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Fusarium species in maize grains and stems (*Zea mays* L.) from subsistence and commercial systems
Especies de *Fusarium* en granos y tallos de maíz (*Zea mays* L.) de sistemas comerciales y de subsistencia

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Abstract
The objective of this research was the morphomolecular identification of species of the genus Fusarium associated with native and commercial maize genotypes in municipalities of Puebla and Morelos, Mexico, as well as to describe the socioeconomic and cultural importance of maize cultivation. Fusarium species were isolated from grains and stem cuttings with purple, brown, and dark brown pigmentations. They were identified morphomolecularly by using taxonomic keys and the Dinocapture 2.0 software, and by DNA extraction by the CTAB method and amplification of the ITS1 and ITS4 region by PCR. Four species were identified: *Fusarium equiseti, Fusarium verticillioides, Fusarium incarnatum* and *Fusarium napiforme* with an identity greater than 98 %. The genotypes with the highest incidence of Fusarium spp. were: Pioneer 30F35 in San Miguel, Teotlalco, Puebla by *F. verticillioides* (A2). The genotypes with the lowest incidence were: Shark from Tetelilla, Morelos by *F. incarnatum* (A1), *F. verticillioides* (A6) and *F. napiforme* (A7). Maize is the main food in many locations in Mexico, however, due to the high consumption of this grain and its derivatives, as well as the high consumption of meat presumably fed with this grain, it could represent a route of ingestion of mycotoxins.
Keywords: *Fusarium equiseti; Fusarium incarnatum*; *Fusarium napiforme*; *Fusarium verticillioides*; incidence; stem rot; ear rot; severity; genotypes; cultivation; pigmentations

Resumen
El objetivo de esta investigación fue la identificación morfomolecular de especies del género *Fusarium* asociadas a genotipos de maíces nativo y comercial en municipios de Puebla y Morelos, México, así como describir la importancia socioeconómica y cultural del cultivo del maíz. Se aislaron especies de *Fusarium* a partir de granos y esquejes de tallo con pigmentaciones moradas, pardas y pardas oscuras. Se identificaron morfomolecularmente mediante el uso de claves taxonómicas y el software Dinocapture 2.0, y mediante extracción de ADN por el método CTAB y amplificación de la región ITS1 e ITS4 por PCR. Se identificaron cuatro especies: *Fusarium equiseti*, *Fusarium verticillioides*, *Fusarium incarnatum* y *Fusarium napiforme* con una identidad superior al 98 %. Los genotipos con mayor incidencia de *Fusarium* spp. fueron: Pioneer 30F35 en San Miguel, Teotlalco, Puebla por *F. verticillioides* (A2). Los genotipos con menor incidencia fueron: Tiburón de Tetelilla, Morelos por *F. incarnatum* (A1), *F. verticillioides* (A6) y *F. napiforme* (A7). El maíz es el principal alimento en muchas localidades de México, sin embargo, debido al alto consumo de este grano y sus derivados, así como al alto consumo de carne presumiblemente alimentado con este grano, podría representar una vía de ingestión de micotoxinas.
Palabras clave: *Fusarium equiseti; Fusarium incarnatum*; *Fusarium napiforme*; *Fusarium verticillioides*; incidencia; pudrición del tallo; pudrición de la mazorca; severidad; genotipos; cultivo; pigmentaciones

1. Introduction

Among diseases that frequently occur in corn crops, which affect root, stem, and ear, are caused by fungi (White, 1999); mainly, stem and ear rot caused by *Gibberella/Fusarium* Link (Nectriaceae) (Levin et al*.,* 2003). The lesions on corn stalk caused by *Fusarium* appear oval or in narrow, vertical areas with a cloudy appearance that start reddish-brown and then turn black, and in advanced stages of rot, the stem breaks at the node, characterized by white mycelium in the bark (Pioneer, 2020a). In maize program of the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) México (2004) described that *Fusarium* wilted plants remain erect when dried and small dark brown lesions are observed on lower internodes. Carmona & Scandiani (2010) add that first symptoms appear on stems that are still green, but as a yellow spot and later turn brown in the lower internodes.

The *Fusarium* genus includes species that infect cereals and are of high concern for agricultural production and food/feed safety worldwide (Desjardins, 2006). The species of this genus are characterized by being the causal agent of diseases in a wide range of host plants, with significant economic impacts (Wang et al*.,* 2011). Among the species that cause ear rot and corn kernels, *Fusarium verticillioides* (Sacc.) Nirenberg, *Fusarium graminearum* Schwabe*, Fusarium oxysporum* Schltdl., *Fusarium equiseti* (Corda) Sacc., *Fusarium subglutinans* (Wollenw & Reinking) P.E. Nelson, Toussoun & Marasas (Nectriaceae) (Görtz et al*.,* 2008; Qin et al*.,* 2014; Ammar et al*.,* 2013; Rahjoo et al*.,* 2008; Macdonald et al*.,* 1997) stand out. *Fusarium verticillioides* is the most common isolated species of corn in the world (Munkvold & Desjardins, 1997), causing seedling blight, stem, root, and ear rot (Shurtleff, 1980). The contamination level and population structure of *Fusarium* spp. in grains could predict the presence of certain mycotoxins (Miller, 1995; Bottalico, 1998) which are toxic to humans or animals that consume them (Brown et al*.,* 2004; Desjardins, 2006; Alexander et al*.,* 2009; Sánchez-Rangel & Plasencia, 2010; Yin et al*.,* 2016), which is why they are strictly regulated throughout the world (Van Egmond & Jonker, 2005). Climatic conditions such as temperature, rainfall, and relative humidity during flowering are critical for primary infection, as well as for toxin accumulation during flowering and prior to harvest (De La Campa et al*.,* 2005; Maiorano et al*.,* 2009; Cao et al*.,* 2014). The accurate knowledge of water amount in grains and seeds is important for commercialization, mainly due to the moisture content, since it influences the fungi growth in storage stage (Christensen & Kaufmann, 1969), while, in the post-harvest stage, the fungi development and mycotoxins synthesis can be well controlled, respecting the maximum limits of relative humidity (Bottalico & Perrone, 2002; Logrieco 2003).

Phytopathogens can cause serious losses in economic terms and production, therefore, the crucial step in disease management under natural field conditions is to properly detect the pathogen (Tewari, 2019). In addition, mycotoxins are a latent threat to human health, as they can act as a silent killer since their consumption in very small doses does not induce obvious clinical symptoms, but over time it can have serious consequences on life quality (Borja & Calvo, 2021). Therefore, the aim of this research was to identify morpho-molecular *Fusarium* species associated with nine genotypes of native and commercial maize in municipalities of Puebla and Morelos states, México, as well as the description of socioeconomic importance and cultural of this crop.

2. Methods, techniques, and instruments

Genetic material

The materials under study were obtained at the end of the production cycle (November 2019) of nine corn plots destined for grain (human and animal consumption) in the municipalities of Contla, San Miguel, Teotlalco Puebla and Tepalcingo and Tetelilla in Morelos state (table 1).

From each genotype, 15 ears (with and without *Fusarium* symptoms) of 10 central rows and 15 stem cuts with pigmentation on the outside were randomly taken (figure 1) between the fourth and fifth internodes, the samples were placed in paper bags, protected in expanded polystyrene coolers, identified, and transferred to Parasitology Department of Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila, México.

Table 1. *Native and hybrid corn genotypes used in this research*.
Tabla 1. *Genotipos de maíz nativo e híbrido utilizados en esta investigación*.

Genetic material origin	Genotypes	Coordenates	Height above sea level (m)	Company
Tetelilla, Morelos	Pioneer P4028W	18.611667, -98.770000	1164	Pioneer
Tepalcingo, Morelos	Pioneer P4028W	18.620266, -98.813735	1160	Pioneer
Tetelilla, Morelos	Tiburón	18.611667, -98.770000	1164	Syngenta
San Miguel, Teotlalco, Puebla	Black Native	18.512159, -98.820937	1044	Native
San Miguel, Teotlalco, Puebla	Pioneer 30F35	18.512159, -98.820937	1044	Pioneer
San Miguel, Teotlalco, Puebla	Zapata 2	18.512159, -98.820937	1044	Agrícola el caudillo
Contla, Teotlalco, Puebla	White Native	18.517819, -98.811872	1055	Native
Contla, Teotlalco, Puebla	Black Native	18.517819, -98.811872	1055	Native
Contla, Teotlalco, Puebla	Pioneer 30F35	18.517819, -98.811872	1055	Pioneer

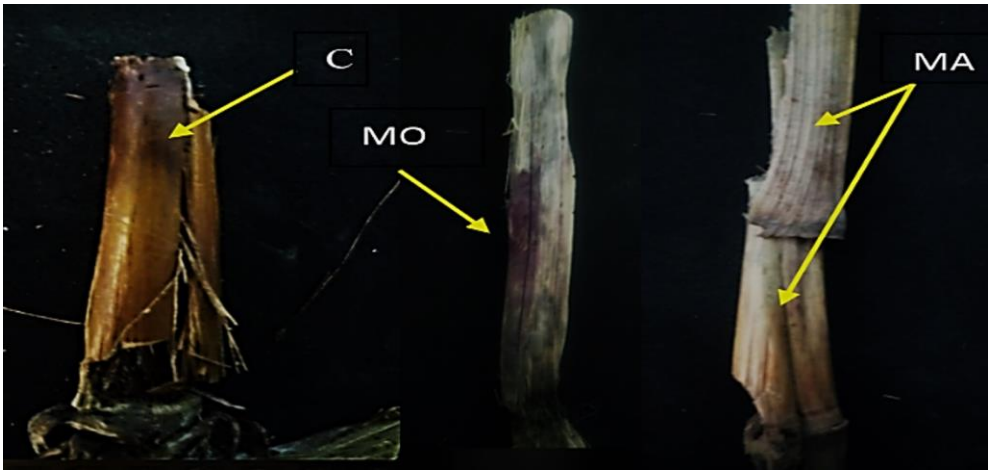

Figure 1. *Exterior pigmentation on corn stalks*.
Note: C = Brown color. Mo = Purple color. MA = Dark brown color.
Figura 1. *Pigmentación exterior en tallos de maíz*.
Nota: C = Color marrón. Mo = Color morado. MA = Color marrón oscuro.

Fusarium spp. isolation from stalk and ear of corn

The corn stalk and grain samples were collected from plants with a complete phenological cycle. The stem samples were sectioned into 1cm^2 sections of healthy and infected plants, under a laminar flow hood, which was superficially disinfected with 3 % sodium hypochlorite for 2 min (three times) and in distilled water for 1 min (three times), then they were left to dry for 10 min, and then three sections were placed in a Petri dish with culture medium Spezieller Nährstoffarmer Agar (SNA) (1 g KH_2PO_4, 1 g KNO_3, 0.5 g $MgSO_47H_2O$, 0.5 g KCL, 0.2 g glucose, 0.2 g sucrose and 20 g agar in 1 L of distilled water) + antibiotics (Gentamicin, 1 mL L^{-1}). The Petri

dishes were sealed and kept in incubation at 26 °C for 168 h, 15 replicates were made per genotype, and where one repetition consisted of a Petri dish with three sections.

