ITEMS FROM MEXICO

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Reaction to Karnal bunt under artificial inoculation of advanced bread wheat lines selected for cultivation in the humid high lands of Jalisco, Mexico.

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Abstract. Twenty-four advanced bread wheat lines selected for cultivation in the humid, high lands of the state of Jalisco, Mexico, were evaluated for resistance to Karnal bunt by artificial inoculation during the 2013–14 crop season at two dates, in the Yaqui Valley, Mexico. The infection range for the first date was 0–73.16%, and 0–32.54% for the second date. Line SOKOLL*2/TROST (CMSA05Y01186T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-03Y-0B) did not show any infected grain on either date, three lines were within the 0.1–2.50 infection category (ROLF07/TUKURU/5/WBLL1*2/4/YACO/ PBW65/3/KAUZ*2/TRAP//KAUZ with 0.19%; GOUBARA-1/2*SOKOLL with 0.67%; and FRET2/KUKUNA//FRET2/3/TUKURU/4/FRET2/TUKURU//FRET2 with 1.46%), three in the 5.1–10.0% infection category, 13 at 10.1–30.0%, and four >30.0%. The mean of the three highest percentages of infection of the susceptible check was 99.02%.

Introduction. Wheat cultivation under rainfed conditions in Mexico has fluctuated from 62,110 to 239,000 ha between 1976 to 1997, with an average grain yield ranging from 1.3 to 2.1 t/ha (Villaseñor-Mir and Espitia-Rangel 2000). In 2013, the area grown with wheat in Mexico under these conditions was 122,321.10 ha, and 6,299 in the state of Jalisco with an average grain yield of 1.06 t/ha (Ireta et al. 2008; SIAP 2015), although, in the 1980s and early 1990s, wheat occupied about 12,000 ha each year with an average grain yield of 3 t/ha in the same state (Chávez and Ireta 1993). Despite the small area dedicated to rainfed wheat cultivation in Mexico, the perspectives are quite wide: more than 1 x 10^6 ha can be used for wheat in 16 states; investment is lower than in irrigated land, the land is cheaper, and the water has no cost; technology can offer improvement in wheat production with a potential grain yield average of 3 t/ha; and costs due to transportation and storage, so that wheat produced during the summer in the central high plateau, may be more accessible than the imported one (Villaseñor-Mir and Espitia-Rangel, 2000). The potential area for wheat production under rainfed conditions in the state of Jalisco is 57,000 ha, and the more prevalent diseases are leaf (*Puccinia triticina*) and stripe (*Puccinia striiformis*) rusts, Septoria leaf (*Septoria tritici*) and glume (*Septoria nodorum*) blotches, Fusarium head blight (*Fusarium graminearum*), and spot blotch (*Bipolaris sorokiniana*) (Chávez and Ireta 1993). Although Karnal bunt is not present in the state of Jalisco (SAGARPA 2002), it is important to screen wheat experimental germplasm for reaction to this and other diseases so that selected material has the attributes not only for rainfed conditions, but tolerance/resistance to diverse biotic factors. Karnal bunt of wheat caused by *Tilletia indica* (syn. *Neovossia indica*) has been reported from India (Mitra 1931), Mexico (Duran 1972), Pakistan (Munjal 1975), Nepal (Singh et al. 1989), Brasil (Da Luz et al. 1993), the United States of America (APHIS 1996), Iran (Torarbi et al. 1996), and the Republic of South Africa (Crous *et al*. 2001). *Triticum aestivum* is the most susceptible plant species to Karnal bunt (Fig. 1), which under artificial inoculation, may show more than 50% infected grain (Fuentes-Dávila et al. 1992; 1993). Although *T. indica* may affect durum wheat (*T. turgidum*) and triticale (X *Triticosecale*; Agarwal et


Fig. 1. Karnal bunt on the grain of bread wheat.

al. 1977), the level of infected grain is generally low. Control of this pathogen is difficult because teliospores are resistant to physical and chemical factors (Krishna and Singh 1982; Zhang et al. 1984; Smilanick et al. 1988). Chemical control is accomplished by applying fungicides during flowering (Fuentes-Dávila et al. 2005); however, this measure is not feasible when quarantines do not allow tolerance levels for seed production. Resistant wheat cultivars are the best means to control this disease. Our objective was to evaluate 24 advanced bread wheat lines for resistance to Karnal bunt, which were selected from the Global Wheat Program of CIMMYT for their acceptable performance under rainfed conditions. These

Table 1. Advanced bread wheat lines artificially inoculated with karnal bunt (*Tilletia indica*) in the field in two sowing dates, during the crop season 2013-2014, in the Yaqui Valley, Sonora, Mexico.

Entry	Pedigree and selection history
1	FRET2/KUKUNA//FRET2/3/TUKURU/4/FRET2/TUKURU//FRET2 CGSS05B00149T-099TOPY-099M-099NJ-099NJ-2WGY-0B
2	SW89-5124*2/FASAN/3/ALTAR 84/AE.SQ//2*OPATA CMSA04M00335S-040ZTP0Y-040ZTM-040SY-16ZTM-04Y-0B
3	VEE/PJN//2*TUI/3/WH576 CMSS95Y00795S-0100Y-81DH-0B-10Y-0B-01Y
4	ACHTAR*3//KANZ/KS85-8-5/4/MILAN/KAUZ//PRINIA/3/BAV92/5/MILAN/KAUZ//PRINIA/3/BAV92 CMSA05M00661T-050Y-040ZTM-040ZTY-26ZTM-02Y-0B
5	PRL/2*PASTOR*2//YANAC CGSS05B00211T-099TOPY-099M-099NJ-099NJ-4WGY-0B
6	SOKOLL*2/TROST CMSA05Y01186T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-03Y-0B
7	SOKOLL*2/TROST CMSA05Y01186T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-03Y-0B
8	WBLL1*2/VIVITSI/6/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*JANZ CMSS05B00713S-099Y-099M-099Y-099ZTM-4WGY-0B
9	HUW234+LR34/PRINIA*2//WHEAR CGSS05B00243T-099TOPY-099M-099NJ-1WGY-0B
10	D67.2/PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/WBLL1*2/TUKURU CMSA04M00492S-040ZTP0Y-040ZTM-040SY-22ZTM-02Y-0B
11	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/ONIX CMSA05Y00325S-040ZTP0Y-040ZTM-040SY-38ZTM-04Y-0B
12	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/ONIX CMSA05Y00325S-040ZTP0Y-040ZTM-040SY-21ZTM-03Y-0B
13	HUW234+LR34/PRINIA*2//WHEAR CGSS05B00243T-099TOPY-099M-099NJ-099NJ-1WGY-0B
14	ROLF07/TUKURU/5/WBLL1*2/4/YACO/PBW65/3/KAUZ*2/TRAP//KAUZ CGSS05B00115T-099TOPY-099M-099Y-099ZTM-2WGY-0B
15	ATTILA/BAV92//PASTOR/3/ATTILA*2/PBW65 CMSA04M00070S-040ZTB-040ZTY-040ZTM-040SY-13ZTM-04Y-0B
16	ESDA/KKTS CMSA04M00178S-040LNB-040ZTY-040ZTM-040SY-5ZTM-03Y-0B
17	GOUBARA-1/2*SOKOLL CMSA04M01020T-050Y-040ZTP0M-040ZTY-040ZTM-040SY-8ZTM-01Y-0B
18	ATTILA*2/PBW65//TNMU CGSS05Y00442S-0B-099Y-099M-099NJ-8RGY-0B
19	GOUBARA-1/2*SOKOLL CMSA04M01020T-050Y-040ZTP0M-040ZTY-040ZTM-040SY-8ZTM-01Y-0B
20	HUW234+LR34/PRINIA*2//YANAC CGSS05B00242T-099TOPY-099M-099NJ-099NJ-28WGY-0B
21	HUW234+LR34/PRINIA*2//YANAC CGSS05B00242T-099TOPY-099M-099NJ-099NJ-13WGY-0B
22	BABAX/LR43//BABAX/5/MOR/VEE#5//2*DUCULA/3/MILAN/4/BAU/MILAN/6/ SKAUZ/BAV92 CMSS05Y00558T-099TOPM-099Y-099M-099Y-099ZTM-5RGY-0B
23	PGO/SERI//BAU/3/DUCULA/4/FRET2/KUKUNA//FRET2 CMSS05Y00357S-0B-099Y-099M-099Y-099ZTM-12WGY-0B
24	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/ONIX CMSA05Y00325S-040ZTP0Y-040ZTM-040SY-40ZTM-04Y-0B

lines could be of use in the humid, high lands (Arandas, Jesús María, and Tepatitlán counties) of the state of Jalisco, Mexico.

