



Full Length Article

Pathogenic Microorganisms Infecting Berries in Mexico

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Abstract

Mexico is one of the major producers of berries worldwide and ranks third amongst the principal exporters of these fruits. However, the presence of diseases in crops of blueberry, blackberry, strawberry, and raspberry in production areas of the country, has a negative impact in production yields. In this work, we presented a revision of all pathogens reported for these berries during the last 64 years in Mexico. Data on the different groups of pathogens including bacteria, stramenopila, and fungi, as well as location and references, are listed for the several types of berries produced. The pathogen species names were actualized according to the current taxonomic status following the specialized nomenclatural websites. Perspectives for future research are discussed. © 2021 Friends Science Publishers

Keywords: Blackberry; Blueberry; Oomycota; Phytopathogenic bacteria; Raspberry; Strawberry

Introduction

Berries are becoming some of the favorite fruits in many countries. During 2018, the total global production of berries was 6.16 million ton (FAOSTAT 2020). The United States, Mexico and Poland accounted for 54% of the total production worldwide in 2018. Mexico was the world's leading producer of blackberries (*Rubus ulmifolius*) with 287,125 tons, second producer of raspberries (*Rubus idaeus*) with 130,187 tons, the second in strawberry (*Fragaria x ananassa*) production with 653,639 tons, and the fifth producer of blueberries (*Vaccinium corymbosum*) with 40,251 tons (FAOSTAT 2020).

In Mexico, berries are produced all year round using irrigated and non-irrigated systems (SIAP 2018; SADER-SIAP 2019). Among the 23 states that cultivate berries (Fig. 1), the highest production comes from the states of Baja California, Jalisco and Michoacan (SIAP 2018). This last, is the main producer of blackberries (96% of national production) and strawberries (70%), while Jalisco is the principal producer of blueberries (46%) and raspberry (71%) (SIAP 2018).

Berry crops are attacked by a large number of plant pathogens including bacteria, fungi and oomycetes. These microorganisms induce diseases in most of the plant organs such as leaves, stems, inflorescences, fruits, and roots,

reducing crop yields during pre- and postharvest. Several species are becoming a problem in berries worldwide, some as the bacteria *Xanthomonas fragariae* in strawberry (Kastelein *et al.* 2014; Kamangar *et al.* 2017; Wang *et al.* 2017), the oomycete *Phytophthora cinnamomi* inducing crown and root rot in *V. corymbosum* (Tamietti 2003; Larach *et al.* 2009; Huarhua *et al.* 2018), the fungi *Fusarium oxysporum* causing wilt disease in blackberry (Gordon *et al.* 2016; Pastrana *et al.* 2017) and blueberries (Liu *et al.* 2014; Moya-Elizondo *et al.* 2019), or several species of *Lasioidiplodia* in different berries, as *Lasioidiplodia theobromae* causing dieback in strawberry (Nam *et al.* 2016) or inducing stem blight and dieback of blueberry plants (Wright and Harmon 2009; Scarlett *et al.* 2019; Rodríguez-Gálvez *et al.* 2020).

Recently in Mexico, *Neofusicoccum algeriense* was detected in berries causing dieback in raspberry for the first time (Serret-López *et al.* 2017). In addition, *Neopetalotiopsis rosae* was reported inducing root rot, crown rot and leaf spot in strawberry in Central Mexico, causing losses of up to 50% of transplanted plants (Rebollar-Alviter *et al.* 2020). *N. rosae* is a new pathogen of strawberry that should be considered as an emerging threat to this fruit crop (Rebollar-Alviter *et al.* 2020).

The objective of the study was to compile all the references of diseases caused by bacteria, fungi and

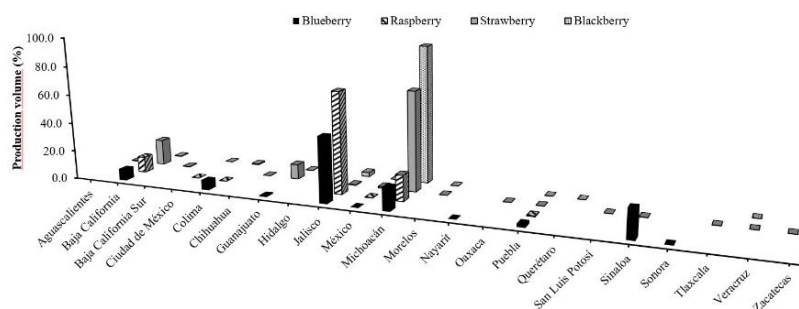


Fig. 1: Percentage of cultivated berries' production volume for each state in Mexico

oomycetes, on commercial crops and wild berries in Mexico. This work includes those reports where plant pathogens were identified using molecular and/or morphological techniques, and the studies were published in scientific papers, books or databases. We consider that this work will be useful for plant pathologists, plant breeders and other scientists that work with berries in Mexico and elsewhere.