Fungal isolation from grains was made according to the National Seed Health System (SNHS 2020). For this purpose, grains were disinfected with 3 % sodium hypochlorite (two times) and subsequently they were rinsed with distilled water for 1 min (two times). The sowing was carried out in polyethylene trays on two layers of sterile blotting paper (previously moistened), 50 grains (with and without *Fusarium* symptoms) were randomly selected and uniformly distributed in the tray, giving a total of 20 replicates per genotype. Finally, the trays were labeled and kept at 25 ± 2 °C for 48 h in a bioclimatic chamber, later, they were frozen at -20 °C for 24 h, and finally they were kept at room temperature (25 °C ± 2) per 264 h, alternating 12:12 h white light and darkness (figure 2).

Figure 2. *Sample of tagged stem and ear corn used for* Fusarium *spp. isolation*.
Figura 2. *Muestra de maíz de tallo y mazorca marcado utilizado para el aislamiento de* Fusarium *spp*.

Pathogens purification by monoconidial cultures

Three 6 mm diameter explants were extracted from each isolated fungus colony and were placed in test tubes with 9 mL of sterile distilled water and 1 mL was extracted and then deposited in a Petri dish with SNA medium, and with a dispersion rod it was spread uniformly over the entire box, 24 h later only one germinated conidium was taken and placed in a new Petri dishes with SNA and kept at 25 ± 2 °C for 120 h.

Morphological identification

The macroscopic identification of colonies was carried out according to the shape, color and texture, and their microscopic identification was based on the structure and composition of 100 conidia, phialides and chlamydospores using a digital microscope with an integrated camera and with the support of measurement DinoCapture software 2.0 (Dinolite, 2020), and for morphological identification the taxonomic keys of Leslie & Summerell (2006) and the interactive key for *Fusarium* of Seifert (1996) were used.

Molecular identification

The cetyl-trimethyl ammonium bromide (CTAB) method was used to extract DNA fungal (Almeyda et al*.,* 2001), to do this, starting from axenic strains, mycelium of each *Fusarium* spp. the strain was macerated with pistil in a porcelain mortar previously sterilized, to which 500 µL of extraction were added with: NaCl 1.4 mM, EDTA 20 mM, PVP 1 % Tris Base 100 mM (pH 8) and 200 µL B- mercaptoethanol. The maceration product was placed into sterile 1.5 mL microtubes, incubated at 65 °C for 45 min at 15 rpm and vortexed for 30 s. Next, 500 µL of SEVAG (chloroform-isoamyl alcohol, 24: 1) were added to the sample and subsequently it was centrifuged at 1200 g for 15 min. The supernatant was recovered and transferred to another microtube, and an equal volume of cold isopropanol was added and kept at -20 °C for 24 h. After that time, it was centrifuged at 1200 g for 10 min, the microtubes were decanted and finally the DNA pellet obtained was resuspended into 60 µL nuclease-

free water and stored at 4 ºC until use. The ITS1 and ITS4 regions were amplified. Mixing was performed for amplification in a final volume of 15 µL, composed of 5.8 µL MQ water, 2.5 µL buffer (10X), 0.5 µL dNTP´s (10mM), 2.5µL of each primer ITS1 (5´TCC GTA GGT GAA CCT GCG G3´) and ITS4 (5´TCC TCC GCT TAT TGA TAT GC3´), 0.2 µL Taq-polymerase, 0.2µL DNA Taq-polymerase and 1µL of DNA. The amplification reactions were carried out using a thermal cycler under the following conditions: 1 cycle 95°C 3 min, followed by 35 cycles to 95°C by 10 s, 57 °C by 30 s and 72 °C by 45 s, ending with a polymerization cycle of 72 °C for 5 min. The PCR products were verified on 1 % agarose gels and visualized under UV light. Finally, the PCR products were purified using the isolate II PCR product and gel kit. The samples were sequenced at Potosino Institute for Scientific and Technological Research (IPYCIT) with the labeled dideoxynucleotide method on the 3130 Genetic Analyzer sequencer, and the sequence obtained was assembled and compared with those available in the database of the National Center for Biotechnology Information (NCBI), using the BLAST tool for highly similar sequences.

Socioeconomic and cultural study of the corn crop

To obtain information on consumers of corn and its derivatives, as well as the methods of its storage in Puebla and Morelos states, a semistructured survey was designed with quantitative and qualitative questions to 200 families per state (table 2).

Table 2. Survey performed with families in towns of Puebla and Morelos states Mexico.
Tabla 2. Encuesta realizada a familias en municipios de los estados de Puebla y Morelos, México.

On the consumption of corn and its derivatives
How old are you?
How many members there are in the family?
Do you consume native or hybrid corn?
What color is the corn you eat?
Do you consume products derived from corn?
How many times a week do you consume corn products?
In what quantity do you consume products derived from corn?
Do you consume meat and/or livestock derivatives?
Do they consume meat and/or derivatives of cattle that incorporate corn in their diet?
How many times a week do you eat meat?
How much do you eat meat?
About storing corn
Do you produce corn?
Do you store corn for consumption or sell it?
What do you store corn in?
Do you apply any product when the corn is stored?
What kind of product do you use in the storage of corn?
How long do you store corn?

Data analysis

The data analysis process of surveys obtained by the families was carried out using Excel® software version 16.0 and R software (R Core Team, 2013).

3. Results and discussion

3.1. Morpho-molecular identification

In general, the fungal strains (all strains were identified in corn stem and grains) isolated in grains and corn stalks from nine localities, flattened colonies of slow and rapid growth were observed, of white, orange, purple colors, with hyaline microconidia in the shape of a club and slightly flattened at each end from 6.597 to 45.788

µm long and 2.537 to 4.760 µm wide. Macroconidia curved to nearly straight; 3-9 septa with foot-shaped basal cell 34.36 to 79.555 µm long and 3.383 to 6.800 µm wide. Chlamydospores (absent in some species), determinants for species of *Fusarium*.

The PCR amplification ranged from 690 to 800 bp (figure 3) identifying four species: *Fusarium equiseti, Fusarium verticillioides*, *Fusarium incarnatum* (Robergge) Sacc. (*Fusarium semitectum*) and *Fusarium napiforme* Marasas, Nelson and Rabie (without sexual reproduction) with macro and microscopic characteristics of each species (figures 4 and 5), with a percentage of molecular identity of 98 to 100 % (table 3).

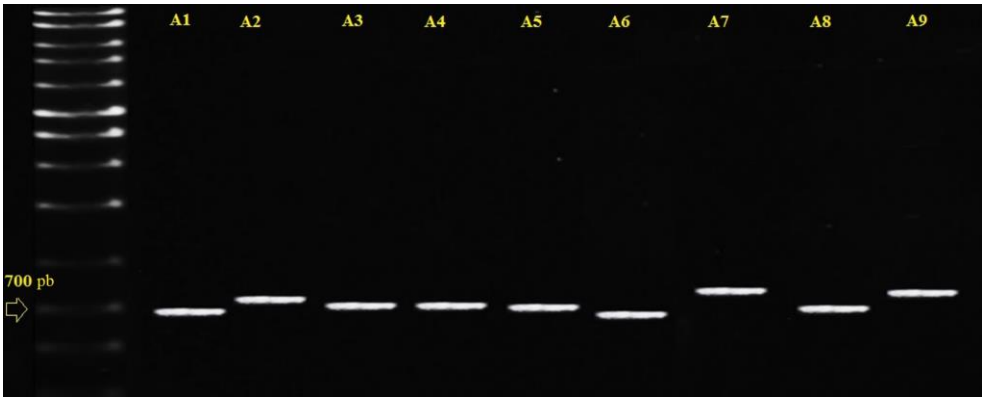

Figure 3. *Molecular markers of identified* Fusarium *species*.
Note: A1 = *F. incarnatum.* A2 = *F. verticillioides.* A3 = *F. verticillioides.* A4 = *F. verticillioides.* A5 = *F. incarnatum.* A6 = *F. verticillioides.* A7 = *F. napiforme.* A8 = *F. equiseti.* A9 = *F. verticillioides.*
Figura 3. *Marcadores moleculares de especies de* Fusarium *identificadas*.
Nota: A1 = *F. incarnatum*. A2 = *F. verticillioides*. A3 = *F. verticillioides.* A4 = *F. verticillioides*. A5 = *F. incarnatum*. A6 = *F. verticillioides*. A7 = *F. napiforme.* A8 = *F. equiseti*. A9 = *F. verticillioides*.

Figure 4. Top view of *Fusarium* species colonies isolated from corn.
Note: A1 = *F. incarnatum.* A2 = *F. verticillioides*, A3 = *F. verticillioides*. A4 = *F. verticillioides*. A5 = *F. equiseti*. A6 = *F. verticillioides*. A7 = *F. napiforme.* A8 = *F. equiseti.* A9 = *F. verticillioides.*
Figura 4. *Vista superior de colonias de especies de Fusarium aisladas de maíz.*
Nota: A1= *F. incarnatum.* A2= *F. verticillioides.* A3 = *F. verticillioides.* A4 = *F. verticillioides.* A5 = *F. equiseti.* A6 = *F. verticillioides.* A7 = *F. napiforme.* A8 = *F. equiseti.* A9 = *F. verticillioides.*