Materials and methods. Twenty-four advanced bread wheat lines (Table 1, p. 21) were evaluated for resistance to Karnal bunt during the 2013–14 fall–winter crop season in block 910 in a clay soil with pH 7.8, in the Yaqui Valley, Sonora, Mexico. Sowing dates were 21 November and 3 December, 2013, using a 1-m bed with two rows. Inoculum was prepared by isolating teliospores from infected kernels, followed by centrifugation in a 0.5% sodium hypochlorite solution, and plating on 2% water-agar Petri plates. After teliospore germination, fungal colonies were transferred and multiplied on potato-dextrose-agar. Inoculations were by injecting 1 mL of an allantoid sporidial suspension (10,000/mL) during the boot stage (Fig. 2) in ten heads/line. High relative humidity in the experimental area was provided by a mist-automized, irrigation system five times per day, 20 min each time (Fig. 3). Harvest was manual, and visual counting of healthy and infected grains determined the percent infection. Evaluated lines originated from the collaborative project between the International Maize and Wheat Improvement Center (CIMMYT) and the National Institute for Forestry, Agriculture and Livestock Research in Mexico (INIFAP).

Fig. 2. Artificial inoculation of bread wheat with a sporidial suspension of *Tilletia indica* by boot injection in the field.

Fig. 3. A mist irrigation system in an experimental field.

Results and discussion. The range of infection for the first planting date was 0–73.16% with a mean of 25.67 (Fig. 4). Four lines did not show any infected grain, one was in the 0.1–2.5% infection category, one at 2.6–5.0%, one at 5.1–10.0, eight at 10.1–30.0, and nine > 30%. The range of infection for the second planting date was 0 to 32.54%, with a mean of 10.32. Four lines did not show infected grains, five were in the 0.1–2.5% infection category, two at 2.6–5.0%, three at 5.1–10.0, nine at 10.1–30.0, and one > 30%. The average infection range for the two dates was 0–51.50% with a mean of 17.74% (Fig. 5, p. 23). The highest average percent infection was in line FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/ ONIX (CMSA05Y00325S-040Z TP0Y-040ZTM-040SY-40ZTM-04Y-0B) with 51.50%, followed by FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/ONIX (CMSA05Y 00325S-040ZTP0Y-040ZTM-040SY-38ZTM-04Y-0B) with 40.85%, PRL/2*PASTOR *2//YANAC with 33.41%, and HUW234+LR34/PRINIA*2//YANAC with 31.02%. In the resistant category, which is less than 5% infection (Fuentes-Dávila and Rajaram 1994), one line did not show any infected grain at both dates (SOKOLL*2/TROST, CMSA05Y01186T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-03Y-0B). Three lines were within the 0.1–2.50% infection category (ROLF07/TUKURU/5/ WBLL1*2/4/YACO/PBW65/3/KAUZ*2/TRAP//KAUZ with 0.19%, GOUBARA-1/2*SOKOLL with 0.67%, and FRET2/KUKUNA//FRET2/3/TUKURU/4/FRET2/ TUKURU//FRET2 with 1.46%) (Fig. 6, p. 23). Four lines were in the 5.1–10.0% infection category, 13 at the 10.1–30.0%, and four were >30%. The mean of the three highest percentages of infection of the susceptible check was 99.02%. Artificial inoculation in the field may be affected by various factors such as inoculum survival and viability, proper injection by the operator, proper amount of the suspension, distribution of sporidia in the suspension, weather conditions prevailing during and after the inoculation (primarily temperature, relative humidity, solar radiation), and the specific phenological

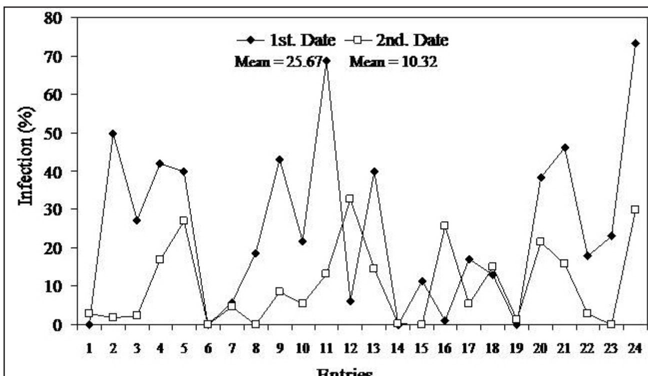

Fig. 4. Percent infection with Karnal bunt (*Tilletia indica*) of 24 advanced bread wheat lines artificially inoculated in the field during the 2013–14 crop season at two dates. Plots were in the Yaqui Valley, Sonora, Mexico.

stage of the plant, therefore, variation in the percentage of infection within a single line is common. We recommend several sowing dates and in several crop seasons in order to avoid escapes. Lines in the resistant category that showed consistency in the level of infection at both dates were SOKOLL*2/TROST (CMSA05Y01186T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-03Y-0B) with 0 difference (Fig. 4, entry 6, p. 22), ROLF07/TUKURU/5/WBLL1*2/4/YACO/PBW65/3/KAUZ*2/TRAP//KAUZ with a 0.38 difference (14), SOKOLL*2/TROST (CMSA05Y01186T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-03Y-0B) with a 1.01 difference (7), GOUBARA-1/2*SOKOLL with a 1.33 difference (19), and FRET2/KUKUNA//FRET2/3/TUKURU/4/FRET2/TUKURU//FRET2 with a 2.93% difference (1). Several weather parameters that prevailed in southern Sonora during 1 January to 10 March, 2014, included a maximum average temperature in January, February, and March (1–10) of 27.1, 28.6, and 26.0°C, respectively; a minimum average temperature of 5.9, 6.5, and 10.2°C, respectively; and an average relative humidity of 70.4, 75.3, and 78.9, respectively (PIEAES 2015). Two days had rainfall in March with a total of 3.7 mm, which, based on the history of the incidence of Karnal bunt in the region, influenced the presence of the disease (out of 1,304 spike samples in seven localities, 21 were positive for infected grain, and out of 34,812 grain samples analyzed in eight counties, 621 were positive), although the number of infected grains/kg was quite low (Ing. Joel Soto-Nolazco, personal communication, Yaqui Valley, Plant Health Council).

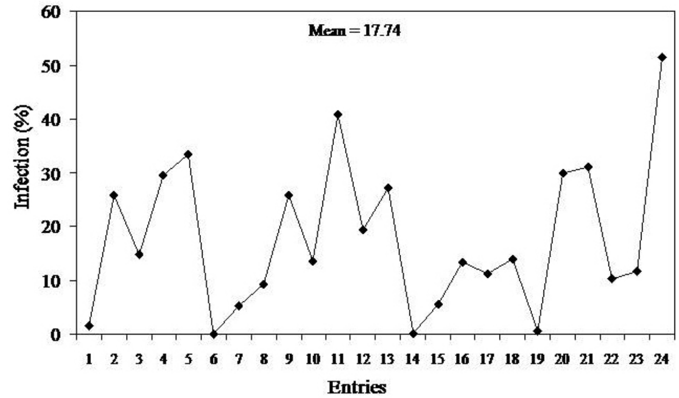

Fig. 5. Average percent infection with Karnal bunt (*Tilletia indica*) of 24 advanced bread wheat lines artificially inoculated in the field during the 2013–14 crop season at two dates. Plots were in the Yaqui Valley, Sonora, Mexico.

