World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Tiller production by bread wheat seed (*Triticum aestivum* L.) infected with karnal bunt (*Tilletia indica* Mitra)

Guillermo Fuentes-Dávila [1,*], María Monserrat Torres-Cruz [1], Pedro Félix-Valencia [2], Ivón Alejandra Rosas-Jáuregui [3] and Alberto Borbón-Gracia [4]

[1] Wheat Pathology, INIFAP, Norman E. Borlaug Experimental Station, P.O. Box 155, km 12 Norman E. Borlaug between 800 and 900 Yaqui Valley, Cd. Obregón, Sonora, Mexico 85200.

[2] Agroclimatology, INIFAP, Norman E. Borlaug Experimental Station, P.O. Box 155, km 12 Norman E. Borlaug beyween 800 and 900 Yaqui Valley, Cd. Obregón, Sonora, Mexico 85200.

[3] Wheat Biotechnology, INIFAP, Norman E. Borlaug Experimental Station, P.O. Box 155, km 12 Norman E. Borlaug between 800 and 900 Yaqui Valley, Cd. Obregón, Sonora, Mexico 85200.

[4] Wheat Breeding, INIFAP, Norman E. Borlaug Experimental Station, P.O. Box 155, km 12 Norman E. Borlaug between 800 and 900 Yaqui Valley, Cd. Obregón, Sonora, Mexico 85200.

World Journal of Advanced Research and Reviews, 2024, 24(03), 1069–1079

Publication history: Received on 31 October 2024; revised on 09 December 2024; accepted on 11 December 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.24.3.3769

Abstract

The tiller production by infected seed with karnal bunt (KB) showing different levels of infection, and uninfected seed of bread wheat cultivar Tacupeto F2001, were evaluated during the crop season 2021-2022 at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico. Plants were artificially inoculated by injection during the 2020-2021 crop season and the seed was selected based on the level of infection [level 1 (point of infection at the base of the seed), 2 (ca 30 % of the seed affected with KB), and 3 (ca 50 % of the seed affected with KB)]. Sowing was carried out on December 2 and 14, 2021 in beds 2 m long with two rows, placing 10 seeds in each row. The range of the number of tillers produced by seed with infection levels 1, 2, and 3, and the uninfected check sown on December 2 was: 15-37, 10-34, 14-28, and 15-39, while for the December 14 sowing date: 13-36, 11-33, 12-35, and 6-34, respectively. The average number of tillers produced was 24, 20, 22, and 25 for seed with levels of infection 1, 2, and 3, respectively, and the uninfected check, sown on December 2; while for December 14, it was 25, 21, 21, and 18 in the same order. The total number of tillers produced by infected seed with levels of infection 1, 2, 3, and the uninfected seed during the December 2 sowing date had a range of 391-500, while for the December 14 it was 366-490. The average temperature during the period of the evaluation was 17.4 °C with a maximum of 36.3 °C and a minimum of 2.3 °C; the average relative humidity was 64.3 %; there were 17.5 mm of precipitation, and the number of heat and cold units was 130 and 589, respectively.

Keywords: *Triticum aestivum*; Bread wheat; Karnal bunt; *Tilletia indica*; Seed infection; Tiller production

1. Introduction

Karnal bunt or partial bunt of wheat caused by the fungus *Tilletia indica* Mitra (syn. *Neovossia indica* Mundkur), affects bread wheat (*Triticum aestivum* L.) [1], durum wheat (*T. turgidum* L.) and triticale (X *Triticosecale* Wittmack) [2]. The disease has been reported from India [1], Mexico [3], Pakistan [4], Nepal [5], Brazil [6], The United States of America [7], Iran [8], the Republic of South Africa [9], and Afghanistan [10]. Since teliospores of the fungus are resistant to physical and chemical factors ([11-14], control of this pathogen is difficult; however, chemical control can be accomplished by spraying fungicides during flowering [15-28]. This measure would not be economically feasible where quarantine of phytosanitary regulations do not allow tolerance levels for seed production [29,30]. Within a disease

* Corresponding author: Guillermo Fuentes-Dávila

Copyright © 2024 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution Liscense 4.0.

management scheme, the use of resistant wheat cultivars is the best control option, which would also contribute to reduce the possibilities of introduction of the disease into other areas where karnal bunt has not been established. The reaction to karnal bunt inoculation of several species of *Triticum* have been evaluated since the 1940's [31-33]. *Triticum aestivum* is the species most affected by the disease; under artificial inoculation some lines may show more than 50 % infected grain [34-37]. It is common that the fungus affects partially some grains in a spike, and not all the spikes are affected in a plant [31], but in some occasions, grains may be totally destroyed; although the fungus may penetrate the embryo, it is not necessarily lethal [38,39]. Sori of infected wheat kernels are filled with many dark-colored teliospores and have a strong fishy odor caused by trimethylamine production [40]. Since both symptoms are undesirable, flour mills reject wheat lots having infected kernels on the basis that they will produce refined flour of inferior baking and organoleptic qualities (color, taste, and odor) [41]. Partially infected grains may produce healthy plants, although there are reports that indicate that the percentage of germination decreases depending on the level of infection of the grain [42-44], and that severely affected seed lose viability or show abnormal germination [43]; however, Fuentes-Dávila *et al*. [45] used random infected seed from various wheat nurseries, and they reported that seed with the highest infection level, but with the embryo intact, produced the highest number of tillers in two sowing dates (December 8 and 17), during the crop season 2008-2009. The objective of this work was to determine the number of tillers produced from seed from a single bread wheat genotype, with different levels of infection caused by *Tilletia indica*, under field conditions.