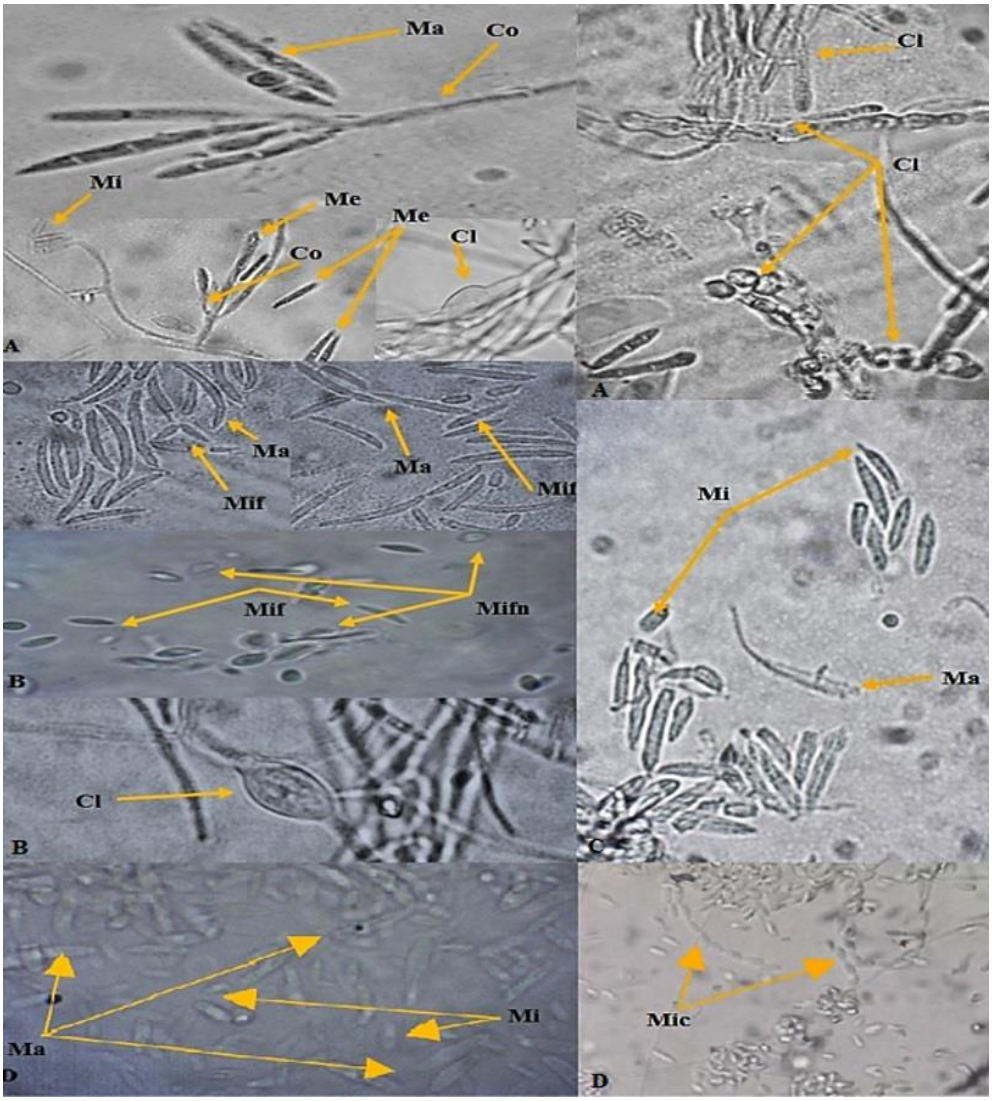

Figure 5. *Typical microscopic structures of* Fusarium *species*.
Note: A = *F. incarnatum*. B = *F. napiforme*. C = *F. equiseti.* D= *F. verticillioides*. Ma = Macroconidia. Mi = Microconidia. Me = Mesoconidia. Co = Conidiophore. Cl = Chlamydospore. Mif = Spindle-shaped microconidia. Mifn = Spindle and napiform microconidia. Mic = Chain microconidia.

Figura 5. *Estructuras microscópicas típicas de especies de* Fusarium.
Nota: A = *F. incarnatum*. B = *F. napiforme*. C = *F. equiseti*, D= *F. verticillioides*. Ma = Macroconidios. Mi = Microconidios. Me = Mesoconidios. Co = Conidióforo. Cl = Clamidospora. Mif = Microconidios fusiformes. Mifn = Microconidios fusiformes y napiformes. Mic = Microconidios en cadena.

Table 3. *Morpho-molecular character values for* Fusarium *species*.
Table 3. *Valores de caracteres morfomoleculares para las especies de* Fusarium.

Code	Pathogen	Macroconidia (µm)		Microconidia (µm)							
		Long	Wide	Long	Wide	PCL	BP	Max score	Total score	% identity	Key*
A1	*F. incarnatum*	39.03	6.33	12.0	5.05	Yes	710	915	1095	98.60	MW534564.1
A2	*F. verticillioides*	40.04	3.98	7.8	2.98	No	700	926	926	100.00	MK790050.1
A3	*F. verticillioides*	34.04	3.38	6.6	2.54	No	750	689	689	98.48	MN871798.1
A4	*F. verticillioides*	40.08	3.98	7.8	3.01	No	750	915	915	100.00	MN121060.1
A5	*F. equiseti*	72.45	6.19	41.7	4.34	No	690	865	865	98.00	MT515832.2
A6	*F. verticillioides*	44.05	4.38	8.5	3.28	No	680	909	909	99.40	MN049928.1
A7	*F. napiforme*	53.38	5.88	8.9	3.11	Yes	800	915	915	99.80	MH862670.1
A8	*F. equiseti*	79.56	6.80	45.8	4.76	No	690	920	1100	100.00	KR819405.1
A9	*F. verticillioides*	39.82	3.96	7.7	2.97	No	750	926	926	99.80	MT505436.1

Note: PCL = Chlamydospores presence. BP = Base pairs. *NCBI-BLAST comparative basis.
Nota: PCL = Presencia de clamidosporas. BP = Pares de bases. *Base comparativa NCBI-BLAST.

3.2. Fusarium spp. incidence in grains and corn stalks

In all locations studied there was an incidence of *Fusarium* species, although not all of them were equally present in grains and stems. The genotypes that showed the highest *Fusarium* spp. incidence was Pioneer 30F35 in San Miguel, Teotlalco, Puebla and the Native white in Contla, Puebla, with 35.2 and 39.6 % in grains and 44.4 and 26.7 % in stems by *F. verticillioides* (A2). The genotypes that showed lowest incidence were Tiburón in Tetelilla, Morelos, with three associated *Fusarium* species and only with an incidence in grains with 1.5, 3.7 and 29.2 % by *F. incarnatum* (A1), *F. verticillioides* (A6) and *F. napiform*e (A7), respectively. On the other hand, Pioneer P4028W genotype in Tepalcingo, Morelos, showed low incidence in grains with 2.2 % by *F. verticillioides* (A3), and 13.7 and 28.9 % in grains and stems respectively by *F. equiseti* (A5) (figure 6).

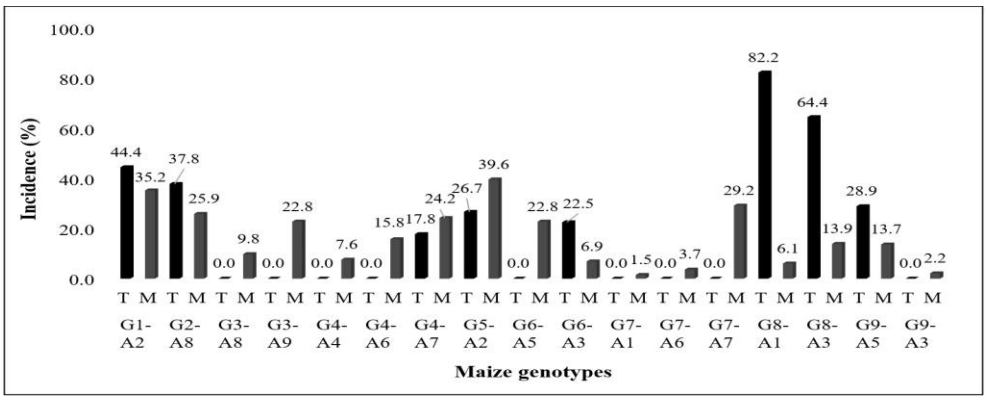

Figure 6. Fusarium *spp. incidence in corn (maize) stem and grain*.
T = Stem incidence. M = Grains incidence. G1 = Pioneer 30F35 from San Miguel, Teotlalco, Puebla. G2 = Native black from San Miguel, Teotlalco, Puebla. G3 = Zapata 2 from San Miguel, Teotlalco, Puebla. G4 = Native black from Contla. G5 = Native white from Contla. G6 = Pioneer 30F35 from Contla, Puebla. G7 = Tiburón from Tetelilla, Morelos. G8 = Pioneer P4028W from Tetelilla, Morelos. G9= Pioneer P4028W from Tepalcingo, Morelos. A1 = *F. incarnatum.* A2 = *F. verticillioides.* A3 = *F. verticillioides.* A4 = *F. verticillioides.* A5 = *F. equiseti.* A6 = *F. verticillioides.* A7 = *F. napiforme.* A8 = *F. equiseti.* A9 = *F. verticillioides.*
Figura 6. *Incidencia de* Fusarium *spp. en tallo y granos de maíz*.
T = Incidencia en tallo. M = Incidencia en granos. G1 = Pioneer 30F35 de San Miguel, Teotlalco, Puebla. G2 = Negro nativo de San Miguel, Teotlalco, Puebla. G3 = Zapata 2 de San Miguel, Teotlalco, Puebla. G4 = Negro nativo de Contla. G5 = Blanco nativo de Contla. G6 = Pioneer 30F35 de Contla, Puebla. G7 = Tiburón de Tetelilla, Morelos. G8= Pioneer P4028W de Tetelilla, Morelos. G9= Pioneer P4028W de Tepalcingo, Morelos. A1 = *F. incarnatum*. A2 = *F. verticillioides*. A3 = *F. verticillioides*. A4 = *F. verticillioides*. A5 = *F. equiseti*. A6 = *F. verticillioides*. A7 = F. *napiforme*. A8 = *F. equiseti*. A9 = *F. verticillioides*.

According to pigmentation, it should be noted that genotype with the highest incidence due to brown color was Zapata 2 from San Miguel, Teotlalco, Puebla, for dark brown it was a Black native from Contla, Puebla, and for purple pigmentation the White native from Contla, Puebla (figure 7). The genotypes that showed the lowest incidence due to brown pigmentation were the Black native from San Miguel, Teotlalco, and Puebla, for the dark brown color they were Zapata 2 from San Miguel, Teotlalco, Puebla and White native from Contla, Puebla, and for purple color the Black native from San Miguel, Teotlalco, Puebla (figure 7).

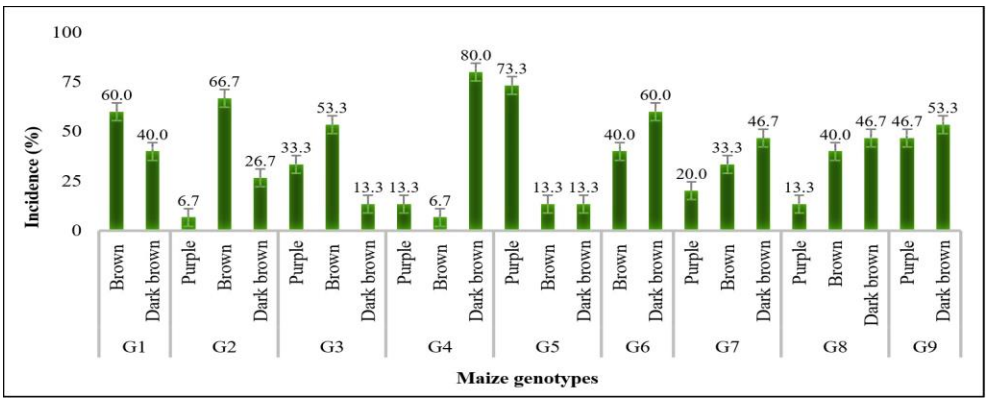

Figure 7. *Pigmentation color on the outside of corn stalks*.
Note: T = G1= Pioneer 30F35 from San Miguel, Teotlalco, Puebla. G2 = Black native from San Miguel, Teotlalco, Puebla. G3 = Zapata 2 from San Miguel, Teotlalco, Puebla. G4 = Black native from Contla, Puebla. G5 = White native from Contla, Puebla. G6 = Pioneer 30F35 from Contla, Puebla. G7 = Tiburón from Tetelilla, Morelos. G8 = Pioneer P4028W from Tetelilla, Morelos. G9 = Pioneer P4028W from Tepalcingo, Morelos.
Figura 7. *Color de pigmentación en el exterior de tallos de maíz*.
Nota: T = G1 = Pioneer 30F35 de San Miguel, Teotlalco, Puebla. G2 = Negro nativo de San Miguel, Teotlalco, Puebla. G3 = Zapata 2 de San Miguel, Teotlalco, Puebla. G4 = Negro nativo de Contla, Puebla. G5 = Blanco nativo de Contla, Puebla. G6 = Pioneer 30F35 de Contla, Puebla. G7 = Tiburón de Tetelilla, Morelos. G8 = Pioneer P4028W de Tetelilla, Morelos. G9 = Pioneer P4028W de Tepalcingo, Morelos.