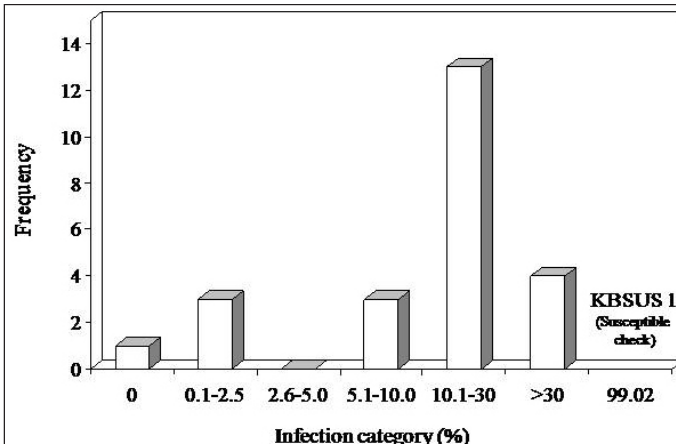

Fig. 6. Results of artificial infection with Karnal bunt (*Tilletia indica*) at two dates of 24 advanced bread wheat lines artificially inoculated in the field during the 2013–14 crop season. Plots were in the Yaqui Valley, Sonora, Mexico. The level of KBSUS1 infection is the mean of the three highest infection scores.

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Performance of bread wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semi-commercial plots in southern Sonora during 2013–14.

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Abstract. We evaluated the performance of bread wheat cultivars Ónavas F2009 and Villa Juárez F2009 released by INIFAP for commercial cultivation, in semi-commercial fields during the 2013–14 crop season under the agronomic management of cooperating farmers. The trials were located in the Yaqui Valley: 1) Bacum County, block 113 (27°30’ 23.87”–100°08’28.26”, 20 masl), sowing date 2 December, 2013, cultivars sown in 12 x 0.8-m beds, 485-m long; and 2) Bacum County, block 809 (27°23’19.40”–110°06’42.21”, 15 masl), sowing date 29 November, 2013, cultivars sown in 12 x 0.8-m beds, 477-m long. Six 10 x 0.8-m beds were used to evaluate stem fresh weight, leaf fresh weight, root fresh weight, spike fresh weight, and the number of spikes/m^2; other variables evaluated were spike dry weight, 1,000-kernel weight, spike and grain length, and number of grains/spike. Grain yield was determined in the area sown using a Parker grain weigh cart model 1555. Variables in which Ónavas F2009 was superior to Villa Juárez F2009 were number of spikes, stem fresh weight in block 809, leaf fresh weight, and root fresh weight. Variables in which differences between blocks were detected included spike dry weight, number of spikes/m^2, number of grains/spike, spike length, spike fresh weight, stem fresh weight, and root fresh weight. In relation to grain yield, Ónavas F2009 performed better than Villa Juárez F2009 in both locations, with a difference of 533 and 608 kg/ha in blocks 809 and 113, respectively. Ónavas F2009 showed a maximum grain yield of 7.5 t/ha in block 113.

Introduction. National wheat production in Mexico in year 2010 was 3.9×10^6 tons, which was not sufficient to supply the needs in the country. Since 2010, 3.3×10^6 tons were imported (OEIDRUS 2011). Before the 1990s, bread wheat was the dominant class in northwest Mexico. In the state of Sonora, bread wheat occupied more than 50% of the area dedicated to wheat from the agricultural season 1983–84 to 1993–94. However, many wheat producers decided to start growing durum wheat, because the Mexican government implemented domestic quarantine No. 16 (SARH 1987), which limited the cultivation of bread wheat in fields where Karnal bunt had been detected at levels greater than 2% infected grains. Other important factors were that durum wheat showed greater grain yield than bread wheat and, that during that period of time, durum wheat did not have problems with leaf rust. In addition, there were opportunities for export of durum wheat. Despite the economic and operational problems caused by Karnal bunt at the beginning of the 1980s, during the 1990–91 agricultural season bread wheat was still grown in 220,409 ha, which represented 89% of the total area dedicated to wheat in the state. However, durum wheat was consolidated as the dominant class grown in Sonora from the 1994-95 agricultural season. The area grown with wheat during the 2010–11 crop season in the state of Sonora was 292,247 ha; 87% (254,531) corresponded to southern Sonora. Durum wheat cultivars CIRNO C2008 and Átil C2000 occupied 40% of the total area. The Mexican federal government has implemented a financial support program for commercialization to enhance the production of bread wheat, which is in demand by the national industry, and along with agriculture by contract, it is intended to increase the area with bread wheat in order to balance the relation with durum wheat. Our objective was to evaluate the performance of two bread wheat cultivars in semi-commercial fields, which were released by INIFAP for commercial cultivation in 2009.

Materials and methods. This work was carried out during the 2013–14 crop season with the bread wheat cultivars Ónavas F2009 (Fig. 7) (Figueroa-López et al. 2013a, b) and Villa Juárez F2009 (Fig. 8) (Valenzuela-Herrera et al. 2012a, b), under the agronomic management of cooperating farmers. The trials were located in the Yaqui Valley: 1) Bacum County block 113 (27° 30' 23.87"–100° 08' 28.26" at 20 masl; sowing date 2 December, 2013) and 2) Bacum County block 809 (27° 23' 19.40"–110° 06' 42.21" at 15 masl; sowing date 29 November, 2013).

Fig. 7. Bread wheat cultivar Ónavas F2009 has an average height of 97 cm. Plants present an intermediate growth habit and a very high frequency of recurved flag leaves. Grain shape is semi-elongated, and coloration after treatment with phenol is light.

Fig. 8. Bread wheat cultivar Villa Juárez F2009 has an average height of 91 cm. Plants are semiprostate and have a very high frequency of recurved flag leaves. Grain shape is semi-elongated, and coloration after treatment with phenol is nil or very light.

Agronomic management. Block 113, after irrigation of the land before sowing and once the land was ready for sowing, Faena was applied at 3 L of commercial product (c.p.)/ha, as well as 400 kg of urea, 12–40 kg of sulphur, 100 kg of zinc, and 1.5 liters of 2,4D amina for weed control. Cultivars were sown in 12 x 0.8-m beds 485-m long. The seeding rate was 130 kg/ha. Complementary irrigations were provided 35 days after sowing; the second 20 days later with an application of ammonia (NH_3, 70 kg/ha), the third 20 days later with an application of NH_3 (70 kg/ha), and the fourth 15 days later.

In Block 809, cultivars were sown in 12 x 0.8 m beds, 477-m long. Urea was applied at 200 kg/ha as well as mono-ammonium phosphate at 100 kg/ha before the land was sown and irrigated. The seeding rate was 150 kg/ha. Complementary irrigations were provided 49 days after sowing with the application of ammonia (60 kg/ha), the second 33 days later with an application of ammonia (50 kg/ha), and a third 23 days later. For aphid control, Velfidor was applied at 150 ml/ha c.p. on 15 January, 2014. For broadleaf weed control, Agramina 6 c.p. was applied at 500 ml/ha on 22 December, 2013, Situi XL at 20 g/ha on 10 February, 2014, and Agramina 6 at 1.5 l/ha on 10 March, 2014. For narrow-leaf weed control, Topik Gold was applied at 350 ml/ha on 27 December, 2013, and at 500 ml/ha on 18 February, 2014. A John Deere 8820 combine was used to harvest block 809 and a 5660 in block 113 (Fig. 9, p. 26). Grain yield (kg/ha) was determined using a Parker grain weigh cart, model 1555 (Fig. 10, p. 26). Six 10 x 0.8-m beds were used to evaluate the following variables: number of spikes, spike fresh weight, stem fresh weight, leaf fresh weight, and root fresh weight (three replications each), all per m^2; spike dry weight (five replications); 1,000-kernel weight (three replications); number of grains/spike (five replications); and grain and spike length (five replications each).