Materials and Methods

We conducted a fully comprehensive search on databases of scientific articles, books, and conference proceedings containing reports of diseases of berries, including blackberry, blueberry, raspberry and strawberry, from Mexico during the last 64 years. Our interest was to focus on reports where molecular and/or morphological analyses were utilized to identify the pathogens affecting these crops. Additionally, a search was conducted in the National Fungus Collections of The Agricultural Research Service of the US Department of Agriculture (Farr and Rossman 2019).

The information collected was organized in a database that included hosts, locality, affected tissue of the plant, the name of the induced disease and the bibliographic reference. Subsequently, the information was ordered according to its taxonomic classification by kingdom, phylum, family, scientific name, and author of the species. The scientific names of the pathogens were corroborated using List of Prokaryotic names with Standing in Nomenclature (LPSN) (Parte *et al.* 2020; www.bacterio.net/-classifphyla.html), Index Fungorum website (www.indexfungorum.org), and MycoBank Database (<http://www.mycobank.org/>).

The taxonomic names of the berry plants were verified using GBIF Secretariat (2019), also the distribution of berry plants reported was accessed to know if these plants have restricted or wide distribution in González-Elizondo and González-Elizondo (2014), and Rzedowski and Calderón (2005).

Results

Diseases of berries were reported in 17/32 states of Mexico. A total of the pathogens reported affecting berries crops in

Mexico is listed in Table 1.

Pathogenic microorganisms by crop

A total of 319 records of plant pathogens causing diseases on berries from Mexico during the period of 1956 to 2020, were detected in the accessed databases. These reports included diseases caused by bacteria, fungi, and oomycetes. The records included 54 genus of plant pathogens represented by 88 species. Five species corresponded to bacteria (5.7%), 75 corresponded to fungi (85.2%), and eight were oomycetes (9.1%). Bacteria belong to 3 families, Stramenopila species appertain to 1 phylum (oomycota) and 2 families, and the fungi representing the largest pathogens group affecting berries, they are grouped in three phyla and 27 families.

Strawberry was the crop most affected with 53 pathogens, raspberry and blackberry presented 29 and 26 pathogens, respectively, while for blueberry there were only 16 pathogens reported (Table 2).

The genera of pathogen most reported were *Agrobacterium*, *Alternaria*, *Botrytis*, *Colletotrichum*, *Fusarium*, *Gerwasia*, *Phytophthora*, *Podosphaera*, *Rhizoctonia* and *Verticillium*. While the most frequently reported species were *Agrobacterium radiobacter*, *Fusarium oxysporum*, *Gerwasia rubi*, and *Kuehneola loeseneriana* affecting *Rubus* species; *Botrytis cinerea*, *Peronospora sparsa* in blackberry; *Alternaria* spp., *Botrytis cinerea*, *Colletotrichum* spp., *Fusarium oxysporum*, *Ramularia grevilleana*, *Rhizoctonia solani*, *Verticillium albo-atrum* and *V. dahlia* in strawberry; and *Colletotrichum* spp. and *Thekopsora minima* in blueberry.

Botanical host species

Most of the reports of berries diseases in Mexico were referred in cultivated species such as *Vaccinium corymbosum* (blueberry), *Rubus idaeus* (raspberry), *Rubus ulmifolius* (blackberry), and *Fragaria x ananassa*, a hybrid of strawberry. However, different botanical host species were also reported being affected by phytopathogens: the wild blackberries *Rubus adenotrichos* and *Rubus humistratus*, or the wild strawberry *Fragaria mexicana* and other species reported in Table 3 where the distributions are shown.