3.3. Socioeconomic and cultural study of the corn crop

The Black and White native and the Pioneer 30F35 in Contla, Puebla (natives and hybrids) represent a serious problem, due to these genotypes are used mainly as food for people and livestock, with a high consumption of corn per day, as well as its derivatives.

According to the interviews carried out with farmers in the study locations, they show that few people know that they consume hybrid and native maize, from white, black, and red colors, and to a lesser extent they do not know what type of maize they are consuming. The mean was obtained by adding all the data on the consumption (corn and derivatives) of each person (mean per family) and the result was divided by the total number of people. The consumption of corn and its derivatives for these study locations is 1.15 and 1.13 kg per day, in an average of 6 days (days in which they consume corn ()), that is, if we do the interpolation at 7 days a week (complete week), it would be an average per capita consumption of 0.9554 and 0.9416 kg per day at Puebla and Morelos, respectively.

3.4. Identification and incidence of Fusarium spp. in grains and corn stalks

The *Fusarium* incidence in grains and corn stalks may be related to the fact that fungicide applications are not carried out in study locations for the prevention (on grains) or control of phytopathogenic fungi in plants. This is mainly due to the lack of information on part of the farmer, as mentioned in the interviews, "we do not apply any fungicide because we do not know it and we do not see the pest", referring to fungi, they said. The latter are microorganisms that constitute the group to which the largest number of agents that cause devastating diseases in animals and plants belong (Dean et al*.,* 2012), being the most numerous groups of pathogens that affect crops (UNL, 2017) and one of the greatest challenges in modern agriculture to achieve its effective and lasting control (Collinge et al*.,* 2010). In addition, they have a great impact, because they cause pre- and post-harvest diseases (Agrios, 2005) and specifically cause losses mainly in five important foods worldwide, rice, wheat, corn, potatoes, and soybeans (Carreras et al*.,* 2021). Regarding losses, these can be quantitative and/or qualitative (taste, texture, color, and shape) (Ashworth et al*.,* 1981; Agrios 1988). Strange & Scott (2005) commented that despite the continuous release of cultivars with some degree of resistance and chemical fungicides, it is

estimated that 10 % of crop yields are lost due to fungal diseases, one of several reasons why farmers in the study localities barely have a production approximately 3-6 tons per ha^{-1} in corn.

Fusarium can infect any part of the plant, from the beginning to the end of the growing season. Stem rot is a common and severe symptom in corn causing reduced growth, rotten leaf sheaths and inner stem tissue with brown stripes on the lower internodes, and in mature plants, it causes a salmon-pink discoloration of tissues of the medulla inner of stem (Shaner & Scott, 2022). Stem rots cause the vascular bundles to discolor to a yellow-dark brown hue and then the appearance of reddish-brown stripes on lower internodes, with symptoms progressing to the fifth internode or more (Sabet et al*.,* 1966), such as happened in the present investigation, whose pigmentations on the outside of the stems with the highest incidence were dark brown.

Stem rot caused by the *Fusarium* genus is commonly associated with two species, *F. verticillioides* and *F. graminearum* (De León, 1984). The *Fusarium* genus is the most common cob pathogen worldwide (García-Lara et al*.,* 2007) and *F. verticillioides* is the main species, considered as the causal agent of ear rot (Logrieco et al*.,* 2002; Munkvold, 2003; Summerell et al*.,* 2003; Adejumo et al*.,* 2007; Folcher et al*.,* 2009; Nayaka et al*.,* 2009; Woloshuk & Wise, 2014; Dekalb, Asgrow & Deltapine, 2017; Kuki et al*.,* 2020; Pioneer, 2020b; Syngenta 2022; Ramos, 2022) and stem (White, 1999; Liu et al*.,* 2012; Gai et al*.,* 2018), furthermore, this pathogen is found everywhere where corn is grown (Pioneer, 2021). In the present research work, the identified species were *F. equiseti, F. verticillioides*, *F. incarnatum* and *F. napiforme,* and it should be noted that the outcomes are largely similar in morphometric characteristics to those reported by other authors (table 4).

Table 4. *References in similar morphometric characters in species found in the present research work*.
Tabla 4. *Referencias en caracteres morfométricos similares en especies encontradas en el presente trabajo de investigación*.

Code	*Fusarium* species	RMOR	RMIC
A1	*F. incarnatum*	Khoa et al. (2004) Wang et al. (2020) Song et al. (2014)	Lezcano et al. (2012) Mao et al. (2020) Shen et al. (2018) Wonglom & Sunpapao (2020) García-Estrada et al. (2020)
A2, A3, A4, A6, A9	*F. verticillioides*	Rahjoo et al. (2008) Figueroa-Rivera et al. (2010) Rosas-Guevara et al. (2014) De la Torre-Hernández et al. (2014) Walker et al. (2016) Leyva-Mir et al. (2017) Kiranjot et al. (2020) Giraldo-Arias et al. (2018) Aparecido & Rosa (2019) Solano-Báez et al. (2011)	
A7	*F. napiforme*	Marasas et al. (1988) Morales-Rodríguez et al. (2007)	
A5, A8	*F. equiseti*	Goswami et al. (2008) Rodrígues & Menezes (2005) Kosiak et al. (2005) Hami et al. (2021)	

Note: RMOR = Similar reference in morphology. RMIC= Similar reference in micrometry.
Nota: RMOR = Referencias similares en morfología. RMIC= Referencias similares en micrometría.

In the present research, *F. verticillioides* was the species with the highest incidence in stems and grains in all locations studied. There are biotic and abiotic factors that contribute to increasing the incidence and severity of *F. verticillioides* infections in the field and under storage conditions that alter the physical integrity of the grain, such as insect and bird pests (Díaz, 2012). The use of glyphosate -based herbicide to weed control and a nitrogen source as fertilizer are factors that can also promote or inhibit the development of *Fusarium* communities (Leplat et al*.,* 2013). Also, the pH and nutritional composition, as well as the water activity, oxygen presence, time, and temperature of storage (Auerbach, 2003). However, the *Fusarium* spores can be spread to new plants by wind and water; this pathogen spreads over short distances, through water, agricultural equipment and infested tools, and over long distances, through diseased plants or soil attached to them, in addition, it is important to emphasize that once the soil is infested, it remains that way indefinitely (Dixon & Tilston, 2010). In the study locations, some producers do not carry out adequate pest control, except for glyphosate use for weeding control due to its low cost. For example, in Mexico one liter of glyphosate (Faena®) it has a cost that ranges from MX $ 115.00 in Morelos state to MX $ 1,250.00 in Tamaulipas state (SE, 2021), in addition to this, producers use nitrogen as the main source of fertilizer in crops. The importance of controlling fungal diseases not only lies in reducing losses in yield, but also consists in avoiding the production of which has implications for grains quality, in public and animal health (Mazzani et al*.,* 1999; García et al*.,* 2006). On the other hand, fumonisins have toxic effects when consumed by humans and animals (Levin et al*.,* 2003; Bush et al*.,* 2004). There are multiple alternatives to prevent colonization of molds in grains and seeds, and thus avoid mycotoxins presence, however, genotype selection and the improvement for resistance to fungal incidence turns out to be the most favorable, due to the great variety of factors that influence the grain deterioration (Chavarri, 2014; taken from Chavarri et al*.,* 2017).

3.5. Socioeconomic and cultural study of the corn crop

Corn consumption in Puebla and Morelos is 0.9554 and 0.9416 kg per day, equivalent to an annual consumption of 348.72 and 343.68 kg (by for example, only the tortilla (made hand) weighs approximately between 30 to 40 g (mean 35 g), people said that they had lunch with a minimum of 5 to 6 tortillas (approximately 210 g) to eat 6 to 7 tortillas (approximately 245 g) and for 3 to 4 tortillas (approximately 140 g), that is, an mean of 595 g in tortillas alone, plus the consumption of corn derivatives) (figure 8), while in México the national level there is an annual *per capita* consumption of 196.4 kg of white corn (PAN, 2016). The consumption of foods prepared with cereals contaminated with fumonisin B, produced mainly by *F. verticillioides* (the pathogen with the highest incidence in this research) has been associated with acute poisonings, in which gastrointestinal manifestations such as vomiting, diarrhea, abdominal pain occur and dehydration (Peraica et al*.,* 1999).

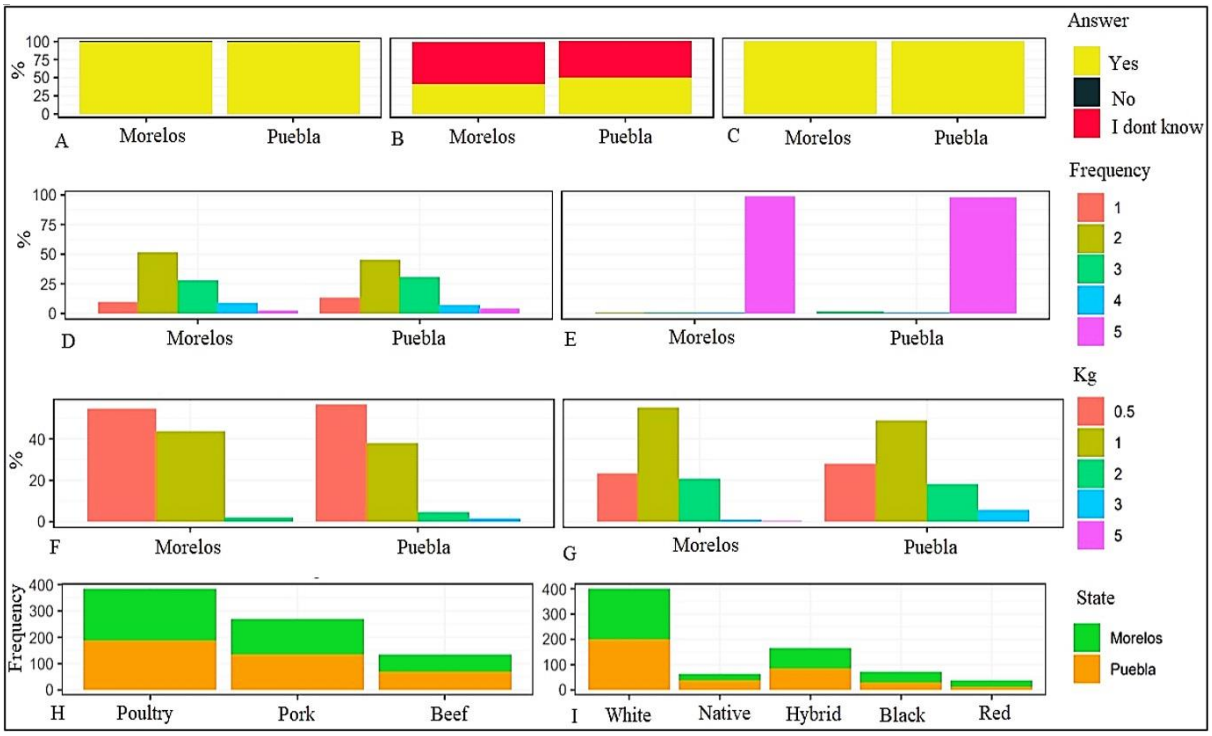

Figure 8. *Means of corn consumption in Puebla and Morelos states y consumption of products derived from corn, as well as meat and livestock derivatives in Puebla and Morelos states*.
Note: A = Do you consume meat and/or livestock derivatives? B = You consume native or hybrid corn? C = You consume products derived from corn? (Answers). D = Do you consume meat and/or livestock derivatives? E= You consume products derived from corn? (Frequency´s). F = Do you consume meat and/or livestock derivatives? G = You consume products derived from corn? (kg). H = Do you consume meat and/or livestock derivatives? (Types). I = You consume native or hybrid corn? (Color and type of corn).
Figura 8. *Formas de consumo de maíz en los estados de Puebla y Morelos y consumo de productos derivados del maíz, así como carnes y derivados pecuarios en los estados de Puebla y Morelos*.
Nota: A = ¿Consume carne y/o derivados pecuarios? B = ¿Consumes maíz nativo o híbrido? C = ¿Consumes productos derivados del maíz? (Respuestas). D = ¿Consume carne y/o derivados pecuarios? E = ¿Consumes productos derivados del maíz? (Frecuencias). F = ¿Consume carne y/o derivados pecuarios? G = ¿Consumes productos derivados del maíz? (kg). H = ¿Consume carne y/o derivados pecuarios? (Tipos). I = ¿Consumes maíz nativo o híbrido? (Color y tipo de maíz).

