fields. The Canadian Entomologist 137(02):202-214. *https://doi.org/10.4039/n04-036*

Ozberk I, Atlı A, Yücel A, Ozberk F, Çoşkun Y (2005). Wheat stem sawfly (*Cephus pygmaeus* L.) damage; impacts on grain yield, quality, and marketing prices in Anatolia. Crop Protection 24:1054-1060. *https://doi.org/10.1016/j.cropro.2005.03.006*

Özberk I, Özberk F, Kaya C, Batmaz IH, Solmaz AA, Cengizer Z, Yıldırım M, Gök M (2022). An assessment on wheat and barley cultivation through farmer surveys under rain-fed conditions in Sanliurfa. KSU Journal of Agriculture and Nature 25(4):757-765. *https://doi.org/10.18016/ksutarimdoga.vi.962723*

Peterson RKD, Knodel J, Shanower T, Patrick B (2016). Integrated pest management of wheat stem sawfly in North Dakota. E1479 (Revised) NDSU Extension Service North Dakota State University. Retrieved 2020 September 6 from: *https://www.ag.ndsu.edu/publications/crops/integrated-pest-management-of-wheat-stem-sawflyin-north-dakota/e1479.pdf*

Rashwani A (1981). Introduction to the major pests of wheat and barley in the Middle East and North Africa. Technical Manuel (ICARDA) 9:58-63.

Runyon JB, Morrill WL, Weaver DK, Miller PR (2002). Parasitism of the wheat stem sawfly (Hymenoptera: Cephidae) by *Bracon cephi* and *B. lissogaster* (Hymenoptera: Braconidae) in wheat fields bordering tilled and untilled fallow in Montana. Journal of Economic Entomology 95(6):1130-1134. *https://doi.org/10.1603/0022-0493-95.6.1130*

Seaman HL, Manson GF, Farstad CW (1994). The effect of wheat stem sawfly (*C. cinthus*) on the heads and grain of infested stems. 75th Annual Report of the Entomological Society of Ontario, pp 10-15.

Shanower TG (2004). Wheat stem sawflies: *Cephus cinctus* Norton, *Cephus pygmeus* (L.) and *Trachelus tabidus* (F.) (Hymenoptera: Cephidae). Encyclopedia of Entomology 3:2545-2548.

Sözen E, Yağdı K (2005). Bazı İleri Makarnalık Buğday Hatlarının Tarımsal Özellikleri Üzerine Araştırmalar. [Research on Agricultural Characteristics of Some Advanced Durum Wheat Lines] Adnan Menderes Ü. Ziraat Fak. Dergi 2(2):51-57.

Spearman C (1904). The proof and measurement of association between two things. American Journal of Psychology 15:72-101. *https://doi.org/10.1037/11491-005*

Steel RGD, Torrie JH, Dickey DA (1997). Principles and procedures of statistics. A biometrical approach. 3rd ed. McGraw Hill Book Co., Inc., New York.

TUİK (2022). Retrieved from: *https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2022-45504*

Tülek A, Kahraman T, Akan K (2013). An important pest on wheat production, European wheat stem sawfly (*Cephus pygmeus* L.). Harman Time, Monthly Plant Production-Animal Husbandry Magazine 1(5):64-66.

Tülek A, Koçak E, Akın K, Kahraman T (2011). Effect of wheat stem sawfly (*Cephus pygmeus* L. (Hymenoptera: Cephidae) on quality and yield components in some bread wheat varieties. Proceedings of the Fourth Turkish National Congress of Entomology, 28-30 June 2011. Kahramanmaraş, Turkey.

Weaver DK, Nansen C, Runyon JB, Sing SE, Morrill WL (2005). Spatial distributions of *Cephus cinctus* Norton (Hymenoptera: Cephidae) and its braconid parasitoids in Montana wheat fields. Biological Control 34:1-11. *https://doi.org/10.1016/j.biocontrol.2005.04.001*

Yağbasanlar T (1996). Makarnalık Buğdayda Verim ve Verim Öğeleri Üzerinde Path Katsayısı Analizi. [Path coefficient analysis on yield and yield components in durum wheat]. Çukurova Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü Çukurova Üniv. Zir. Fak. Dergisi 3(1):118-125.