Fig. 9. Combines used for harvesting wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial blocks 809 and 113 in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

Fig. 10. Grain yield determination of wheat cultivars Ónavas F2009 and Villa Juárez F2009 using a Parker grain yield cart model 1555 in semicommercial blocks 809 and 113 in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

Results and discussion. Based on the results obtained, cultivars Ónavas F2009 and Villa Juárez F2009 were similar for spike dry weight (the average was a little higher in Ónavas in both blocks, Fig. 11), 1,000-kernel weight (Fig. 12), number of grains/spike (the average was a little higher in Ónavas in both blocks, Fig. 13), grain length (Fig. 14), spike length (Fig. 15, p. 27), and spike fresh weight (the average was a little higher in Villa Juárez in both blocks, Fig. 16, p. 27). Variables in which Ónavas F2009 showed a greater average than Villa Juárez F2009 were number of spikes/m^2, with a difference of 58 and 24 in blocks 809 and 113, respectively (Fig. 17, p. 27); stem fresh weight in block 809 with a difference of 136 g (Fig. 18, p. 27); leaf fresh weight with a difference of 138 and 21 g in blocks 809 and 113, respectively (Fig. 19, p. 27); and root fresh weight with a difference of 33 and 74 g in blocks 809 and 113, respectively (Fig. 20, p. 27).

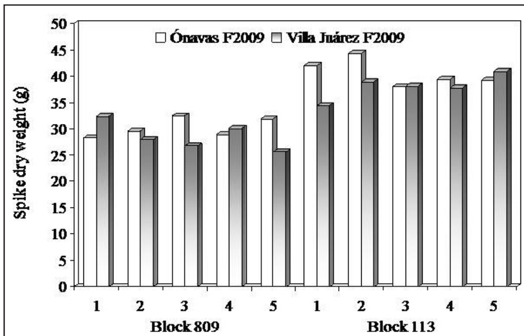

Fig. 11. Spike dry weight (g; five spikes (replicatons)) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

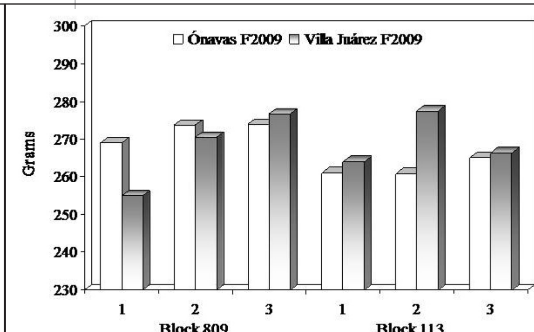

Fig. 12. 1,000-kernel weight (g; three replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

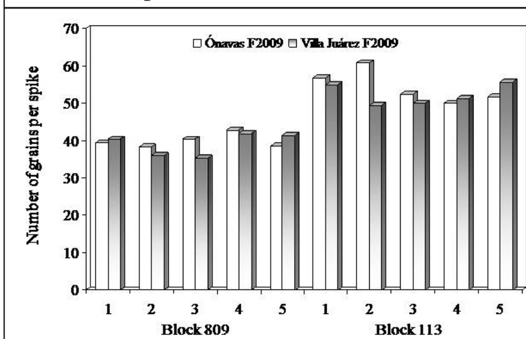

Fig. 13. Number of grains/spike (five replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

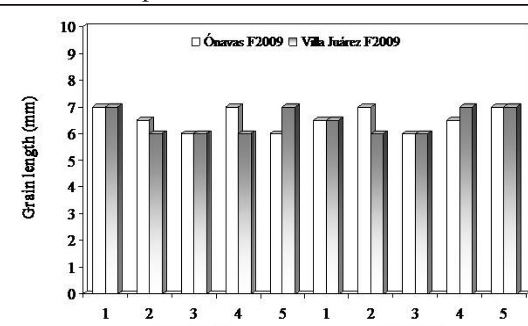

Fig. 14. Grain length (mm; five replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, in the 2013–14 crop season.

Variables in which differences between blocks were detected were spike dry weight (a greater weight in block 113 with a difference in favor of 10.36 for Ónavas and 9.5 g for Villa Juárez, Fig. 11, p. 26), number of spikes/m² (a greater number in block 809 with a difference of 114 spikes for Ónavas and 80 spikes for Villa Juárez, Fig. 17), number of grains/spike (greater number in block 113 with a difference of 15 for Ónavas and 14 for Villa Juárez, Fig. 13, p. 26), spike length (greater length in block 113 with a difference of 3 cm for Ónavas and 2 cm for Villa Juárez, Fig. 15), spike fresh weight/m² (greater weight in block 113 with a difference of 139 g for Ónavas and 133 g for Villa Juárez, Fig. 16), stem fresh weight/m² (greater weight in block 809 with a difference of 178 g for Ónavas and 42 g for Villa Juárez, Fig. 18), and root fresh weight/m² (greater weight in block 809 with a difference of 33 g for Ónavas and 74 g for Villa Juárez, Fig. 20).

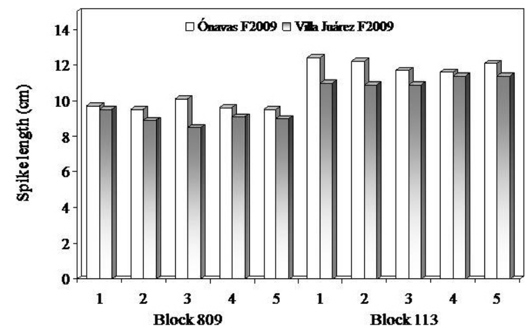

Fig. 15. Spike length (cm; five replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

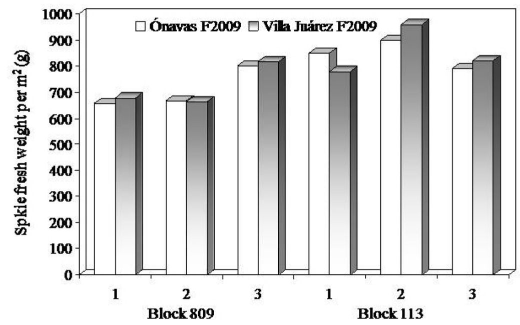

Fig. 16. Spike fresh weight/m² (g; three replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

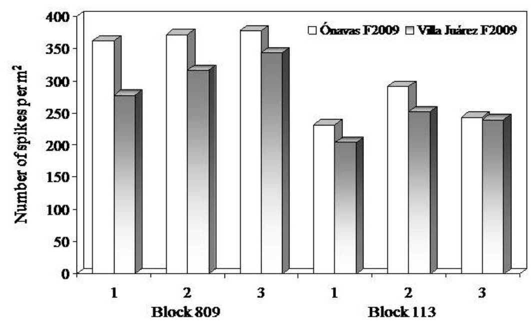

Fig. 17. Number of spikes/m² of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

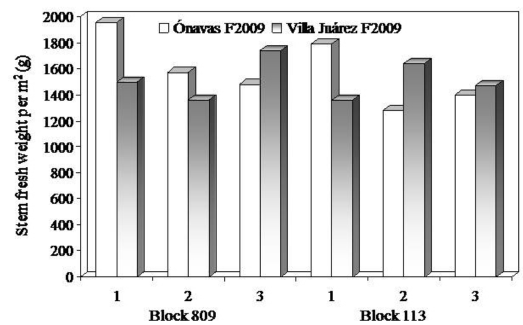

Fig. 18. Stem fresh weight/m² (g; three replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

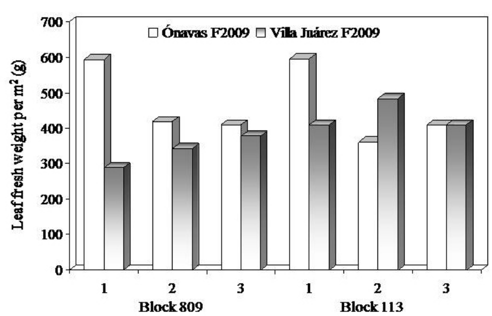

Fig. 19. Leaf fresh weight/m² (g; three replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

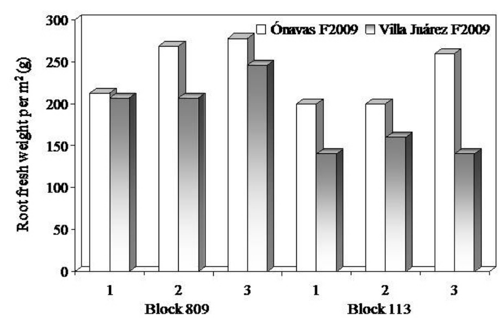

Fig. 20. Root fresh weight/m² (g; three replications) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