Especially in corn dough, global fumonisin concentrations range from <10 ppm in the United States of America to > 100 ppm in some locations in China and Africa (Marasas, 2001), however, subsequent results indicate that fumonisins role depends on the environment and genetic context in plant-pathogen interaction (Desjardins et al., 2007). For example, in Africa considering that per capita consumption of corn is among the highest in the world (400 g/d), Shephard et al. (2007) estimated that the average daily intake of fumonisin B1 of an average adult (60 kg) is between 3.43 and 8.67 mg/kg of body weight per day, greatly exceeding the provisional maximum tolerable intake of 2 mg/kg of body weight per day established by the World Health Organization (WHO, 2002). The high corn consumption and its derivatives in México for the localities of this study, would be a strong problem when consuming more than doubled *per capita* consumption than in Africa, in addition to consuming beef, pork and poultry on a daily basis, highlighting that the consumption of mycotoxins in people is facilitated by the consumption of products of plant and animal origin, which are contaminated when animals consume significant amounts of mycotoxins and are transported to final products (meat, milk or eggs) (Duarte

& Villamil, 2006; Battacone et al., 2010; Bandera et al., 2011; Baliukoniene et al., 2012), however, these studies are necessary.

The contamination of food with mycotoxins is considered a process that begins in the field and continues during the harvest, the grains drying and the storage of field products (CAST, 2003), mainly in cereals, which are the basis of food in México and developing countries (Santillán-Mendoza et al., 2017). Among mycotoxins, fumonisins are produced mainly by *F. verticillioides* and produce fumonisins B1, B2, B3 and B4 (Proctor et al., 2006) with an important role as a potential Group 2B cancer promoting agent (Ueno, 1993; IARC, 2002), in equine leukoencephalomalacia, porcine pulmonary edema, and rat hepatocarcinoma (Marasas, 1995; Marasas et al., 1988; Gelderblom et al., 1998; Covarelli et al., 2012), furthermore, it is one of the species frequently implicated in human infections together with *F. solani* and *F. oxysporum* (Dignani & Anaissie, 2004).

Fusarium napiforme is one of the species that together with *F. subglutinans* are a problem by causing mycosis in humans (De Souza et al., 2014), it also causes hypersensitivity pneumonitis (Lee et al., 2000) and hyalohyphomycosis (Melcher et al., 1993). On the other hand, *F. incarnatum* is a field fungus that affects crops such as sorghum, rice, and corn, and mainly occurs in temperate and subtropical regions, in addition, it produces toxins such as deoxynivalenol and fumonisin (Riddell et al., 2010; Gupta, 2017), while *F. equiseti* is a weak pathogen in cereals and is occasionally associated with grains infected by other *Fusarium* species (Goswami & Kistler, 2004).

Currently, the toxicological risk associated with mycotoxins has become a central aspect of the problem of fungal invasion of crops or stored grains (Devries et al., 2002), since, during corn storage, fungi mostly cause problems due to heating, compaction, and deterioration of grains; and the use of fungal inhibitors delays heating, reduces the growth rate of fungi and keeps the grain dry (Bolivar, 2007). The relative humidity and temperature of the grain must be controlled to avoid the development of fungal pathogens that cause grains deterioration (Antonio-Bautista et al., 2021). Several studies have shown that species composition of *Fusarium* is influenced by climatic conditions, as well as cultural practices (Arino & Bullermann, 1994; Flett et al., 1998; Mansfield et al., 2005; Scala et al., 2016; Fernández et al., 2008; Edwards & Jennings, 2018).

In the study locations, there is a minimum of people who apply a product when the corn is in storage; in the people interviewed by state, in Puebla only 16 % store corn and of these, 6 % apply aluminum phosphide and the largest number of people store it for less than 6 months, while in Morelos state only 10 % of the people interviewed store corn, of which 1 % apply the previous product, and store it for a period of between 6 to 12 months in inappropriate conditions, such as; black polyethylene bags, water tanks, unventilated rooms, polyethylene barrels and gallons, sacks and even wooden sheds (figure 9), what causes an increase in damage, for example, direct damage; when insects consume the grain, causing weight loss, reduced germination, and fever nutrients and indirect damage; heating and humidity and the transmission of parasites to people and animals (Agroware, 2016), as fungi development and mycotoxins (Fusé et al., 2013).

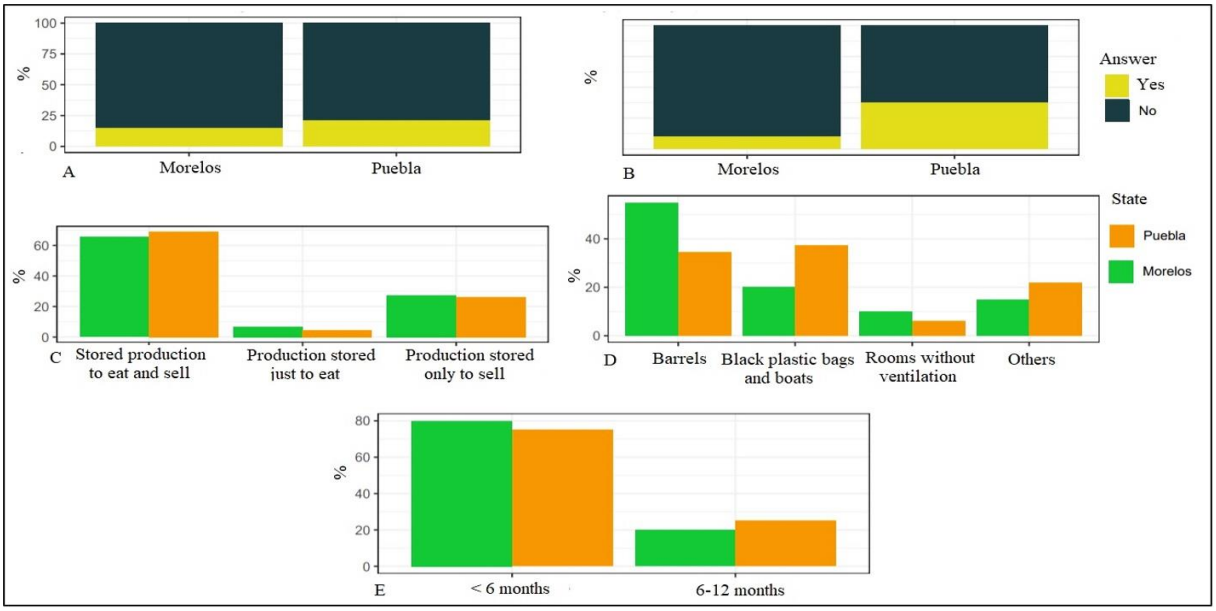

Figure 9. *Corn production in Puebla and Morelos states.*
Note: A = Do you produce corn? B = Do you apply any product when the corn is stored? C = Do you store corn for consumption or sell it? D = What do you store corn in? E = How long do you store corn?
Figura 9. *Producción de maíz en los estados de Puebla y Morelos*.
Nota: A = ¿Usted produce maíz? B = ¿Aplica algún producto cuando se almacena el maíz? C = ¿Almacena maíz para consumo o lo vende? D = ¿En qué almacena el maíz? E = ¿Cuánto tiempo almacena el maíz?

4. Conclusions

Four species of *Fusarium* fungus were found associated with stem and ear rot that were identified as *F. equiseti, F. verticillioides*, *F. incarnatum* and *F. napiforme* in hybrid and native maize with an identity of 98 %. Corn is the main food for the study locations, however, due to the high corn consumption and its derivatives, there is a need to implement quality measures that guarantee safe grains production for animal and human consumption and avoid possible diseases due to direct and indirect mycotoxin contamination.

5. Supplementary information

No.

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Interest conflict

The authors declare that there is no conflict of interest.

References

Adejumo, T. O., Hettwer, U., & Karlovsky. P. (2007). Occurrence of *Fusarium* species and trichothecenes in Nigerian maize. *International Journal of Food Microbiology, 116*, 350–357. https://doi.org/10.1016/j.ijfoodmicro.2007.02.009

Agrios, G. N. (1988). Plant Pathology. Third Edition. New York, USA, Academic Press.

Agroware (2016). Métodos para el control de plagas en granos almacenados. https://sistemaagricola.com.mx/blog/control-de-plagas-en-granos-almacenados/

Alexander, N. J., Proctor, R. H. & McCormick, S. P. (2009). Genes, gene clusters, and biosynthesis of trichothecenes and fumonisins in *Fusarium*. *Toxin Reviews, 28*, 198–215. https://doi.org/10.1080/15569540903092142

Almeyda, L. I. H., Rocha, P. M. A., Piña, R. J., & Martínez, J. P. S. (2001). The Use of Polymerase Chain Reaction and Molecular Hybridization for Detection of Phytoplasmas in Different Plant Species in Mexico. *Revista Mexicana de Fitopatología, 19*, 1-9.

Ammar, M., Merfat, A., Walid, N., Paul, H. V., & Mohammad, H. (2013). Morphological and Molecular Characterization of *Fusarium* isolated from maize in Syria. *Journal of Phytopathology*, *161*, 452–458. https://doi.org/10.1111/jph.12085

Antonio-Bautista, A., Vázquez-Badillo, M. E., Galindo-Cepeda, M. E., Flores-Naveda, A., Benítez-Neri, E., Sánchez-Arizpe, A., & Arispe-Vázquez, J. L. (2021). Effect of the temperature and relative humidity in stored sotol (*Dasylirion cedrosanum* Trel.) seeds on fungi biodiversity. *Journal of Phytology, 13*, 16–20. https://doi.org/10.25081/jp.2021.v13.6603

Aparecido, C. C., & Rosa, E. C. (2019). Avaliação morfologia e molecular para identificação de *Fusarium* sp. *Divulgação científica. Biológico*, *São Paulo*, 81, 1-7. https://doi.org/10.31368/1980-6221v81a10014

Arino, A. A., & Bullermann, L. B. (1994). Fungal colonization of corn grown in Nebraska in relation to year, genotype and growing conditions. *Journal of Food Protection, 57*(12), 1084–1087. https://doi.org/1084-1087. 10.4315/0362-028X-57.12.1084

Ashworth, L. J., Huisman, O. C., Weinhold, A. R., & Hancock, J. G. (1981). Estimating Yield Losses Caused by Soil-Borne Fungi. In: Crop Loss Assessment Methods. Supplement 3. Chiarappa L. (eds) pp. 91-95. FAO. CAB. England, U.K.