2. Material and methods

Plant tiller production was evaluated during the crop season 2021-2022 at the Norman E. Borlaug Experimental Station (CENEB) in the Yaqui Valley, Sonora, Mexico, located in block 910 (27° 22'04.64'' latitude north and 109° 55'28.26'' longitude west, 37 masl). The region has a warm climate [BW (h)] and extreme heat according to Köppen´s classification modified by García [46]. CENEB belongs to the National Institute for Forestry, Agriculture, and Livestock Research. The infected seed was obtained from inoculations in the field with *Tilletia indica* during the previous crop season 2020-2021 of bread wheat cultivar Tacupeto F2001 [47]. For inoculum preparation, infected grains about 1 year old were shaken in test tubes in a water-Tween 20 solution, filtered through a 60 µm nylon sieve and kept in the same type of solution for 24 h, in order to enhance teliospore germination. Then, the suspension was centrifuged at 3000 rpm, and after discarding the supernatant, sodium hypochlorite 0.5 % a.i. was used to disinfect teliospores for 2 min while centrifuging again. Teliospores were rinsed twice with sterile distilled water while centrifuging, resuspended in sterile distilled water in the centrifuge tube and one milliliter of the teliospore suspension was spread on Petri plates with 2 % water-agar (AA), which were incubated at 20-22 °C in darkness. After 6 to 9 days, teliospore germination was evaluated using a compound microscope at 10X. Pieces of AA with germinated teliospores were removed and placed upside down on the lid of Petri plates containing potato-dextrose-agar (PDA). After 10 to 14 days, 2 to 3 mL of sterile distilled water were added to the plates and the colonies were scraped gently using a sterile spatula. Hyphae and sporidia were inoculated onto other plates with PDA using a sterile syringe, and the plates were incubated at 20-22 °C in darkness for about nine days [48]. After incubation, pieces of PDA with the different fungal propagules were transferred and placed upside down on the lids of sterile glass Petri plates, in order to induce production of allantoid secondary sporidia [49,50]. Three mL of sterile distilled water were added to the bottom of the plates. Water from the plates was collected every 24 h, secondary allantoid sporidia were collected and counted using a heamocytometer; then, the concentration was adjusted to 10,000 per mL. Inoculations were performed by injecting 1 mL of the allantoid sporidial suspension (10,000/mL) during the boot stage of the plant (stage 49, Zadoks *et al*.) [51]. Upon maturity, inoculated spikes were collected, threshed by hand and the infected seed was selected based on the extent of lesions, and was classified as level 1 (point of infection at the base of the seed), 2 (ca 30 % of the seed affected with karnal bunt), and 3 (ca 50 % of the seed affected) (Figure 1).

Figure 1 Seed infection levels with karnal bunt (*Tilletia indica*). A. Level of infection 1 (point of infection at the base of the seed). B. Level of infection 2 (ca 30% of the seed affected with karnal bunt). C. Level of infection 3 (ca 50% of the seed affected)

The selected seed was stored at ca 10 °C until de following wheat season. Sowing was carried out on December 2 and 14, 2021, on beds 2 m long with two rows in a clay soil with pH 7.8. For the first sowing date, 20 seeds with the level of infection 1 were used, 20 with level of infection 2, and 20 with the level of infection 3, having a total of 8 rows which included two rows of uninfected seed of Tacupeto F2001. For the second sowing date, the same number of seeds with similar levels of infection were used as well as the uninfected seed used as check. The agronomic management of the small plots followed the technical recommendations by Figueroa-López *et al*. [52], with the exception that weed control was carried out manually. Counting of the number of tillers produced by each seed was made during maturity. The temperature, relative humidity, and rainfall as well as the accumulated number of cold and heat units was obtained from the weather station CIANO-910, which belongs to the automated weather station network of Sonora [53], from December 1, 2021 to April 30, 2022. Cold units were calculated as the temperature > 0.1°C to < 10°C that occurs in a given hour, and the heat units as the number of hours with temperature above 30 °C [54].

3. Results and discussion

The range of the average temperature during the period of evaluation was 17.4-23.6 °C (Figure 2), while for the maximum temperature it was 19.2-36.3 °C and 2.3-17.1 °C for the minimum temperature. The occurrence of temperatures above 30 °C were more consistent from March 23 (Figure 3) to April 30. However, it did not affect the proper development of plants, particularly the first phenological stages, since the maximum number of tillers recorded was 39. The accumulation of cold units (CU) started from December 6, 2021 up to April 30, 2022, with a total of 589. The accumulation of CU was more consistent after December 17, 2021; during the week of December 12-18 there were 17 CU, 35 in December 19-25, 2 in December 26-January 1, 42 in January 2-8, 2 in January 9-15, 16 in January 16-22, 52 in January 23-29, 59 in January 30-February 5, 62 in February 6-12, 46 in February 13-19, 42 in February 20-26, 39 in February 27-March 5, 72 in March 6-12, 40 in March 13-19, 33 in March 20-26, and 23 in March 27-April 2. All phenological stages of the wheat plant are sensitive to changes of temperature; high temperatures favor a greater metabolic activity speeding up the physiologic processes that determine its growth and development [55]. Plants also require accumulation of CU, to extend their biological cycle, which generally leads to a higher grain yield [54]. Recommended wheat sowing dates for southern Sonora lie between November 15 to December 15; generally, if sowing is done later, plants will not tiller properly and will be exposed to heat stress [52].