For grain yield, Ónavas F2009 performed better than Villa Juárez F2009 in both locations, with a difference of 533 kg/ha and 608 kg/ha in block 809 and 113, respectively (Fig. 21, p. 28). This result agrees with that of Figueroa-López et al. (2013b) who indicate that Ónavas F2009 shows competitive grain yield (a maximum of 7.5 t/ha in block 113) with the durum wheat cultivars grown in southern Sonora. On the other hand, Villa Juárez F2009, previous to its release for commercial cultivation, showed a yield of 8.1 t/ha in semi-commercial plots (Valenzuela et al. 2012b),

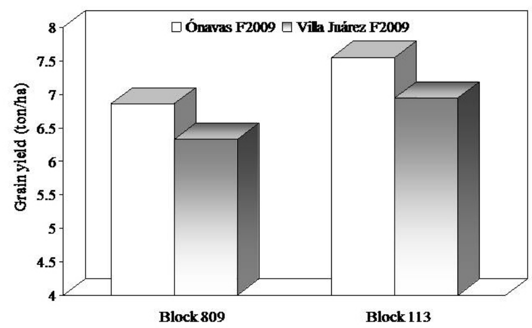

Fig. 21. Grain yield (tons/ha) of wheat cultivars Ónavas F2009 and Villa Juárez F2009 in semicommercial plots in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

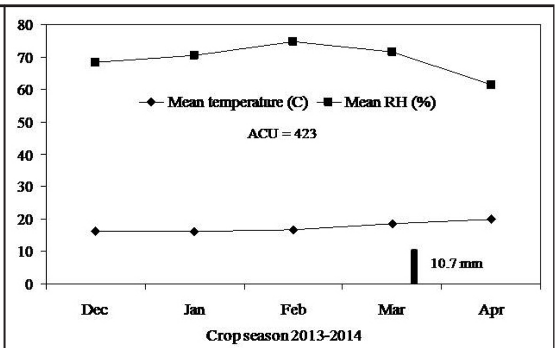

Fig. 22. Mean temperature and relative humidity, rainfall, and accumulated cold units in the Yaqui Valley, Sonora, Mexico, during the 2013–14 crop season.

which was not expressed in this work, possibly due to the agronomic management applied by the cooperating farmers and/or due to the lack of sufficient cold units (Fig. 22), which for optimal yield expression should be at least 600 in this region (Fig. 22) (Félix-Valencia et al. 2009).

The validation plots represent an important tool for evaluating wheat candidate lines for commercial release by INIFAP, whose objectives are to 1) generate information about their performance and expression potential under the management of cooperating farmers, and to provide such information to the wheat farmers of the region and 2) enhance the cultivation of bread wheat in the region, since several years ago, more than 80% of the area cultivated with wheat has been under durum wheat (SIAP 2013). Efforts by the national wheat industry and the federal government have been implemented in order to increase bread wheat cultivation so as to diminish the import of this type of wheat.

Conclusions. Cultivar Ónavas F2009 was superior to Villa Juárez F2009 in number of spikes, stem fresh weight in block 809, leaf fresh weight, and root fresh weight. Ónavas F2009 performed better than Villa Juárez F2009 for grain yield in both locations, with a difference of 533 kg/ha and 608 kg/ha in blocks 809 and 113, respectively. Ónavas F2009 showed a maximum grain yield of 7.5 t/ha in block 113, therefore, it represents a good bread wheat option for wheat producers in southern Sonora.

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Reaction of bread wheat cultivars to artificial inoculation with Karnal bunt after fertilization with nitrogen and sulphur.

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Abstract. The reaction of cultivars Tacupeto F2001, Kronstad F2004, Navojoa M2007, and Roelfs F2007, to inoculation with Karnal bunt was evaluated at the Norman E. Borlaug Experimental Station during the 2012–13 crop season. Cultivars were subjected to two nitrogen treatments (200 and 300 kg/ha) and four sulphur treatments (0, 30, 60, and 90 kg/ha), with three replications. The trial was sown on 30 November and 15 December, 2012. For the 2013–14 crop season, cultivars Kronstad F2004 and Roelfs F2007 were used to study the effect of sulphur in two dates (28 November and 11 December, 2013), keeping the nitrogen rate at 300 kg/ha. Depending on the rate and opportunity of application of sulphur treatments as ammonium sulphate (21N-00P-00K-24S), the application of 121.5 kg N/ha in each of the two first complementary irrigations were complemented with urea. Therefore, within each sowing date and cultivar, sulphur treatments of 0-0, 15-0, 30-0, 45-0, 0-15, 0-30, 0-45, 15-15, 15-30, 15-45, 30-15, 30-30, 30-45, 45-15, 45-30, and 45-45, which allowed total sulphur applications from 0 to 90 kg S/ha, were studied. Inoculations were made by injecting 1 mL of an allantoid sporidial suspensión (10,000/mL) during the boot stage, in 10 heads/row in each treatment. The range of infection for cultivar Roelfs F2007 were 23.06–50.27% with a mean of 39.65%, and 8.07–37.80%, with a mean of 24.66%, for the 1st and 2nd sowing dates during the 2012–13 crop season, respectively; 8.94–36.89% and a mean of 18.62%, and 1.29–13.83% with a mean of 6.13% for Navojoa M2007; 30.02–64.66% and a mean of 51.33%, and 23.40–53.35% with a mean of 35.92% for Tacupeto F2001; and 17.83–37.90% with a mean of 29.72%, and 4.04–33.81% with a mean of 20.82%, for Kronstad F2004. The range of infection for cultivar Roelfs F2007 was 8.69 to 27.59, with a mean of 17.05%, and 4.60 to 25.77, with a mean of 16.77%, for the 1st and 2nd sowing dates during the 2012–13 crop season, respectively; and 2.98 to 16.42, with a mean of 8.07%, and 8.92 to 21.59, with a mean of 14.15%, for Kronstad F2004.

Introduction. Sulphur is an important element in sulphidryl and disulphur (S–S) bond formation, important for protein structure stabilization and partly responsible of the viscoelastic properties of wheat gluten (Naeem and MacRitchie 2003). A sulphur deficiency, in the presence of adequate nitrogen fertilization, modifies the dough properties (increasing maximum resistance and lowering extensibility) as the gluten sulphur-protein-rich proportions are reduced (particularly the low-molecular-weight glutenin subunits and the α, β, and γ-gliadins), although there is a higher proportion of polypeptides low in sulphur, such as ω-gliadins and high-molecular-weight glutenins (Randall and Wrigley 1986). Sulphur deficiency is dependent on soil type, locality, and climate. Soil pH also may affect the availability of sulphur (Freney and Williams 1983) and is volatized by debris burning. A 1.2 mg/g sulphur content and an N:S ratio of 16:1 or 17:1 in the wheat grain appears to be critical for optimal quality (Zhao et al. 1999). Usually, the maximum response to sulphur application in wheat is obtained between 10–20 kg/ha (McGrath et al. 1996). Tea et al. (2007) reported the synergy between nitrogen fertilizers and sulphur upon their intake increase in the grain and the influence of fertilization with sulphur in the quantities and proportions of the different types of gluten proteins (Wieser et al. 2004).

Karnal bunt occurs in bread wheat, durum wheat, and triticale. Generally, infected grains are partially affected, and completely infected kernels are uncommon (Mitra 1935). Control of this pathogen is difficult because teliospores are resistant to physical and chemical factors (Krishna and Singh 1982; Zhang et al. 1984; Smilanick et al. 1988). Chemical control is accomplished by applying fungicides during flowering (Salazar-Huerta et al. 1997). Resistant wheat cultivars are the best means for control. Our objective was to evaluate the reaction to Karnal bunt under artificial inoculation of the commercial bread wheat cultivars Tacupeto F2001, Kronstad F2004, Navojoa M2007, and Roelfs F2007, subjected to two nitrogen (200 and 300 kg/ha) and four of sulphur (0, 30, 60, and 90 kg/ha) treatments. Results of the general percent infection at two sowing dates and the highest percentage infection obtained with the different nitrogen–sulphur combinations follow.