Table 1: Phytopathogenic bacteria, oomycete and fungi inducing berries diseases reported in Mexico, arranged hierarchically by taxonomic group. Synonyms indicated in parentheses

PHYLLUM	FAMILY	PATHOGEN	DISEASE	HOST	LOCALITY	REFERENCE	
BACTERIA	Lysobacteraceae	<i>Xanthomonas fragariae</i>	Angular leaf spot	Strawberry	Guanajuato, Michoacán, Morelos	García-Álvarez 1976; Narro-Sánchez <i>et al.</i> 2006; Fernández-Pavía <i>et al.</i> 2014	
	Rhizobiaceae	<i>Agrobacterium radiobacter</i> (= <i>Agrobacterium tumefaciens</i>)	Crown and cane gall	Raspberry, strawberry, blackberry	Baja California, Ciudad de México, Estado de México, Michoacán	García-Álvarez 1976, 1981, Fernández-Pavía <i>et al.</i> 2015, López-Aranda <i>et al.</i> 2016	
Tenericutes	Acholeplasmataceae	<i>Candidatus</i> Phytoplasma spp. group 16SrXIII-(A/I)	Green petal, periwinkle virescence, inedible fruit	Blueberry, raspberry, strawberry, blackberry	Jalisco, Michoacán	Pérez-López and Dumonceaux 2016, Pérez-López <i>et al.</i> 2017	
		<i>Candidatus</i> Phytoplasma spp. group Aster yellow	Green petal, periwinkle plants with virescence	Strawberry	Guanajuato, Michoacán	Narro-Sánchez <i>et al.</i> 2006	
		<i>Candidatus</i> Phytoplasma spp. group 16SrXIII	Green petal, periwinkle plants with virescence	Strawberry	Michoacán	Avendaño-Benequen <i>et al.</i> 2017	
STRAMENOPILA							
Oomycota	Peronosporaceae	<i>Peronospora sparsa</i>	Downy mildew (dryberry)	Blackberry	Michoacán, México, does not specify locality	Tejera and Ochoa 2004; Agustín and García 2007; Horst 2013; Rodríguez-Díaz <i>et al.</i> 2017	
		<i>Phytophthora cactorum</i>	Leather rot on fruit and crown rot and wilt	Strawberry	Estado de México, Guanajuato, Michoacán	Castro-Franco <i>et al.</i> 1993; Mendoza-Zamora and Romero-Cova 1989; Narro-Sánchez <i>et al.</i> 2006; Fernández-Pavía <i>et al.</i> 2015	
		<i>Phytophthora capsici</i> <i>Phytophthora fragariae</i> var. <i>fragariae</i>	Fruit rot Red stele root rot	Strawberry Strawberry	Estado de México Michoacán	Mendoza-Zamora and Romero-Cova 1989 Ceja-Torres <i>et al.</i> 2008	
		<i>Phytophthora rubi</i> (= <i>Phytophthora fragariae</i> var. <i>rubi</i>) <i>Phytophthora</i> spp.	Root rot Root rot and dry wilt	Raspberry Strawberry	México, does not specify locality Estado de México, Guanajuato, Michoacán	López-Aranda <i>et al.</i> 2016 García-Álvarez 1976; Castro-Franco and Dávalos 1990; Mendoza 1992; Fraire-Cordero <i>et al.</i> 2003; Ceja-Torres <i>et al.</i> 2008, Fernández-Pavía <i>et al.</i> 2015	
	Pythiaceae	<i>Pythium aphanidermatum</i>	Dry wilt	Strawberry	Michoacán	Ceja-Torres <i>et al.</i> 2008	
		<i>Pythium</i> spp.	Dry wilt	Raspberry	Jalisco	López-Aranda <i>et al.</i> 2016	