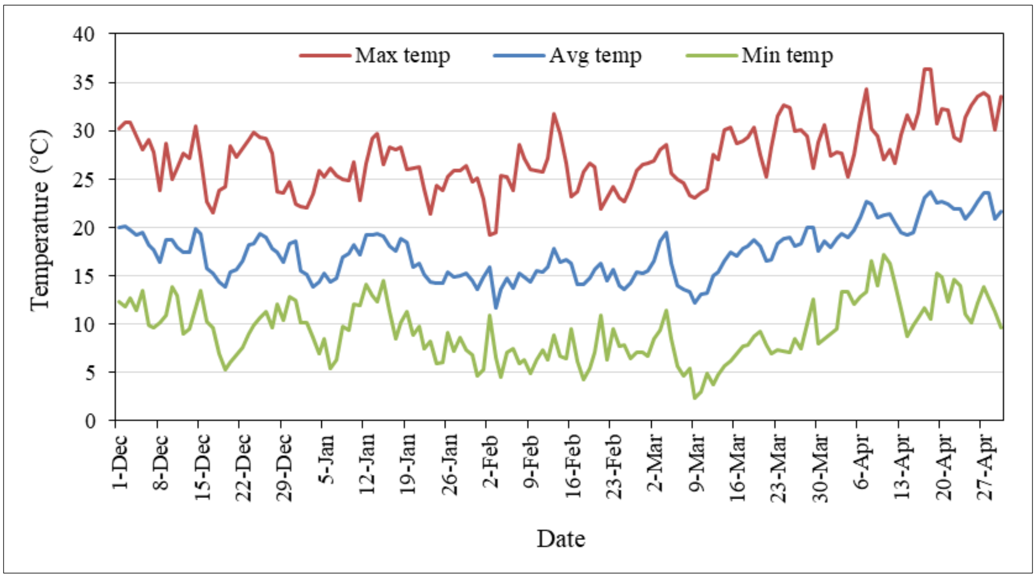

Figure 2 Average temperatures from December 1, 2021 to April 30, 2022, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2021-2022

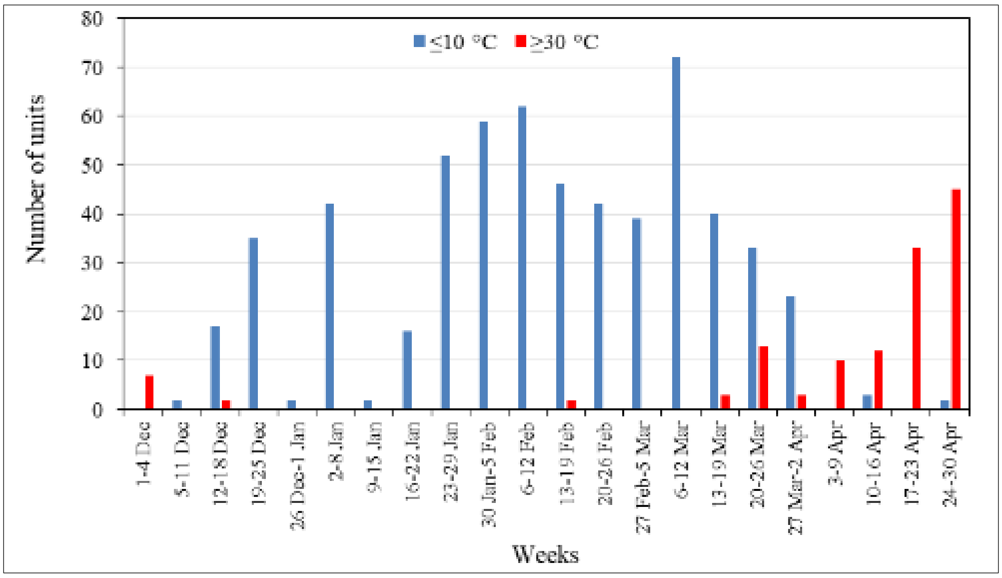

Figure 3 Number of cold and heat units accumulated from December 1, 2021 to April 30, 2022, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2021-2022

In contrast to the report of Fuentes-Dávila *et al.* [45] where they obtained 100, 100 and 95 % seed germinations with the three levels of infection in the first sowing date, while the percentage of seed germination in the second sowing date was 85, 90, and 85 % for the three levels of infection, respectively, in the present work all the seeds germinated regardless of the level of infection or if they were uninfected (Figure 4). Rai and Singh (1978) [43] reported a decrease in seed percentage germination of cultivar Arjun (HD 2009) with similar levels of infection as the ones used in this work, from 84 % seed germination in infected seeds with low level of infection to 57 % in infected seed with medium level of infection and to 49 % in infected seed with high level of infection, while the healthy seed showed 94 % germination, from the 1975 harvest. For the 1976 harvest, the percentage of seed germination in the same order was 84 to 72 and to 58 %, respectively while the healthy seed showed 98 %. Abnormal seedling percentage in 1975 was 13.1, 17.5, 22.4, and 1.1 % for the low, medium and high level of seed infection, and the healthy seed, respectively, while for 1976, abnormal seedling percentage in the same order was 7.1, 20.8, 24.1, and 0.0 %, respectively. The viability tests carried out by Rai and Singh [43] were carried out by the rolled towel paper method [56]. In the case of Singh [44] who raised seedlings by the Myhill and Konzak´s technique [57], the 1000 seed weight between the healthy check and the lowest infection grade was negligible (40.7 vs 40.5 g), however, the difference between the weight of seed with infection grade 1 and 4 was 13.3 g (32.8 %), while the percent loss in seedling length between those two grades was 29.1 %, and the difference in seed germination was 29.7 %. Similar tendencies were found by Bansal *et al*. (1984) using five grades of infection on four cultivars [42]. The percentage of seed germination observed in our work and the one reported by Fuentes-Dávila *et al*. [45] was much higher than those reported by other researchers, especially the germination of seed with the highest infection level; similar results were obtained by Warham *et al*. [58]. In our work, the range of the number of tillers produced by seed with infection levels 1, 2, and 3, and the uninfected check sown on December 2 was as follows: 15-37, 10-34, 14-28, and 15-39 (Figure 5), while for the December 14 sowing date, it was 13-36, 11-33, 12-35, and 6-34, respectively (Figure 6). Fuentes-Dávila *et al*. [45] reported than using the same levels of seed infection with sowing dates on December 8 and 17, recorded an overall range of tiller production of 7-37 and 8-43, respectively, which is somewhat similar to the results obtained in the present study: 10-39 tillers for the December 2 sowing date and 6-36 for the December 14 sowing date.