Auerbach, H. (2003). Mould growth and mycotoxin contamination of silages: sources, types and solutions. In: Lyons TJK. (ed) Proceedings of Alltech's Nineteenth Annual Symposium, pp 247-265.

Baliukoniene, V., Bakutis, B., Vaivadaite, T., Bartkienė, & E., & Jovaišienė, J. (2012). Prevalence of fungi and mycotoxins in silage and milk in Lithuania. Veterinarija ir Zootechnika, 59: 3-9.

Bandera, E., Chandran, U., Buckley, B., Lin, Y., Isukapalli, S., Marshall, I., King, M., & Zarbl, H. (2011). Urinary Mycoestrogens, Body Size and Breast Development in New Jersey Girls. *Science of the Total Environment, 409*, 5221-5227. https://doi.org/10.1016/j.scitotenv.2011.09.029

Battacone, G., Nudda, A., & Pulina, G. (2010). Effects of Ochratoxin A on Livestock Production. *Toxins, 2*, 1796-1824. https://doi.org/10.3390/toxins2071796

Bolivar, B. M. (2007). Manejo de granos en almacenamiento, causas de deterioro y prevención. XX Reunión ALPA, XXX Reunión APPA-Cusco-Perú. Arch. Latinoam. Prod. Anim. 15 (Supl. 1). 180-184.

Borja, E. B., & Calvo, T. M. A. (2021). Control de micotoxinas en alimentación y salud pública. Internet Resource: https://raed.academy/revista-15/control-micotoxinas-alimentacion/

Bottalico, A. (1998). *Fusarium* disease of cereals, species complex and related mycotoxin profiles Europe. *Journal of Plant Pathology,* 80, 85-103. http://dx.doi.org/10.4454/jpp.v80i2.807

Bottalico, A., & Perrone, G. (2002). Toxigenic *Fusarium* species and mycotoxins associated with head blight in small-grain cereals in Europe*. European Journal of Plant Pathology,108,* 611-624.

Brown, D. W., Dyer, R. B., McCormick, S. P., Kendra, D. F., & Plattner, R. D. (2004). Functional demarcation of the *Fusarium* core trichothecene gene cluster. *Fungal Genetics and Biology,* 454–462. https://doi.org/10.1016/j.fgb.2003.12.002

Bush, B. J., Carson, M. L., Cubeta, M. A., Hagler, W. M., & Payne, G. A. (2004). Infection and fumonisin production by *Fusarium verticillioides* in developing maize kernels. *Phytopathology*, *94*, 88-93. https://doi.org/10.1094/PHYTO.2004.94.1.88

Cao, A., Santiago, R., Ramos, A. J., Souto, X. C., Aguín, O., Malvar, R. A., & Butrón, A. (2014). Critical environmental and genotypic factors for *Fusarium verticillioides* infection, fungal growth and fumonisin contamination in maize grown in northwestern Spain. *International Journal of Food Microbiology*, *177*, 63-71. https://doi.org/10.1016/j.ijfoodmicro.2014.02.004

Carmona, M., & Scandiani M. (2010). Las pudriciones de tallo y raíces del maíz Pudriciones por *Fusarium.* El manejo de la enfermedad comienza por la semilla de maíz. AAPRESID. 131-138. Internet Resource: https://www.agroconsultasonline.com.ar//ticket.html/Pudriciones%20de%20maiz%20AAPRESID%202010%20revista%20maiz.pdf?op=d&ticket_id=10424&evento_id=21630

Carreras, V. N., Hernández, D. E. E., & Sánchez, R. D. (2021). Conociendo a los hongos fitopatógenos. Instituto de Ecología, A.C. (INECOL). Internet Resource: https://www.inecol.mx/inecol/index.php/es/2013-06-05-10-34-10/17-ciencia-hoy/1042-conociendo-a-los-hongos-fitopatogenos

CAST (The Science source of food, Agricutural and Environmental Issues) (2003). Internet Resource: http://www.cast-science.org

Chavarri, M., Barroyeta, J., Ochoa, Y., Rumbos, N., & Alezones, J. (2017). Detección de *Fusarium verticillioides* y fumonisinas en granos de maíz blanco provenientes de los estados Yaracuy y Guárico, Venezuela. Nova Scientia, *9*, 173-184.

Christensen, C. M., Kaufmann, H. H. (1969). Grain storage. The role of fungi in quality loss. Minneapolis, MN, USA, University of Minnesota Press.

CIMMYT (Centro Internacional de Mejoramiento de Maíz y Trigo) (2004). Programa de Maíz. Enfermedades del maíz: una guía para su identificación en el campo. Cuarta edición. México, D.F. CIMMYT.

Collinge, D. B., Jorgensen, H. J., Lund, O. S., & Lyngkjaer, M. F. (2010). Engineering pathogen resistance in crop plants: current trends and future prospects. *Annual Review of Phytopathology, 48*, 269–291. https://doi.org/10.1146/annurev-phyto-073009-114430

Covarelli, L., Stifano, S., Beccari, G., Raggi, L., Lattanzio, V. M., & Albertini, E. (2012). Characterization of *Fusarium verticillioides* strains isolated from maize in Italy: Fumonisin production, pathogenicity and genetic variability. *Food Microbiology, 31*, 17–24. https://doi.org/10.1016/j.fm.2012.02.002

Dekalb, Asgrow and Deltapine (2017). *Fusarium* ear rot causing fumonisin contamination in corn. The Dekalb®, Asgrow® and Deltapine®. https://www.dekalbasgrowdeltapine.com/en-us/agronomy/fusarium-ear-rot-causing-fumonisin-contamination-in-corn.html

De La Campa, R., Hooker, D. C., Miller, J. D., Schaafsma, A. W., & Hammond, B. G. (2005). Modeling effects of environment, insect damage, and Bt genotypes on fumonisin accumulation in maize in Argentina and the Philippines. *Mycopathologia, 159,* 539–552. https://doi.org/10.1007/s11046-005-2150-3

De la Torre-Hernandez, M. E., Sánchez, D., Sánchez, E., & Plasencia, J. (2014). Fumonisinas – Síntesis y función en la interacción de *Fusarium verticillioides* - maíz. *Revista Especializada en Ciencias Químico-Biológicas, 17*, 77–91.

De León, C. (1984) Enfermedades del maíz, guía para su identificación en campo. 3 Ed. México, D.F. CIMMYT.

De Souza, M., Matsuzawa, T., Lyra, L., Busso-Lopes, A. F., Gonoi, T., Zaninele-Schreiber, A., Kamei, K., Moretti, M. L., & Trabasso, P. (2014). *Fusarium napiforme* systemic infection: case report with molecular characterization and antifungal susceptibility tests. *Springerplus, 3,* 492. https://doi.org/10.1186/2193-1801-3-492

Dean, R., Van Kan, J. A., Pretorius, Z. A., Hammond-Kosack, K. E., Di Pietro, A., Spanu, P. D., Rudd, J. J., Dickman, M., Kahmann, R., Ellis, J., & Foster, G. D. (2012). The Top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology*, *13*(4), 414–430. https://doi.org/10.1111/j.1364-3703.2011.00783.x

Desjardins, A. E. (2006). *Fusarium* Mycotoxins: Chemistry, Genetics, and Biology. St. Paul Minnesota, American Phytopathological Society Press.

Desjardins, A.E., Busman, M., Muhitch, M.J. & Proctor, R. (2007). Complementary Host-Pathogen Genetic Analyses of the Role of Fumonisins in the *Zea mays-Gibberella* Moniliformis Seedling Interaction. *Physiological and Molecular Plant Pathology, 70*, 149-160.

Devries, J. W., Trucksess, M. W., & Jackson, L. S. (2002). Mycotoxins and food safety. New York, USA. Academic/Plenum Publishers.

Di menna, M. E., Lauren, D. R., & Hardacre, A. (1997). *Fusarium* and *Fusarium* toxins in New Zealand maize plants. *Mycopathologia, 139.* 165–173.

Diaz, C. G., Rodríguez, R. A., Aguaysol, N. C., Juárez, J., Saleme, P. M., & Ploper, L. D. (2012) Relación entre incidencia de *Fusarium verticillioides* y variables de calidad de grano bajo condiciones de almacenamiento de maíz en Tucumán, Argentina. *Revista Agronómica del Noroeste Argentino, 32,* 47-53. http://hdl.handle.net/20.500.12123/5256

Dignani, M. C., & Anaissie, E. (2004). Human fusariosis. *Clinical Microbiology and Infection, 10*, 67-75. https://doi.org/10.1111/j.1470-9465.2004.00845.x

Dino-lite (2020). DinoCapture 2.0 windows software for Dino-Lite. Digital Microscope. Internet https://www.dinolite.us/es/dinocapture/

Dixon, G. R., & Tilston, E. L. (2010). Soil-borne pathogens and their interactions with the soil environment. pp: 197-271. In: Dixon GR, Tilston EL. (eds). Soil microbiology and sustainable crop production. Switzerland AG. Springer Science+Business Media B.V. https://doi.org/10.1007/978-90-481-9479-7

Duarte, S., &Villamil, L. (2006). Micotoxinas en la Salud Pública. *Revista de Salud Pública, 8*, 129-135.

Edwards, S. G., & Jennings, P. (2018). Impact of agronomic factors on fusarium mycotoxins in harvested wheat. *Food additives & contaminants. Part A, Chemistry, analysis, control, exposure & risk assessment, 35*(12), 2443–2454. https://doi.org/10.1080/19440049.2018.1543954

Fernández, M. R., Huber, D., Basnyat, P., & Zentner, R. P. (2008). Impact of agronomic practices on populations of Fusarium and other fungi in cereal and noncereal crop residues on the Canadian Prairies. *Soil & Tillage Research, 100*, 60-71.

Figueroa-Rivera, M. G., Guerrero-Aguilar, B. Z., González-Chavira, M. M., & Pons-Hernández, J. L. (2010). Caracterización de Especies de *Fusarium* Asociadas a la Pudrición de Raíz de Maíz en Guanajuato, México. *Revista Mexicana de Fitopatología, 28,* 124-134.

Flett, B. C., McLaren, N. W., & Wehner, F. C. (1998). Incidence of Ear Rot Pathogens Under Alternating Corn Tillage Practices. *Plant Disease, 82*(7), 781–784. https://doi.org/10.1094/PDIS.1998.82.7.78

Folcher, L., Jarry, M., Weissenberger, A., Gérault, F., Eychenne, N., Délos, M., & Regnault-Roger, C. (2009). Comparative activity of agrochemical treatments on mycotoxin levels with regard to corn borers and Fusarium mycoflora in maize (*Zea mays* L.) fields. Crop Protection, 28, 302-308. https://doi.org/10.1016/J.CROPRO.2008.11.007

Fusé, C. B., Villaverde, M. L., Padín, S. B., De Giusto, M., Juárez, M. P. (2013) Evaluación de la actividad insecticida de tierras de diatomeas de yacimientos argentinos. *RIA, 39,* 207-213. http://sedici.unlp.edu.ar/handle/10915/96669

Gai, X., Dong, H., Wang, S., Liu, B., Zhang, Z., Li, X., & Gao, Z. (2018). Infection cycle of maize stalk rot and ear rot caused by *Fusarium verticillioides*. *PloS one, 13(7),* e0201588. https://doi.org/10.1371/journal.pone.0201588

García, R., Riera, R., Zambrano, C., & Gutiérrez, L. (2006). Desarrollo de un fungicida biológico a base de la cepa del hongo *Trichoderma harzianum* proveniente de la Región Andina Venezolana. *Fitosanidad, 10,* 115-121.