	FUNGI	Aspergillaceae	<i>Aspergillus</i> spp.	Soft fruit rot	Strawberry	Michoacán	Fraire-Cordero <i>et al.</i> 2003
			<i>Penicillium</i> spp.	Soft fruit rot	Strawberry	Michoacán	Fraire-Cordero <i>et al.</i> 2003
		Botryosphaeriaceae	<i>Lasiodiplodia</i> spp.	Necrosis of leaves, branches and stems	Blackberry	Michoacán	Contreras-Pérez <i>et al.</i> 2019
			<i>Neofusicoccum algeriense</i> <i>Neofusicoccum parvum</i>	Dieback Stem Blight and Dieback	Raspberry Blueberry, blackberry	Michoacán Jalisco, Michoacán	Serret-López <i>et al.</i> 2017 Boyzo-Marín <i>et al.</i> 2016
<i>Neofusicoccum</i> spp.			Stem canker	Blueberry	Michoacán	Mondragón-Flores <i>et al.</i> 2012	
<i>Sphaeropsis</i> spp.			Fruit rot	Strawberry	Estado de México, Guanajuato	García-Álvarez 1976	
Chaetomiaceae		<i>Chaetomium</i> spp.	Plant bud blight	Blueberry	Michoacán	Mondragón-Flores <i>et al.</i> 2012	
Cladosporiaceae		<i>Cladosporium</i> spp.	Blossom blight	Strawberry	México, Michoacán	Fraire-Cordero <i>et al.</i> 2003	
Diaporthaceae		<i>Phomopsis obscurans</i> (= <i>Dendrophoma obscurans</i>)	Leaf blight	Strawberry	Estado de México	Mendoza-Zamora and Romero-Cova 1988	
		<i>Phomopsis</i> spp.	Stem canker	Blueberry	Michoacán	Mondragón-Flores <i>et al.</i> 2012	
Didymellaceae	<i>Ascochyta</i> spp.	Marginal leaf spot or leaf blight	Strawberry	Estado de México, Guanajuato	Mendoza-Zamora and Romero-Cova 1988		
	<i>Phoma</i> spp.	Stem canker, root and crown rot	Blueberry, strawberry	Estado de México, Guanajuato, Michoacán	Mendoza-Zamora and Romero-Cova 1989; Mondragón-Flores <i>et al.</i> 2012		
Dipodascaceae	<i>Geotrichum</i> spp.	Soft fruit rot	Strawberry	Michoacán	Fraire-Cordero <i>et al.</i> 2003		
Drepanopezizaceae	<i>Diplocarpon earlianum</i> (= <i>Diplocarpon earliana</i>)	Leaf scorch	Strawberry	Estado de México, Guanajuato, Morelos	García-Álvarez 1976; Narro-Sánchez <i>et al.</i> 2006; Fernández-Pavía <i>et al.</i> 2015		
	<i>Diplocarpon fragariae</i> (= <i>Marssonina fragariae</i>)	Leaf scorch	Strawberry	Estado de México	Mendoza-Zamora and Romero-Cova 1988		
	<i>Marssonina</i> spp. (= <i>Gloeosporium</i> spp.)	Leaf scorch	Strawberry	Aguascalientes, Estado de México, Hidalgo, Michoacán	García-Álvarez 1981; Mendoza-Zamora and Romero-Cova 1988; Fernández-Pavía <i>et al.</i> 2015		
Elsinoaceae	<i>Elsinoe veneta</i>	Cane spot	Raspberry, blackberry	Puebla, México, does not specify locality	García-Álvarez 1976		
Erysiphaceae	<i>Podosphaera aphanis</i> (= <i>Sphaerotheca macularis</i> f. <i>fragariae</i>)	Powdery mildew	Strawberry	Estado de México, Guanajuato, Michoacán	García-Álvarez 1976; Mendoza-Zamora and Romero-Cova 1988; Narro-Sánchez <i>et al.</i> 2006		