Figure 4 Growth of seeds with different infection levels with karnal bunt (*Tilletia indica*), at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season fall-winter 2021 2022. Photographs taken on December 21, 2021, January 3, and 24, 2022, and on April 18, 2022

The average number of tillers produced was 24, 20, 22, and 25 for seed with levels of infection 1, 2, and 3, respectively, and the uninfected check, sown on December 2; while for the sowing date on December 14, it was 25, 21, 21, and 18 in the same order. The total number of tillers produced by infected seed with levels of infection 1, 2, 3, and the uninfected seed during the December 2 sowing date had a range of 391-500, while for the December 14 it was 366-490 (Figure 7). Comparisons for the level of infection in the two sowing dates (December 2 and 14), were as follows: for infection level 1: 482 vs 490, level 2: 391 vs 421, level 3: 442 vs 417, and for uninfected check: 500 vs 366, being the main difference between sowing dates.

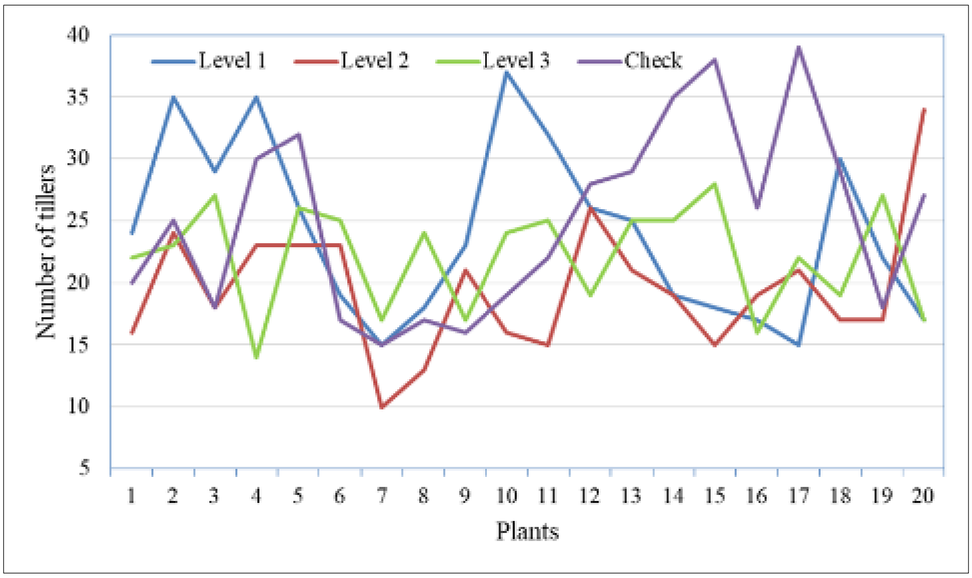

Figure 5 Number of tillers produced by infected seed with *Tilletia indica* with different levels of infection, and the uninfected check, of bread wheat cultivar Tacupeto F2001, during the crop season 2021-2022, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico. Sowing date December 2, 2021

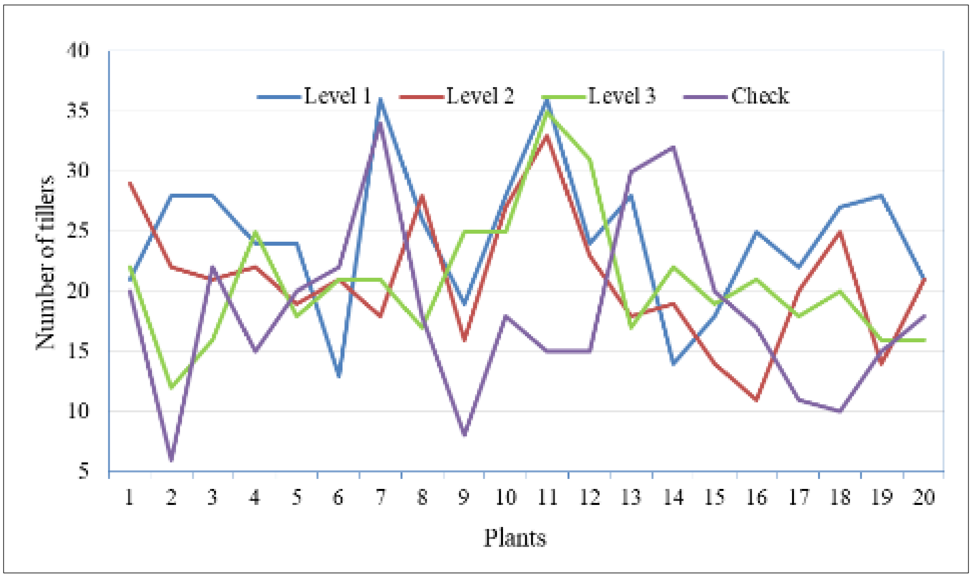

Figure 6 Number of tillers produced by infected seed with *Tilletia indica* with different levels of infection, and the uninfected check, of bread wheat cultivar Tacupeto F2001, during the crop season 2021-2022, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico. Sowing date December 14, 2021