Materials and methods. Bread wheat cultivars Tacupeto F2001, Kronstad F2004, Navojoa M2007, and Roelfs F2007 were subjected to two nitrogen (200 and 300 kg/ha) and four of sulphur (0, 30, 60, and 90 kg/ha) treatments, in a trial with three replications. Sowing was on 30 November and 15 December, 2012, with one irrigation to promote crop establishment and four complementary irrigations, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, in a clay soil with pH 7.8. Within each date, treatment combinations corresponding to nitrogen, sulphur, and cultivars were established in the field under a randomized, split-plot, experimental design. Cultivars were the main plot, and the nitrogen x sulphur treatment combinations were distributed randomly within each main plot. Four 5-m beds with two rows each were sown for each treatment. Inoculations were by injecting 1 mL of a secondary sporidial suspension (10,000/mL) in 10 spikes per bed, in two beds of each treatment in each sowing date (spikes of one replicate of the nitrogen x sulphur treatments in each cultivar), using a hypodermic syringe during boot stage. Inoculum preparation followed the methodology of Fuentes-Dávila et al. (2012). Spikes from the first sowing date were inoculated on 22 February, 2013, and the second on 1 March. Harvest and head threshing were done manually, and the counting of healthy and infected grains was done visually to determine the percent infection. For the 2013–14 crop season, cultivars Kronstad F2004 and Roelfs F2007 were used to study the effect of sulphur in two sowing dates (28 November and 11 December, 2013), while keeping the nitrogen rate at 300 kg/ha, because no differences were observed in yield and quality between that rate and 200 kg/ha in the previous crop season. According to Zhao et al. (1999), excess of nitrogen causes an imbalance in the relationship N:S in favor of N, which is reflected in a reduction in bread loaf volume. Nitrogen was divided into three applications: pre-sowing (57 kg N/ha using 100 kg of urea, 46N-00P-00K, and 100 kg of mono-ammonium phosphate (11-52-00)) and right before the first and second complementary irrigations. Depending on the rate and opportunity of application of sulphur treatments as ammonium sulphate (21N-00P-00K-24S), the application of 121.5 kg N/ha in each of the two first complementary irrigations were complemented with urea. Therefore, within each sowing date and cultivar, sulphur treatments were 0–0, 0–15, 0–30, 0–45, 15–0, 15–15, 15–30, 15–45, 30–0, 30–15, 30–30, 30–45, 45–0, 45–15, 45–30, and 45–45, which allowed total sulphur applications from 0 to 90 kg S/ha to be studied. Inoculum preparation followed methodology previously described, and inoculations were made on 12 and 20 February, 2014.

Results. At the first sowing date of the 2012–13 crop season, the percent infection for cultivar Roelfs F2007 was 23.06–50.27%, with a mean of 39.65%; for Navojoa M207, 8.94–36.89%, with a mean of 18.62%; for Tacupeto F2001, 30.02–64.66%, with a mean of 51.33%; and for Kronstad F2004, 17.83–37.90%, with a mean of 29.72% (Table 2). The overall range for the four cultivars was 8.94–64.66 with a mean of 34.83%. The susceptible check showed 89.61% infection at the first date. The percent infection at the second sowing date for cultivar Roelfs F2007 was 8.07–37.80%, with a mean of 24.66%; for Navojoa M2007, 1.29–13.83%, with a mean of 6.13%; for Tacupeto F2001, 23.40–53.35%, with a mean of 35.92%; and for Kronstad F2004, 4.04–33.81%, with a mean of 20.82% (Table 2). The overall range for the four cultivars was 1.29–53.35% with a mean of 21.88%. The susceptible check showed 97.90% infection at the second date. The highest percent infection for cultivar Roelfs F2007 at the first sowing date, under different N–S combinations were 44.69%, 44.22%, and 43.41% for combinations 200–30, 200–90, and 300–30, respectively; for Navojoa M2007, 25.13%, 21.65%, and 20.17% for combinations 300–0, 300–60, and 200–30; for Tacupeto F2001, 60.89%, 60.81%, and 57.53% for combinations 300–0, 300–60 and 200–0; and for Kronstad F2004, 34.45%, 33.80%, and 32.19% for combinations 300–0, 200–30, and 300–30 (Table 3). The highest percent infection for cultivar Roelfs F2007 in the second sowing date were 36.80%, 29.98%, and 26.19% for combinations 300–0, 300–90, and 300–30, respectively; for Navojoa M2007, 11.53%, 7.28%, and 6.33% for combinations 300–60, 300–0, and 200–0; for Tacupeto F2001, 48.16%, 42.16%, and 37.05% for combinations 300–0, 200–60, and 200–0; and for Kronstad F2004 29.58%, 28.82%, and 27.49% for combinations 300–30, 300–60, and 200–60 (Table 3, p. 31).

Table 2. Percent infection with Karnal bunt of bread wheat commercial cultivars Roelfs F2007, Navojoa M2007, Tacupeto F2001, and Kronstad F2004, at the first and second sowing dates, in the Yaqui Valley, Sonora, during the 2012–13 crop season.

30 November, 2012				15 December, 2012			
Roelfs	**Navojoa**	**Tacupeto**	**Kronstad**	**Roelfs**	**Navojoa**	**Tacupeto**	**Kronstad**
47.48	22.91	56.60	34.03	27.64	5.43	37.61	8.41
41.91	8.94	38.98	27.00	32.32	6.49	36.49	24.34
39.76	16.15	40.81	30.86	16.40	2.38	23.40	4.04
45.79	14.90	36.98	30.61	21.62	5.37	37.75	17.96
23.06	11.37	57.12	29.71	21.19	7.38	39.14	27.69
47.57	23.47	64.66	37.90	22.65	7.18	45.19	8.98
37.40	18.72	62.15	31.29	19.74	9.22	25.99	33.24
40.30	15.96	59.47	30.19	8.07	13.83	38.36	24.41
36.56	23.38	54.20	35.14	22.35	5.65	35.85	29.61
50.27	19.92	60.85	29.24	30.02	7.01	26.91	29.56
40.97	21.33	30.02	31.66	35.80	7.75	25.45	23.32
47.47	19.01	51.63	37.23	37.80	1.29	37.95	9.58
23.44	20.04	52.51	22.86	14.72	7.89	25.10	10.47
39.74	11.59	58.26	29.36	31.98	2.42	43.19	26.62
34.59	36.89	60.14	17.83	26.17	5.31	53.35	21.17
38.16	13.37	36.85	20.64	26.02	3.47	42.98	33.81

Table 3. Percent infection with Karnal bunt of commercial bread wheat cultivars Roelfs F2007, Navojoa M2007, Tacupeto F2001, and Kronstad F2004, subjected to several combinations of nitrogen x sulphur (N–S) fertilization during the first and second sowing dates in the Yaqui Valley, Sonora, during the 2012–13 crop season.

	30 November, 2012				15 December, 2012			
N–S	Roelfs	Navojoa	Tacupeto	Kronstad	Roelfs	Navojoa	Tacupeto	Kronstad
200–0	35.32	15.93	57.53	30.74	13.91	6.33	37.05	18.33
200–30	44.69	20.17	40.82	33.80	21.92	4.52	31.70	16.37
200–60	36.37	17.42	38.89	19.24	26.10	3.88	42.16	27.49
200–90	44.22	15.53	55.38	26.11	23.35	5.16	30.57	16.45
300–0	42.78	25.13	60.89	34.45	36.8	7.28	48.16	11.00
300–30	43.41	17.34	47.79	32.19	26.19	5.96	32.18	29.58
300–60	38.85	21.65	60.81	30.73	19.01	11.53	31.38	28.82
300–90	31.59	15.81	48.50	30.51	29.98	4.39	34.14	18.54

The percent infection in the first sowing date during the 2013–14 crop season for cultivar Roelfs F2007 was 8.69–27.59%, with a mean of 17.05%, and for Kronstad F2004, 2.98–16.42%, with a mean of 8.07%. The overall range for the two cultivars was 2.98–27.59% with a mean of 12.56% (Table 4). The susceptible check showed 88.98% infection at the first date. The percent infection at the second sowing date for cultivar Roelfs F2007 was 4.60–25.77%, with a mean of 16.77%, and for Kronstad F2004, 8.92–21.59% with a mean of 14.15% (Table 4). The overall range for the two cultivars was 4.60–25.77% with a mean of 15.46%. The susceptible check showed 89.95% infection at the second date. A marked difference in percent infection for Kronstad F2004 between dates was observed, which was higher at the second date with the exception of treatments 30–45 (13.21–12.35%) and 45–45 (16.42–9.50%); the difference between the second and first planting dates ranged from 0.64% to 15.45%. For Roelfs F2007, the percent infection was higher in eight treatments at the second date, ranging from 1.31% to 13.39%, whereas the other eight were higher at the first date, ranging from 0.51% to 10.32%.