Garcia-Estrada, R. S., Marquez, I., Tovar-Pedraza, J. M., & Cruz-Lachica, I. (2020). First Report of Cucumber Fruit Rot Caused by *Fusarium incarnatum* in Mexico. Plant disease, 10.1094/PDIS-07-20-1533-PDN. Advance online publication. https://doi.org/10.1094/PDIS-07-20-1533-PDN

García-Lara, S., Espinosa, C. C., & Bergvinson, D. J. (2007). Manual de plagas en granos almacenados y tecnologías alternas para su manejo y control. México, D.F., CIMMYT.

Gelderblom, W. C., Jaskiewicz, K., Marasas, W. F., Thiel, P. G., Horak, R. M., Vleggaar, R., & Kriek, N. P. (1988). Fumonisins--novel mycotoxins with cancer-promoting activity produced by *Fusarium moniliforme*. *Applied and Environmental Microbiology, 54*(7), 1806–1811. https://doi.org/10.1128/aem.54.7.1806-1811.1988

Giraldo-Arias, J., Celis-Zapata, S., Franco-Sierra, N. D., Arroyave-Toro, J. J, Jaramillo-Mazo, C., & Alvarez, J. C. (2018). Identification of *Fusarium* cf. *verticillioides* as The Causal Agent of Pokka Boheng Disease in Sugarcane in the Department of Antioquia, Colombia. *Ingeniería y Ciencia. 14*, 113-134.

Görtz, A., Oerke, E., Steiner, U., Waalwijk, C., Vries, I., & Dehne, H. (2008). Biodiversity of *Fusarium* species causing ear rot of maize in Germany. *Cereal Research Communications, 36,* 617–622. https://doi.org/10.1556/crc.36.2008.suppl.b.51

Goswami, R. S., & Kistler, H. C. (2004). Heading for disaster: Fusarium graminearum on cereal crops. *Molecular Plant Pathology, 5*(6), 515–525. https://doi.org/10.1111/j.1364-3703.2004.00252.x

Goswami, R. S., Dong, Y., & Punja, Z. K. (2008). Host range and mycotoxin production byFusarium equiseti isolates originating from ginseng fields1. *Canadian Journal of Plant Pathology, 30,* 155–160. https://doi.org/10.1080/07060660809507506

Gupta, R. K. (2017). Foodborne infectious diseases. In Dudeja P, Gupta RK, Singh M. (eds). Food Safety in the 21st Century, Elsevier.

Hami, A., Rasool, R. S., Khan, N. A., Mansoor, S., Mir, A. M., Ahmed, N., & Masood, K. Z. (2021). Morpho-molecular identification and first report of *Fusarium equiseti* in causing chilli wilt from Kashmir (Northern Himalayas). *Scientific Reports, 11,* 3610. https://doi.org/10.1038/s41598-021-82854-5

IARC (International Agency for Research on Cancer) (2002). Some Traditional Herbal Medicines, Some Mycotoxins. Naphthalene and Styrene. *Monographs on the Evaluation of Carcinogenic Risks to Humans, 82,* 301–366.

Khoa, L. V., Hatai, K., & Aoki, T. (2004). *Fusarium incarnatum* isolated from black tiger shrimp, *Penaeus monodon* Fabricius, with black gill disease cultured in Vietnam. *Journal of fish diseases, 27*(9), 507–515. https://doi.org/10.1111/j.1365-2761.2004.00562.x

Kiranjot, K., Jaspal, K., Anita, P., & Karmjit, S. (2020). Cultural, Morphological and Molecular Characterization of *Fusarium verticillioides* causing Maize Ear Rot under Punjab Condition. International Journal of Current Microbiology and Applied Sciences, *9*, 1698-1706. https://doi.org/10.20546/ijcmas.2020.910.205

Kosiak, E. B., Holst-Jensen, A., Rundberget, T., Gonzalez Jaen, M. T., & Torp, M. (2005). Morphological, chemical and molecular differentiation of *Fusarium equiseti* isolated from Norwegian cereals. *International Journal of Food Microbiology, 99*(2), 195–206. https://doi.org/10.1016/j.ijfoodmicro.2004.08.015

Kuki, M. C., Barth, P. R. J. B., Bengosi, B. F. A., Tessmann, D. J., do Amaral, J. A. T., Scapim, C. A., & Brendan, H. J. (2020). Association mapping and genomic prediction for ear rot disease caused by *Fusarium verticillioides* in a tropical maize germplasm. *Crop Science, 60*, 2867– 2881. https://doi.org/10.1002/csc2.20272

Lee, S. K., Kim, S. S., Nahm, D. H., Park, H. S., Oh, Y. J., Park, K. J., Kim, S. O., & Kim, S. J. (2000). Hypersensitivity pneumonitis caused by *Fusarium napiforme* in a home environment. *Allergy, 55*(12), 1190–1193. https://doi.org/10.1034/j.1398-9995.2000.00650.x

Leplat, J., Friberg, H., Abid, M., & Steinberg, C. (2013). Survival of *Fusarium graminearum*, the causal agent of *Fusarium* head bligh. A review. *Agronomy for Sustainable Development, 33,* 97-111. https://doi.org/10.1007/s13593-012-0098-5

Leslie, J. F., & Summerell, B. A. (2006). The *Fusarium* Laboratory Manual. Iowa, USA, Blackwell Publishing Professional.

Levin, L., Ridao, A., & Castaño, F. (2003). Fusariosis de la espiga en el maíz. Facultad de Ciencias Agrarias. 20ª Jornada de actualización profesional en cultivos de verano. Universidad Nacional de Mar de Plata, Argentina.

Leyva-Mir, S. G., Vega-Portillo, H. E., Villaseñor-Mir, H. E., Tlapal-Bolaños, B., Vargas-Hernández, M., Camacho-Tapia, M., & Tovar-Pedraza, J. M. (2017). Characterization of *Fusarium* species causing root rot of wheat in the Bajio, Mexico. *Chilean Journal of Agricultural & Animal Sciences, ex Agro-Ciencia, 33,* 142-151.

Lezcano, J. C., Martínez, B., & Alonso, O. (2012). Caracterización cultural y morfológica e identificación de diez aislamientos de *Fusarium* procedentes de semillas de *Leucaena leucocephala* cv. Perú almacenadas. *Pastos y Forrajes, 35,* 187-196.

Liu, B., Giesler, L. J., Jackson-Ziems, T. A., Wegulo, S. N., Harveson, R. M., Korus, K. A., & Klein, R. N. (2012). Major *Fusarium* Diseases on Corn, Wheat, and Soybeans in Nebraska. *Papers in Plant Pathology, 542.* https://digitalcommons.unl.edu/plantpathpapers/542/

Logrieco, A., Bottalico, A., Mule, G., Moretti, A., & Perrone, G. (2003). Epidemiology of toxigenic fungi and their associated mycotoxins for some Mediterranean crops. *European Journal of Plant Pathology, 109,* 645-67. https://doi.org/10.1023/A:1026033021542

Logrieco, A., Mulè, G., Moretti, A., & Bottalico, A. (2002). Toxigenic *Fusarium* species and mycotoxins associated with maize ear rot in Europe. *European Journal of Plant Pathology, 108*, 597–609. https://doi.org/10.1023/A:1020635214971

Macdonald, M. V., & Chapman, R. (1997). The incidence of *Fusarium moniliforme* on maize from Central America, Africa and Asia during 1992– 1995. *Plant Pathology, 46,* 112-125. https://doi.org/10.1046/j.1365-3059.1997.d01-200.x

Maiorano, A., Reyneri, A., Magni, A., & Ramponi, C. A. (2009). Decision tool for evaluating the agronomic risk of exposure to fumonisins of different maize crop management systems in Italy. *Agricultural Systems, 102*, 17–23. https://doi.org/10.1016/j.agsy.2009.06.003

Mansfield, M. A., De Wolf, E. D., & Kuldau, G. A. (2005). Relationships Between Weather Conditions, Agronomic Practices, and Fermentation Characteristics with Deoxynivalenol Content in Fresh and Ensiled Maize. *Plant Disease, 89*(11), 1151–1157. https://doi.org/10.1094/PD-89-1151

Mao, Y., Zhang, Y., Zhou, M., & Duan, Y. (2020). Occurrence of Crown Rot Disease Caused by *Fusarium incarnatum* on Cucumber (*Cucumis sativus*) in China. *Plant Disease,* 104: 593. https://doi.org/10.1094/PDIS-07-19-1561-PDN

Marasas, W., Rabie, C., Lübben, A., Nelson, P., Toussoun, T., & Van Wyk, P. (1987). *Fusarium napiforme*, a New Species from Millet and *Sorghum* in Southern Africa. *Mycologia, 79,* 910-914. https://doi.org/10.2307/3807697

Marasas, W. F. (2001). Discovery and occurrence of the fumonisins: a historical perspective. Environmental health perspectives, 109 Suppl 2(Suppl 2), 239–243. https://doi.org/10.1289/ehp.01109s2239

Marasas, W. F., Kellerman, T. S., Gelderblom, W. C., Coetzer, J. A., Thiel, P. G., & van der Lugt, J. J. (1988). Leukoencephalomalacia in a horse induced by fumonisin B1 isolated from *Fusarium moniliforme*. *The Onderstepoort Journal of Veterinary Research, 55*(4), 197–203.

Marasas, W. F. (1995). Fumonisins: their implications for human and animal health. Natural toxins, 3(4), 193–221. https://doi.org/10.1002/nt.2620030405

Mazzani, C., Borges, O., Luzón, O., Barrientos, V., & Quijada, P. (1999). Incidencia de *Aspergillus flavus, Fusarium verticillioides,* aflatoxinas y fumonisinas en ensayos de híbridos de maíz en Venezuela. *Fitopatología Venezolana. 12,* 9-13.

Melcher, G. P., McGough, D. A., Fothergill, A. W., Norris, C., & Rinaldi, M. G. (1993). Disseminated hyalohyphomycosis caused by a novel human pathogen, Fusarium napiforme. *Journal of Clinical Microbiology, 31(*6), 1461–1467. https://doi.org/10.1128/jcm.31.6.1461-1467.1993

Miller, J. D. (1995). Miller Fungi and mycotoxins in grain: implication for stored product research. *Journal of Stored Products Research, 31*, 1-16.