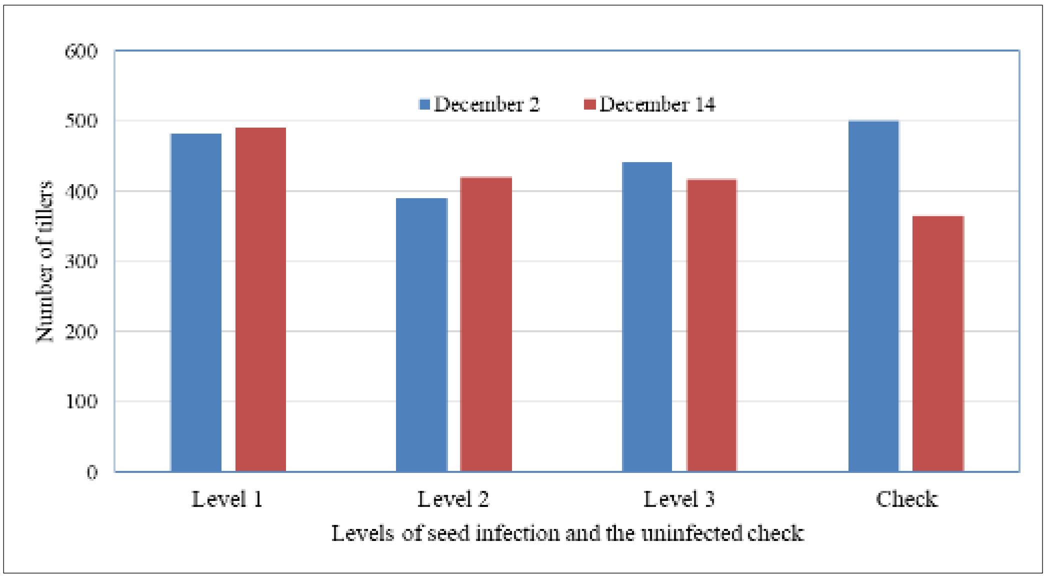

Figure 7 Total number of tillers produced by infected seed with *Tilletia indica* with different levels of infection, and the uninfected check, of bread wheat cultivar Tacupeto F2001, during the crop season 2021-2022, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, in two sowing dates

Unlike to what Bansal *et al*., Rai and Sing, and Singh did [42-44], we did not evaluate seedling development, and the seed used was obtained from a single cultivar unlike the study done by Fuentes-Dávila *et al*. [45]. The results obtained have important implications for wheat producers in areas where karnal bunt has established, since infected seed without the embryo affected, give rise to normal and high grain-yielding plants. It has also been demonstrated that regardless of the number of infected seeds used for sowing, the presence and incidence of the disease will depend on weather conditions that prevail during a given crop season and not on the continuous use of infected seed [59].

4. Conclusion

The range of the number of tillers produced by seed with karnal bunt infection levels 1, 2, and 3 [level 1 (point of infection at the base of the seed), 2 (ca 30 % of the seed affected with KB), and 3 (ca 50 % of the seed affected with KB)], and uninfected seed of bread wheat cultivar Tacupeto F2001, sown on December 2, 2021, was as follows: 15-37, 10-34, 14-28, and 15-39, while for the December 14 sowing date: 13-36, 11-33, 12-35, and 6-34, respectively.

The average number of tillers produced was 24, 20, 22, and 25 for seed with levels of infection 1, 2, and 3, respectively, and the uninfected check, sown on December 2; while for the sowing date on December 14: 25, 21, 21, and 18 in the same order.

The total number of tillers produced by infected seed with levels of infection 1, 2, 3, and the uninfected seed during the December 2 sowing date had a range of 391-500, while for the December 14 it was 366-490.

The average temperature during the period of the evaluation was 17.4 °C with a maximum of 36.3 °C and a minimum of 2.3 °C; the average relative humidity was 64.3 %; there were 17.5 mm of precipitation, and the number of heat and cold units was 130 and 589, respectively.

Compliance with ethical standards

Acknowledgments

This research was financially supported by the Mexican National Institute for Forestry, Agriculture, and Livestock Research (INIFAP).

Disclosure of conflict of interest

No conflict of interest to be disclosed..

Statement of ethical approval

The present research work does not contain any studies performed on animals/humans subjects by any of the authors'.

References

[1] Mitra, M. 1931. A new bunt of wheat in India. Annals of Applied Biology 18:178-179. https://doi.org/10.1111/j.1744-7348.1931.tb02294.x.

[2] Agarwal VK, Verma HS, and Khetarpal RK. 1977. Occurrence of partial bunt on triticale. Plant Protection Bulletin 25:210-211.

[3] Durán R. 1972. Further aspects of teliospore germination in North American smut fungi. II. Canadian Journal of Botany 50:2569-2573. https://doi.org/10.1139/b72-329.

[4] Munjal RL. 1975. Status of Karnal bunt (*Neovossia indica*) of wheat in Northern India during 1968-1969 and 1969-1970. Indian Journal of Mycology and Plant Pathology 5(2):185-187.