Table 4. Percent infection with Karnal bunt of two commercial, bread wheat cultivars Kronstad F2004 and Roelfs F2007, subjected to several combinations of nitrogen x sulphur (N–S) fertilization at two sowing dates, in the Yaqui Valley, Sonora, during the 2013–14 crop season.

(N–S)	30 November, 2012		15 December, 2012	
	Kronstad	Roelfs	Kronstad	Roelfs
0–0	11.82	22.17	12.46	14.35
15–0	9.32	8.69	20.69	12.94
30–0	7.53	24.68	12.92	23.15
45–0	4.33	20.16	16.63	14.70
0–15	4.30	18.51	13.38	16.69
0–30	5.33	14.98	14.76	17.84
0–45	6.14	15.54	21.59	18.04
15–15	8.26	17.03	19.96	18.35
15–30	2.98	16.18	12.06	18.16
15–45	8.39	12.38	12.80	25.77
30–15	8.04	18.15	8.92	9.05
30–30	9.54	11.84	17.69	4.60
30–45	13.21	27.59	12.35	17.27
45–15	6.37	17.07	8.97	16.57
45–30	7.07	14.26	11.68	15.96
45–45	16.42	13.50	9.50	24.87

Conclussions. Although there were clear interactions between levels for all factors for the reaction of bread wheat cultivars to artificial inoculation with Karnal bunt, the effects of sowing and inoculation dates and cultivar were apparent in both years. Higher levels of infection were observed at the earlier sowing and inoculation dates during the 2012–13 crop season, whereas the opposite occurred in 2013–14. The highest infection during the first season was recorded in Tacupeto F2001 (sowing 30/11/12, inoculation 22/02/13) and the lowest in Navojoa M2007 (sowing 15/12/12, inoculation 01/03/13). As the nitrogen rate increased, the greater the percent infection with no apparent effect by the sulphur rate, for all cultivars averaged across sulphur rates when the trial was sown on 15/12/12 and inoculated on 01/03/13. In the 2013–14 crop season, of the two cultivars evaluated, Roelfs F2007 had a higher percent infection than Kronstad F2004; and as in the first season, without an apparent effect by the sulphur rate.

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Effect of temperature, relative humidity, and rainfall on wheat grain yield in southern Sonora during the 2014–15 crop season.

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Abstract. The effect of temperature on wheat production for the 2014–15 crop season was evaluated using data obtained from 23 weather stations in southern Sonora. Temperature accumulated within the range >0 to ≤10°C at a ≥30°C threshold were measured and compared with data from three previous seasons. The effect of relative humidity, rainfall, and average temperature also were evaluated. The accumulation of cold hours, within the range >0 to ≤10°C, caused weak seedlings, and the tillers gave rise to spikes with various degrees of sterility, which, in turn, produced few or small grains. During the 2014–15 crop season, thermal hours in the temperature threshold ≥30°C increased to 2,610, which occurred frequently from 11 March on, coinciding with flowering and the initial and half-way development of the grain. Sterility increased during the reproductive stage, resulting in a few grains/spike, an increase in the number of wrinkled grains, and grains with low specific weight. The heat waves caused flower abortion and/or kernel development and a reduction of final grain weight. For each 1% increase in relative humidity, starting at 67.1%, an average wheat production reduction of 176 kg; 112 kg for each 1 mm of rainfall accumulated from flowering onward; and 572 kg for each 1°C temperature increase, starting at 15.9°C, were observed. The temperature trend during this crop season had a greater negative effect than that of rainfall and relative humidity. The interaction between temperature and RH indicates that, as the average temperature increased at 2.1°C and 3.2% RH, the average wheat grain production was reduced by 1.945 ton.

Introduction. In the region of southern Sonora, the main economic activity is agriculture. Wheat is the most important crop, which is frequently affected by the presence of adverse climatic phenomena, such as the abscence or uneven distribution of the cold during the winter, early and/or late frosts, excess or lack of rainfall, and the presence of diseases and pests. Wheat production during the 2014–15 crop season had a an average reduction of 1.9 ton/ha, affecting more than 240,000 ha. Abiotic and biotic factors associated with this negative impact on wheat production were increases in temperature, relative humidity, and rainfall, which also were associated with the occurrence of several diseases. This study determined the factors highly associated with the reduction of wheat production during the 2014–15 crop season in southern Sonora.

Materials and methods. To evaluate the effect of temperature on wheat production for the 2014–15 crop season, data obtained from 23 out of 29 weather stations in southern Sonora (Fig. 23) (PIEAES 2015), covering the Yaqui and Mayo Valleys, was used for the analysis. This data consisted of measuring the effect of the temperature accumulated within the range of >0 to ≤10°C (conceptualized as accumulated cold hours) at a ≥30°C threshold, compared with data from the 2011–12, 2012–13, and 2013–14 wheat seasons. The effects of relative humidity, rainfall, and average temperature also were evaluated. Damage to the spike was analyzed in several farmers' fields, by measuring the percent sterility, number of wrinkled grains, and number of grains with spots.

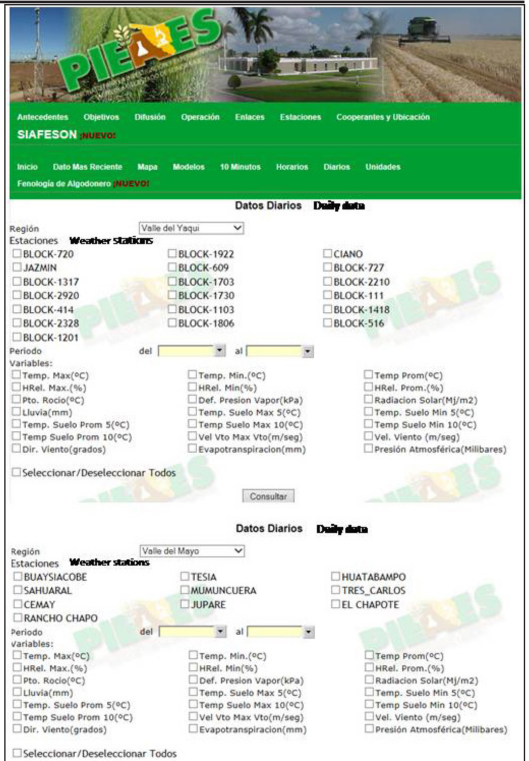

Fig. 23. Weather stations located in the Yaqui and Mayo Valleys, in southern Sonora, Mexico.