Morales-Rodríguez, I., Yañez-Morales, M., Silva-Rojas, H. V., García-de-Los-Santos, G., & Guzmán-de-Peña, D. A. (2007). Biodiversity of Fusarium species in Mexico associated with ear rot in maize, and their identification using a phylogenetic approach. *Mycopathologia, 163*(1), 31–39. https://doi.org/10.1007/s11046-006-0082-1

Munkvold, G. P. 2003. Epidemiology of *Fusarium* Diseases and their Mycotoxins in Maize Ears. *European Journal of Plant Pathology 109,* 705–713. https://doi.org/10.1023/A:1026078324268

Munkvold, G. P., & Desjardins, A. E. (1997). Fumonisins in Maize: Can We Reduce Their Occurrence?. *Plant disease, 81(*6), 556–565. https://doi.org/10.1094/PDIS.1997.81.6.556

Nayaka, S. C., Shankar, A. C., Reddy, M. S., Niranjana, S. R., Prakash, H. S., Shetty, H. S., & Mortensen, C. N. (2009). Control of Fusarium verticillioides, cause of ear rot of maize, by Pseudomonas fluorescens. *Pest Management Science, 65*(7), 769–775. https://doi.org/10.1002/ps.1751

PAN (Panorama Agroalimentario) (2016). Maíz. Fideicomisos Instituidos en Relación con la Agricultura. https://www.gob.mx/cms/uploads/attachment/file/200637/Panorama_Agroalimentario_Ma_z_2016.pdf

Peraica, M., Radić, B., Lucić, A., & Pavlović, M. (1999). Toxic effects of mycotoxins in humans. *Bulletin of the World Health Organization, 77*(9), 754–766.

Pioneer (2020a) Pioneer *Fusarium* Ear Rot. https://www.pioneer.com/us/agronomy/fusarium_ear_rot_cropfocus.html

Pioneer (2020b) Manejo de Pudrición de Tallos en Maíz. Boletín técnico Pioneer. https://www.pioneer.com/CMRoot/International/Argentina/productos_y_servicios/MANEJO_PUDRICION_DE_TALLOS.pdf

Pioneer (2021) Pudrición del tallo de maíz por *Fusarium*. https://www.corteva.es/content/dam/dpagco/corteva/eu/es/es/files/otros-documentos/Pudricion-del-tallo-de-maiz-por-Fusarium.pdf

Proctor, R. H., Plattner, R. D., Desjardins, A. E., Busman, M., & Butchko, R. A. (2006). Fumonisin production in the maize pathogen *Fusarium verticillioides*: genetic basis of naturally occurring chemical variation. *Journal of Agricultural and Food Chemistry, 54*(6), 2424–2430. https://doi.org/10.1021/jf0527706

Qin, Z. H., Ren, X., Jiang, K., Wu, X. F., Yang, Z. H., & Wang, X. M. (2014). Identification of *Fusarium* species and *F. graminearum* species complex causing maize ear rot in China. *Acta Phytopathologica Sinica, 41,* 589–596. https://doi.org/10.13802/j.cnki.zwbhxb.2014.05.032

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rahjoo, V., Zad, J., Javan-Nikkhah, M., Mirzadi, G. A., Okhovvat, S. M., Bihamta, M. R., Razzaghian, J., & Klemsdal, S. S. (2008). Morphological and molecular identification of *Fusarium* isolated from maize ears in Iran. *Journal of Plant Pathology, 90*, 463-468.

Ramos, C. H. O. (2022). Manual de plagas y enfermedades del maíz. Asociación Andes. http://andes.center/wp-content/uploads/2019/10/Manual-Plagas-y-efermedades-del-Maiz.pdf

Riddell, J., 4th, Woodside, K. J., Leavitt, M. A., Newton, D. W., & Punch, J. D. (2010). *Fusarium incarnatum/equiseti* hemodialysis graft infection. *Infectious Disease Reports, 2*(2), e14. https://doi.org/10.4081/idr.2010.e14

Rodrigues, A. A. C., & Menezes, M. (2005). Identification and pathogenic characterization of endophytic *Fusarium* species from cowpea seeds. *Mycopathologia, 159,* 79–85. https://doi.org/10.1007/s11046-004-7138-x

Rosas-Guevara, V., Hernández-Arenas, M., Miranda-Marini, R., Bravo-Mosqueda, E., & Berriozabal-Onofre, A. (2014). Identificación y variabilidad morfológica de pokkah boeng (*Fusarium* spp) en caña de azúcar. *Investigación Agropecuaria, 11*, 119-126.

Sabet, K. A., Samra, A. S., & Mansour, I. M. (1966). Interaction between *Fusarium oxysporum*, *F. vasifectum* and *Cephalosporium maydis* on cotton and maize. *Annals of Applied Biology, 58*, 93-101.

Sánchez-Rangel, D., & Plasencia, J. (2010). The role of sphinganine analog mycotoxins on the virulence of plantpathogenic fungi. *Toxin Reviews, 29,* 73-86.

Santillán-Mendoza, R., Rodríguez-Alvarado, G, Fernández-Pavía, S. P., Vázquez-Marrufo, G., Montero-Castro, J. C. Benítez-Malvido, J. (2017). "Micotoxinas: ¿Qué son y cómo afectan a la salud pública?" *Revista Digital Universitaria (RDU), 18, 6.*

Scala, V., Aureli, G., Cesarano, G., Incerti, G., Fenelli, C., Scala, F., Reverberi, M., Bonanomi, G. (2016). Climate, Soil Management, and Cultivar Affect *Fusarium* Head Blight Incidence and Deoxynivalenol Accumulation in Durum Wheat of Southern Italy. *Frontiers in Microbiology, 7,* 1014. https://doi.org/10.3389/fmicb.2016.01014

SE (Secretaría de Economía) (2021) Sistema Nacional de Información e Integración de Mercados. Mercados Nacionales, Insumos Agrícolas. http://www.economia-sniim.gob.mx/nuevo/Home.aspx?opcion=inf_disp.asp

Seifert, K. (1996). Fuskey. *Fusarium* interactive key. Agriculture & Agri-Food Canada, Research Branch, Eastern Cereal & Oilseed Research Centre, Otawa, Canada.

Shaner, G. E., & Scott, D. H. (2022) Stalk rots of corn. Purdue University Cooperative Extension Service. Extension Sheet BP-59. https://extension.purdue.edu/extmedia/BP/BP-59.html

Shen, H., Jiang, S., Lin, B. R., Sun, D., Zhang, J., & Pu, X. (2018). First Report of Fruit spot of *Toxicodendron sylvestre* Caused by *Fusarium incarnatum* in China. *Plant Disease, 103,* 376-376. https://doi.org/10.1094/PDIS-07-18-1290-PDN

Shephard, G. S., Marasas, W. F., Burger, H. M., Somdyala, N. I., Rheeder, J. P., Van der Westhuizen, L., Gatyeni, P., & Van Schalkwyk, D. J. (2007). Exposure assessment for fumonisins in the former Transkei region of South Africa. *Food Additives and Contaminants, 24*(6), 621–629. https://doi.org/10.1080/02652030601101136

Shurtleff, M. C. (1980). Compendium of Corn Diseases. (2nd edition) St. Paul, Minnesota, USA. American Phytopathological Society Press.

Solano-Báez, A. R., De León-García, D. A. C., Valdovinos-Ponce, Silva-Rojas, H. V., & Soto-Rojas, L. (2011) La pigmentación de *Fusarium verticillioides* (Sacc.) como factor de virulencia en plántulas de maíz. *Agronomía Mesoamericana, 22,* 297-307.

Song, M., Yun, H. Y., & Kim, Y. H. (2014). Antagonistic Bacillus species as a biological control of ginseng root rot caused by *Fusarium* cf. *incarnatum*. *Journal of Ginseng Research, 38*(2), 136–145. https://doi.org/10.1016/j.jgr.2013.11.016

Strange, R. N., & Scott, P. R. (2005). Plant disease: a threat to global food security. *Annual Review of Phytopathology, 43*, 83–116. https://doi.org/10.1146/annurev.phyto.43.113004.133839

Summerell, B. A., Salleh, B., & Leslie, J. F. (2003). A Utilitarian Approach to Fusarium Identification. *Plant Disease, 87*(2), 117–128. https://doi.org/10.1094/PDIS.2003.87.2.117

Syngenta (2022). *Fusarium* ear rot (*Fusarium verticillioides*) *Fusarium* ear rot: biology. https://www.syngenta.ca/pests/disease/en/fusarium-ear-rot/Corn

Tewari, S., & Sharma, S. (2019). Molecular Techniques for Diagnosis of Bacterial Plant Pathogens. pp. 481–497. In. Das S, Dash H (eds.). Microbial Diversity in the Genomic Era. London, England. Academic Press.

Ueno, Y., Aoyama, S., Sugiura, Y., Wang, D. S., Lee, U. S., Hirooka, E. Y., Hara, S., Karki, T., Chen, G., & Yu, S. Z. (1993). A limited survey of fumonisins in corn and corn-based products in Asian countries. *Mycotoxin Research, 9*(1), 27–34. https://doi.org/10.1007/BF03192229

UNL (Universidad Nacional del Litoral) (2017) Estudian el mejor tratamiento contra hongos del maíz. https://www.unl.edu.ar/noticias/news/view/estudian_el_mejor_tratamiento_contra_hongos_del_ma%C3%ADz#.Yg0ms9_MJPY

Van Egmond, H. P., & Jonker, M. A. (2005). Worldwide regulations on aflatoxins. In: Abbas, HK (ed.). Aflatoxin and Food Safety. New York, USA. Taylor and Francis.

Walker, C., Caciara, M. C., Milanesi, P. M., Muniz, M. F. B., Mezzomo, R., & Schultz, P. C. (2016). Caracterização morfológica, molecular e patogenicidade de *Fusarium acuminatum* e *Fusarium verticillioides* a *Cordia americana*. *Ciência Florestal, 26*, 463-473.

Wang, G. F., Tian, T., Meng, J. F., Xiao, X. Q., & Xiao, Y. N. (2020). First report of *Fusarium incarnatum* causing rot disease on lotus in China. *Journal of Plant Pathology, 595.*

Wang, H., Xiao, M., Kong, F., Chen, S., Dou, H. T., Sorrell, T., Li, R. Y., & Xu, Y. C. (2011). Accurate and practical identification of 20 *Fusarium* species by seven-locus sequence analysis and reverse line blot hybridization, and an in vitro antifungal susceptibility study. *Journal of Clinical Microbiology, 49*(5), 1890–1898. https://doi.org/10.1128/JCM.02415-10

White, D. G. (1999). Compendium of Corn Diseases. 3rd Edition, St. Paul, Minnesota, USA. American Phytopathological Society Press.

WHO (World Health Organization) (2002) Evaluation of certain mycotoxins in food. Fifty-sixth report of the joint FAO/WHO expert committee on food additives (JECFA). WHO technical report 906. https://apps.who.int/iris/bitstream/handle/10665/42448/WHO_TRS_906.pdf?sequence=1&isAllowed=y

Woloshuk, C., & Wise, K. (2014). Diseases of corn: *Fusarium* Ear Rot. Purdue University. BP-86-W. https://extension.purdue.edu/extmedia/BP/BP-86-W.pdf

Wonglom P, Sunpapao A. (2020) *Fusarium incarnatum* is associated with postharvest fruit rot of muskmelon (*Cucumis melo*). *Journal of Phytopathology, 168,* 204-210. https://doi.org/10.1111/jph.12882

Yin, S., Guo, X., Li, J., Fan, L., & Hu, H. (2016). Fumonisin B1 induces autophagic cell death via activation of ERN1-MAPK8/9/10 pathway in monkey kidney MARC-145 cells. *Archives of Toxicology, 90*(4), 985–996. https://doi.org/10.1007/s00204-015-1514-9