[5] Singh DV, Agarwal R, Shrestha KJ, Thapa RB, and Dubin HJ. 1989. First report of *Tilletia indica* on wheat in Nepal. Plant Disease 73:273. DOI: 10.1094/PD-73-0273B.

[6] Da Luz WC, Mendes MAS, Ferreira MASV, and Urben AF. 1993. *Tilletia indica* on wheat in the south of the state of Rio Grande do Sul, Brazil and measures for eradication. Fitopatologia Brasileira 18:S329.

[7] Ykema RE, Floyed JP, Palm ME, and Peterson JL. 1996. First report of Karnal bunt of wheat in United States. Plant Disease 80:1207. DOI: 10.1094/PD-80-1207B.

[8] Torarbi M, Mardoukhi V, and Jalaiani N. 1996. First report on the occurrence of partial bunt on wheat in the southern parts of Iran. Seed and Plant 12:8-9.

[9] Crous PW, Van Jaarsveld AB, Castlebury LA, Carris LM, Frederick RD, and Pretorius ZA. 2001. Karnal bunt of wheat newly reported from the African continent. Plant Disease 85:561. https://doi.org/10.1094/PDIS.2001.85.5.561B.

[10] CIMMYT (International Maize and Wheat Improvement Center). 2011. Training to beat karnal bunt in Afghanistan. http://blog.cimmyt.org/tag/karnal-bunt/. Accessed March 1, 2014.

[11] Krishna A, and Singh RA. 1982. Effect of physical factors and chemicals on the teliospore germination of Neovossia indica. Indian Phytopathology 35(3):448-455.

[12] Zhang Z, Lange L, and Mathur SB. 1984. Teliospore survival and plant quarantine significance of *Tilletia indica* (causal agent of Karnal bunt) particularly in relation to China. European Plant Protection Bulletin 14:119-128. https://doi.org/10.1111/j.1365-2338.1984.tb01858

[13] Smilanick JL, Hoffmann JA, and Royer MH. 1985. Effect of temperature, pH, light, and desiccation on teliospore germination of *Tilletia indica*. Phytopathology 75:1428-1431. DOI: 10.1094/Phyto-75-1428.

[14] Smilanick JL, Hoffmann JA, Secrest LR, and Wiese K. 1988. Evaluation of chemical and physical treatment to prevent germination of *Tilletia indica* teliospores. Plant Disease 72:46-51. DOI: 10.1094/PD-72-0046.

[15] Singh A, and Prasad R. 1980. Control of Karnal Bunt of wheat by a spray of fungicides. Indian Journal of Mycology and Plant Pathology 10:2. (Abstract).

[16] Singh SL, and Singh PP. 1985. Effect of some fungicide applications against Karnal Bunt (*Neovossia indica*) of wheat. Indian Phytopathology 38:593. (Abstract).

[17] Smilanick JL, Hoffmann JA, Cashion NL, and Prescott JM. 1987. Evaluation of seed and foliar fungicides for control of Karnal bunt of wheat. Plant Disease 71:94-96. Doi: 10.1094/PD-71-0094.

[18] Figueroa LP, and Valdés AJC. 1991. Evaluation of systematic fungicides for the control of Partial bunt *Tilletia indica* (Mit.) in wheat in the Yaqui Valley. Proceedings of the XVIII Congreso Nacional de la Sociedad Mexicana de Fitopatología, del 24 al 26 de julio de 1991. Puebla, Puebla, México. (Abstract). p 209.

[19] Salazar-Huerta FJ, Figueroa-Lopez P, Smilanick JL, and Fuentes-Davila G. 1997. Evaluation of foliar fungicides for control of Karnal bunt of wheat during 1986-1989 in northwestern Mexico. Revista Mexicana de Fitopatología 15:73-80.

[20] Figueroa-López P, and Álvarez-Zamorano R. 2000. Opus (epoxiconazole): a new option to control partial bunt in wheat (*Tilletia indica* Mitra) in foliar application. pp. 31-34. In: G. Fuentes-Dávila (ed.). XIIth Biennial Workshop on the Smut Fungi. Sociedad Mexicana de Fitopatología, A.C. 65 p.

[21] Goel LB, Singh DP, Sinha VC, Singh DV, Srivastava KD, Rashmi A, Aujla SS, Indu Sharma, Bagga PS, Singh RV, Singh AK, Singh SP. 2000. Evaluation of Tilt against Karnal bunt of wheat. Indian Phytopathology 53(3):301-302.

[22] Singh R, Beniwal MS, Karwasra SS. 2000. Field evaluation of fungicides against Karnal bunt of wheat through foliar spray. Department of Plant Pathology, Chaudhary Charan Singh Haryana Agricultural University, Hisar - 125 004, India. : Wellesbourne, UK: Association of Applied Biologists. Tests of Agrochemicals and Cultivars 21:9-10.

[23] Fuentes-Dávila G, Tapia-Ramos E, Toledo-Martínez JA, and Figueroa-López P. 2005. Evaluation of biological effectiveness of folicur 250 EW (Tebuconazole) for the control of partial bunt (*Tilletia indica*) of wheat (*Triticum aestivum*), in the Yaqui Valley, Sonora, Mexico, during the 2003-2004 crop cycle. Proceedings of the XIII Congreso Latinoamericano de Fitopatología, III Taller de la Asociación Argentina de Fitopatólogos. 19-22 de Abril, 2005. Villa Carlos Paz, Córdoba, Argentina. Resumen HC-29, página 271. 640 p.

[24] Sharma AK, Singh DP, Kumar J, Sharma I, and Sharma BK. 2005. Efficacy of some new molecules against Karnal bunt (*Tilletia indica*) of wheats (*Triticum aestivum* and *T. durum*). Indian Journal of Agricultural Sciences 75(6):369-370.