Results and discussion. The accumulation of cold hours, within the range >0–≤10°C (Fig. 24), was reduced from the early growth stages of the wheat plant (Fig. 25). Seedlings were weak and the tillers gave rise to spikes with various degrees of sterility, producing few or small grains. Because of their size, these grains were not retained by the combine during harvest (Fig. 26) (Félix et al. 2009). Weak stems are more susceptible to lodging and weak tillers exert an effect of competition as a weed with respect to the main stem. The lack of cold (∑ >0 to ≤10°C) also causes a reduction of the foliar area index, equal to the foliar mass reduction, which is not compensated for during the rest of the season and is closely related with a drop in production (Félix et al. 2009). During the 2014–15 crop season, thermal hours in the temperature threshold ≥30°C increased to 2,610 (Fig. 27, p. 34). This level of temperature occurred frequently from 11 March onward, coinciding with flowering and with the initial and half-way development of the grain (Table 5, p. 34). The increase in sterility during the reproductive stage, resulting in a reduction in number of grains/spike and an increase in the number of wrinkled grains and grains with low specific weight (Figs. 28 and 29, p. 34), were noticable. The heat

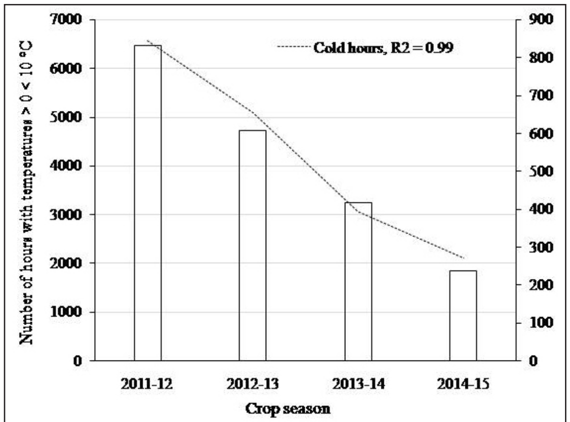

Fig. 24. Relationship between wheat production with thermal hour accumulation within >0–≤10°C conceptualized as accumulated cold hours (registered data from weather station in the Yaqui and Mayo Valleys, Sonora, Mexico.

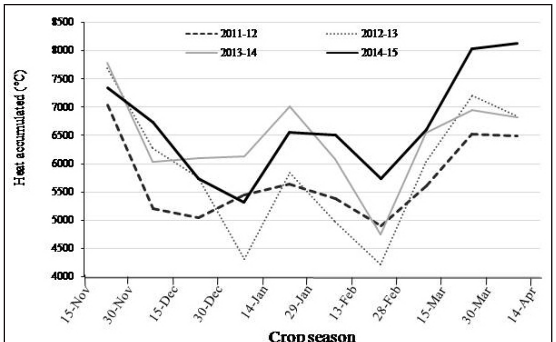

Fig. 25. Dynamics of heat acumulation during the 2011–12 to 2014–15 crop seasons in the Yaqui and Mayo Valleys, Sonora, Mexico.

Fig. 26. Spikes and their corresponding grain from a field in Hornos, Sonora, Mexico, sown on 15 November, 2014; average grain yield was 6.1 t/ha.

wave (Table 5) had a negative impact on pollination causing flower abortion (Figs. 28 and 29) on those recently pollinated, which affected kernel development and the developing kernels from a quarter kernel to milky stage, coinciding with stages Z6.5–Z7.05 (described by Zadoks et al. 1974). This level of temperature stress was manifested in a reduction of final grain weight.

Table 5. Temperatures greater than 30°C, time of exposure, and frequency, during March and April, 2015, in the Yaqui and Mayo Valleys, Sonora, Mexico (rows with the same color, indicate heat waves as temperatures above 30°C occurred during consecutive days).

Day/month	Temperature (°C)	Number of hours
11/03	30.1	1
14/03	30.0–31.1	3
15/03	30.0	1
22/03	30.1	1
23/03	30.7–31.8	4
24/03	30.2–30.4	3
27/03	30.0–32.5	5
28/03	30.0–32.0	6
29/03	30.1–30.4	3
01/04	31.1–32.8	4
02/04	30.1–30.8	5
05/04	30.1–30.8	4
06/04	30.9–32.2	6
07/04	30.0–33.1	6
08/04	30.4–31.8	5
09/04	31.1–32.6	4
10/04	30.1–30.6	5
13/04	30.3–30.8	4
14/04	30.5–31.9	6
15/04	30.1–32.9	7

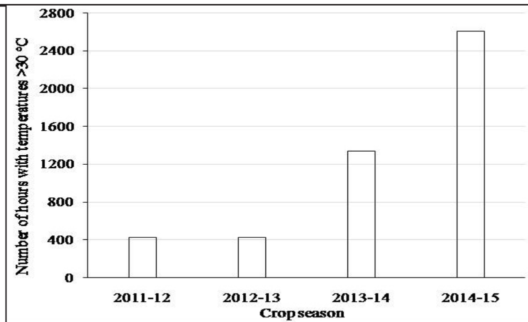

Fig. 27. Thermal hour accumulation in the range of ≥30°C, conceptualized as a heat wave on the wheat plant.

Fig. 28. A commercial field with wheat cultivar CIRNO C2008 in block 1730, planting date 25 November, 2014, with a 160 kg/ha seeding rate, three complimentary irrigations, and flowering 83–86 days after sowing (~11–15 February, 2015). Fungicides were applied to control rusts and Karnal bunt. The average yield for 300 ha was 5.3 t/ha, fewer grains/m^2, and spikes with small grain. Black point at harvest was 6%; yellow berry was ≤1%.

Fig. 29. Spikes of wheat cultivar CIRNO C2008 and their corresponding grain and grain weight from an area on the north side of a low canal. Planting date was 18 November, 2014, with a 180 kg/ha seeding rate, three complimentary irrigations, and flowering 85–90 days after sowing (~11–15 February, 2015). No fungicides were applied. Grain yield was 5.9 t/ha, 1.5 t/ha less than in the 2013–14 growing season, fewer grains/m^2, and sterile spikes and spikes with small and wrinkled grain. Black point at harvest was 5%; yellow berry was 5%.

For each 1% increase in relative humidity, starting at 67.1%, wheat production was reduced by an average of 176 kg. For each 1 mm of rainfall accumulated (Fig. 30, p. 30) from flowering onward, average production was reduced by 112 kg, in response to damage by fungal diseases such as Karnal bunt (*Tilletia indica*) and black point (*Alternaria* spp.) (Fig. 31, p. 30), and spot blotch (*Bipolaris sorokiniana*). For each 1°C temperature increase, starting at 15.9°C, average wheat production was reduced 572 kg. The temperature trend present during this crop season had a greater negative effect than the effect of rainfall and relative humidity, although the interaction of temperature and RH indicates that as the average temperature increased during the crop season in 2.1°C and 3.2% RH. The average grain production was reduced to 1.945 ton in 240,000 ha, which is equivalent to a volume of 466,800 ton, significantly affecting the regional economy in southern Sonora.

Damage to the plant and floral organs occurs when extreme climatic conditions prevail. Temperature damage is typified by its levels, because plants will not tolerate it at a given specific phenological stage. Damage might occur depending on the level of expression of these three principles: temperature level, time of exposure, and frequency. According to Table 5, the data complies with the temperature level, time of exposure (hours), and the frequency in days, in order to consider this climatic parameter as a heat wave, the main abiotic factor that caused the low wheat grain yield during the 2014–15 crop season.

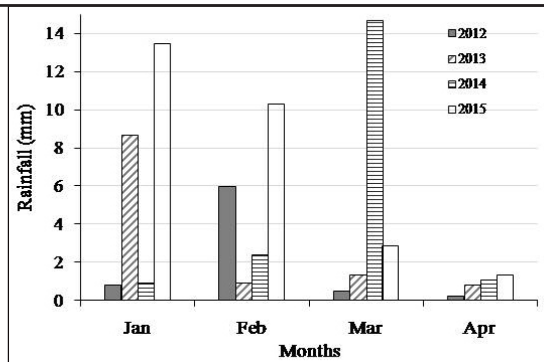

Fig. 30. Rainfall during January to April, 2015, in southern Sonora, Mexico.

Conclusion. In what is considered a normal wheat season, the average temperature is 16.2°C with 64% relative humidity. During the 2014–15 season, the average temperature was 18.8°C with 77.4% relative humidity, which caused heat waves (temperature fluctuations between 30 and 33°C) during tillering, flowering, and part of grain filling. Several periods had more than 80% relative humidity during the season and atypical precipitation patterns occurred in January, February, March, and at the beginning of April. These climatic conditions caused general damage to the wheat plant, which was expressed in a significant reduction in grain production, as well as negative effects on quality for export.


Fig. 31. Symptoms of Karnal bunt (left) and black point (right) in wheat.

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