[25] Fuentes-Dávila G, Félix-Valencia P, Ayón-Ibarra CA, Figueroa-López P, Camacho-Casas MA, Félix-Fuentes JL, Chávez-Villalba G, and Rosas-Jáuregui IA. 2016. Biological effectiveness of several fungicides for control of karnal bunt (*Tilletia indica*) of wheat, in the field. Annual Wheat Newsletter 62:28-31.

[26] Fuentes-Dávila G, Rosas-Jáuregui IA, Ayón-Ibarra CA, Álvarez-Amado KD, Félix-Valencia P, and Félix-Fuentes JL. 2018. Biological effectiveness of Opus, Folicur, Juwel, and Bemistop for control of Karnal bunt (*Tilletia indica*) of wheat in the field. Annual Wheat Newsletter 64:30-33.

[27] Fuentes-Dávila G, Torres-Cruz MM, Félix-Valencia P, Rosas-Jáuregui IA, and Félix-Fuentes JL. 2022. Biological effectiveness of fungicides Priori Xtra, Folicur, Approach Prima, and Maxtrobin Xtra for control of karnal bunt. International Journal of Agriculture, Environment and Bioresearch 7(4):83-94. https://doi.org/10.35410/IJAEB.2022.5747.

[28] Fuentes-Dávila, G., Torres-Cruz, M.M., Félix-Valencia, P., Rosas-Jáuregui, I.A., and Borbón-Gracia, A. 2024. Biological effectiveness of Tebuconazole under three commercial names and Epoxyconazole, for control of Karnal Bunt in the field. World Journal of Advanced Research and Reviews 24(02):713-722. DOI: 10.30574/wjarr.2024.24.2.3381.

[29] SARH (Secretariat of Agriculture and Water Resources). 1987. Internal Quarantine interior No. 16 against partial bunt of wheat. Secretaría de Agricultura y Recursos Hidráulicos. Diario Oficial, (jueves) 12 de Marzo de 1987, México.

[30] SAGARPA (Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food). 2002. Official Mexican Norm NOM-001-FITO-2001, establishing the campaign against wheat partial bunt. Diario Oficial viernes 8 de Febrero, 2002. México, D.F. pp. 1-18.

[31] Bedi SKS, Sikka MR, and Mundkur BB. 1949. Transmission of wheat bunt due to *Neovossia indica* (Mitra) Mundkur. Indian Phytopathology 2:20-26.

[32] Singh DV, Joshi LM, and Srivastava KD. 1986. Varietal susceptibility and spread of Karnal Bunt of wheat in India. Rachis 5:40-42.

[33] Singh A, Singh KP, and Tewari AN. 1988. Salient findings of Karnal bunt research at Pantnagar. Department of Plant Pathology, G.B. Pant University of Agriculture and Technology, Pantnagar 263 145.

[34] Fuentes-Davila G, Rajaram S, Pfeiffer WH, and Abdalla O. 1992. Results of artificial inoculation of the 4th Karnal Bunt Screening Nursery (KBSN). Annual Wheat Newsletter 38:157-162. Available at: https://wheat.pw.usda.gov/ggpages/awn/38/.

[35] Fuentes-Dávila G., Prakash-Singh R, Rosas-Jáuregui IA, Félix-Fuentes JL, and Ayón-Ibarra CA. 2018. Evaluation of bread wheat lines for resistance to karnal bunt. Global Advanced Research Journal of Agricultural Science 7(8):268-271. Available online http://garj.org/garjas/home.

[36] Fuentes-Dávila G, Prakash-Singh R, Rosas-Jáuregui IA, Ayón-Ibarra CA, Torres-Cruz MM, Félix-Valencia P, Félix-Fuentes JL, and Chávez-Villalba G. 2020. Evaluation of advanced bread wheat lines for Karnal bunt resistance in

the field during the 2014-15 crop season. Annual Wheat Newsletter 66:58-62. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://wheat.pw.usda.gov/ggpages/awn/66/ AWNVOL66.pdf.

[37] Fuentes-Dávila G, Prakash-Singh R, Rosas-Jáuregui IA, Ayón-Ibarra CA, Torres-Cruz MM, Félix-Valencia P, and Félix-Fuentes JL. 2021. Reaction of bread wheat advanced lines to karnal bunt artificial inoculation during the 2015-2016 season. International Journal of Agriculture, Environment, and Bioresearch 6(5):94-104. https://doi.org/10.35410/IJAEB.2021.5667.

[38] Chona BL, Munjal RL, and Adlakha KL. 1961. A method for screening wheat plants for resistance to *Neovossia indica*. Indian Phytopathology 14:99-101.

[39] Mitra M. 1935. Stinking smut (bunt) of wheat with a special reference to *Tilletia indica* Mitra. Indian Journal of Agricultural Sciences 5:1-24.

[40] Joshi LM, Singh DV, and Srivastava KD. 1980. Wheat disease survey 1. Karnal bunt 1975-1980. Wheat Pathology Series 7, August 1980. Division of Mycology and Plant Pathology, Indian Agriculture Research Institute, New Delhi, India. 28 p.

[41] Peña RJ, Amaya A, and del Toro E. 1992. Effect of grain washing and storage of wheat samples (Cultivar Seri M82) with different infection levels of Karnal Bunt (*Tilletia indica*) on quality parameters. pp. 21-28. In: G Fuentes-Davila, and GP Hettel (Eds.). Update on Kamal Bunt Research in Mexico. Wheat Special Report No.7. Mexico, D.F.: CIMMYT.

[42] Bansal R, Singh DV, and Joshi LM. 1984. Effect of Karnal bunt pathogen [*Neovossia indica* (Mitra) Mundkur] on weight and viability of wheat seed. Indian Journal of Agricultural Sciences 54(8):663-666.

[43] Rai RC, and Singh AA. 1978. A note on the viability of wheat seeds infected with Karnal bunt. Seed Research 6:188-190.

[44] Singh DV. 1980. A note on the effect of Karnal bunt infection on the vigour of wheat seed. Seed Research 8:81-82.

[45] Fuentes-Dávila G, Figueroa-López P, Cortés-Jiménez JM, Félix-Valencia P, Camacho-Casas MA, Chávez-Villalba G, Félix-Fuentes JL, and Ortiz-Ávalos AA. 2013. Effect of the level of wheat seed infection with karnal bunt, on germination and tiller production. Annual Wheat Newsletter 59:45-48. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://wheat.pw.usda.gov/ggpages/awn/59/TEXTFILES/MEXICO.pdf

[46] García E. 2004. Modifications to the Köppen climate classification system. Institute of Geography of the National Autonomous University of Mexico. Book Series number 6. México, D.F. 90 p. Available at: http://www.publicaciones.igg.unam.mx/index. php/ig/catalog/view/83/82/251-1. Accessed on May 11, 2023.

[47] Camacho-Casas MA, Singh RP, Figueroa-López P, Huerta-Espino J, Fuentes-Dávila G., and Ortiz-Monasterio-Rosas I. 2003. Tacupeto F2001: new variety of bread wheat for northwest Mexico. Technical Brochure Number 50, National Institute of Forestry, Agricultural and Livestock Research, Northwest Regional Research Center, Yaqui Valley Experimental Station. Ciudad Obregón, Sonora, México. 20 p.

[48] Fuentes-Bueno I, and Fuentes-Dávila G. 2007. Reaction of wheat cultivars WL-711 (*Triticum aestivum*) and Altar C84 (*T. turgidum* subsp. *turgidum*) to inoculation with *Tilletia indica* cultures obtained from infected wheat cultivars Baviacora M92 (*T. aestivum*) and Altar C84 under natural conditions in the Yaqui valley, Sonora, Mexico. Annual Wheat Newsletter 53:48-52. Available at: https://wheat.pw.usda.gov/ggpages/awn/53/Textfiles/MEXICO.html.

[49] Dhaliwal HS. 1989. Multiplication of secondary sporidia of *Tilletia indica* on soil and wheat leaves and spikes and incidence of Karnal bunt. Canadian Journal of Botany 67, 2387-2390. Doi:10.1139/b89-304.

[50] Fuentes-Davila G, Rajaram S, Pfeiffer WH, Abdalla O, Van-Ginkel M, Mujeeb-Kazi A, and Rodríguez-Ramos R. 1993. Results of artificial inoculations from the 5th selection nursery for resistance to *Tilletia indica* Mitra. Revista Mexicana de Micología 9:57-65. https://doi.org/10.33885/sf.1993.3.800.

[51] Zadoks JC, Chang TT, and Konzak CF. 1974. A decimal code for the growth stages of cereals. Weed Research 14:415-421. https://doi.org/10.1111/j.1365-3180.1974.tb01084.x

[52] Figueroa-López P, Fuentes-Dávila G, Cortés-Jiménez JM, Tamayo-Esquer LM, Félix-Valencia P, Ortiz-Enríquez E, Armenta-Cárdenas I, Valenzuela-Herrera V, Chávez-Villalba G., and Félix-Fuentes JL. 2011. Guide to producing wheat in southern Sonora. Brochure for producers No. 39. INIFAP-CIRNO, Norman E. Borlaug Experimental Station. Cd. Obregón, Sonora, México. 63 p. ISBN: 978-607-425-518.8.

[53] REMAS (Automated Weather Station Network of Sonora). 2022. Download data. Available at http://www.siafeson.com/remas/.

[54] Félix-Valencia P, Ortíz-Enríquez JE, Fuentes-Dávila G, Quintana-Quiróz JG, and Grageda-Grageda J. 2009. Cold hours in relation to wheat yield: production areas of the state of Sonora. INIFAP, Northwest Regional Research Center, Yaqui Valley Experimental Station. Technical Brochure No. 63. Cd. Obregón, Sonora, México. 40 p. ISBN 978-607-425-159-3.

[55] Moreno Dena JM, Salazar Solano V, and Rojas Rodríguez IS. 2018. Economic impacts of cold hours on wheat production in Sonora, Mexico. Entreciencias: diálogos en la sociedad del conocimiento: 6(16):15-29. https://doi.org/10.22201/enesl.20078064e.2018. 16.63206.

[56] ISTA (International Seed Testing Association). 1966. Seed Testing Rules. Proc. Int. Seed Test. Ass. 31:1-152.

[57] Myhill RR and Konzak CF. 1967. A new technique for culturing and measuring barley seedlings. Crop Science 7:275-276. https://doi.org/10.2135/cropsci1967.0011183x000700030038x.

[58] Warham EJ. 1990. Effect of *Tilletia indica* infection on viability, germination and vigor of wheat seed. Plant Disease 74(2):130-132. DOI: 10.1094/PD-74-0130.

[59] Fuentes-Dávila G. 2014. Incidence of karnal bunt in experimental plots sown with infected wheat seed during several crop seasons. Annual Wheat Newsletter 60:42-46. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://wheat.pw.usda.gov/ggpages/awn/60/TEXTFILES/MEXICO.pdf.