Table 1: Continued

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	<i>Podospaera macularis</i> (= <i>Sphaerotheca humuli</i>)	Powdery mildew	Strawberry	Chihuahua, Guanajuato, Jalisco, Morelos	García-Álvarez 1976; Fernández-Pavía <i>et al.</i> 2015
	<i>Podospaera</i> spp.	Powdery mildew	Blackberry	Michoacán	Tejera & Ochoa 2004; Agustín and García 2007
Glomerellaceae	<i>Colletotrichum acutatum</i>	Anthraxnose fruit rot	Strawberry	Michoacán	Espinoza-Altamirano <i>et al.</i> 2017
	<i>Colletotrichum gloeosporioides</i>	Anthraxnose	Blackberry	México, does not specify locality	Horst 2013
	<i>Colletotrichum</i> spp.	Anthraxnose fruit rot, leaf blight	Blueberry, raspberry, strawberry	Estado de México, Guanajuato, Jalisco, Michoacán, Morelos	García-Álvarez 1976; Fraire-Cordero <i>et al.</i> 2003; Narro-Sánchez <i>et al.</i> 2006; Ceja-Torres <i>et al.</i> 2008; Mondragón-Flores <i>et al.</i> 2012; Fernández-Pavía <i>et al.</i> 2015; López-Aranda <i>et al.</i> 2016
Meliolaceae	<i>Appendiculella calostroma</i>	Sooty mold	Blackberry	Veracruz	Farr and Rossman 2019
Mycosphaerellaceae	<i>Cercospora</i> spp.	Leaf Spot	Raspberry, strawberry	Jalisco, México, does not specify locality	García-Álvarez 1981; Fernández-Pavía <i>et al.</i> 2015; López-Aranda <i>et al.</i> 2016
	<i>Cercospora</i> spp.	Rosette	Raspberry, blackberry	Ciudad de México	García-Álvarez 1981
	<i>Mycosphaerella rubi</i> (= <i>Septoria rubi</i>)	Leaf spot	Raspberry, blackberry	Puebla, México, does not specify locality	García-Álvarez 1976, 1981; Farr and Rossman 2019
	<i>Ramularia grevilleana</i> (= <i>Ramularia tulasnei</i> , <i>Mycosphaerella fragariae</i>)	Leaf spot	Strawberry	Estado de México, Guanajuato, Michoacán, México, does not specify locality	García-Álvarez 1976, 1981; Mendoza-Zamora and Romero-Cova 1988; Narro-Sánchez <i>et al.</i> 2006; Fernández-Pavía <i>et al.</i> 2015; Farr and Rossman 2019
	<i>Septoria darrowii</i>	Leaf spot	Blackberry	México, does not specify locality	Farr and Rossman 2019
	<i>Septoria</i> spp.	Leaf spot	Raspberry, blackberry	Ciudad de México	García-Álvarez 1976
Nectriaceae	<i>Albonectria rigidiuscula</i> (= <i>Fusarium rigidiusculum</i>)	Root and crown rot	Strawberry	Estado de México	Mendoza-Zamora and Romero-Cova 1989
	<i>Cylindrocarpon</i> spp.	Black Root Rot	Strawberry	Guanajuato, Michoacán	Ceja-Torres <i>et al.</i> 2008; Mariscal-Amaro <i>et al.</i> 2017
	<i>Fusarium brachygibbosum</i>	Dry wilt	Strawberry	Guanajuato	Mariscal-Amaro <i>et al.</i> 2017
	<i>Fusarium equiseti</i>	Dry wilt	Raspberry	Jalisco	López-Aranda <i>et al.</i> 2016
	<i>Fusarium fujikuroi</i> (= <i>Fusarium subglutinans</i> , <i>F. verticillioides</i> , <i>F. moniliforme</i>)	Dry wilt	Raspberry, strawberry	Jalisco, Guanajuato, Michoacán	Mendoza-Zamora and Romero-Cova 1989; López-Aranda <i>et al.</i> 2016; Mariscal-Amaro <i>et al.</i> 2017
	<i>Fusarium oxysporum</i>	Dry wilt	Blackberry, raspberry, strawberry	Estado de México, Guanajuato, Jalisco, Michoacán, Morelos	Téliz-Ortíz <i>et al.</i> 1986; Mendoza-Zamora and Romero-Cova 1989; Castro-Franco and Dávalos 1990; Ceja-Torres <i>et al.</i> 2008; Gordon <i>et al.</i> 2016; López-Aranda <i>et al.</i> 2016; Mariscal-Amaro <i>et al.</i> 2017; Bárcenas-Santana <i>et al.</i> 2019
	<i>Fusarium oxysporum</i>	Dry wilt	Blackberry, raspberry, strawberry	Estado de México, Guanajuato, Jalisco, Michoacán, Morelos	Téliz-Ortíz <i>et al.</i> 1986; Mendoza-Zamora and Romero-Cova 1989; Castro-Franco and Dávalos 1990; Ceja-Torres <i>et al.</i> 2008; Gordon <i>et al.</i> 2016; López-Aranda <i>et al.</i> 2016; Mariscal-Amaro <i>et al.</i> 2017; Bárcenas-Santana <i>et al.</i> 2019
	<i>Fusarium oxysporum</i> f. spp. <i>mori</i>	Dry wilt	Blackberry	Michoacán, México, does not specify locality	Pastrana <i>et al.</i> 2017; Hernández-Cruz <i>et al.</i> 2020
	<i>Fusarium oxysporum</i> f. spp. <i>fragariae</i>	Fusarium wilt of strawberry	Strawberry	Guanajuato, Michoacán	Dávalos-González <i>et al.</i> 2004; Narro-Sánchez <i>et al.</i> 2006
	<i>Fusarium proliferatum</i>	Vascular Wilt	Strawberry	Guanajuato	Mariscal-Amaro <i>et al.</i> 2017
	<i>Fusarium pseudonygamai</i>	Dry wilt	Strawberry	Guanajuato	Mariscal-Amaro <i>et al.</i> 2017
	<i>Fusarium roseum</i>	Dry wilt	Strawberry	Estado de México	Mendoza-Zamora and Romero-Cova 1989
	<i>Fusarium</i> spp.	Dry wilt	Raspberry, strawberry, blackberry	Ciudad de México, Estado de México, Guanajuato, Michoacán, México, does not specify locality	García-Álvarez 1976, 1981; Mendoza-Zamora and Romero-Cova 1989; Castro-Franco and Dávalos 1990; Mendoza 1992; Dávalos-González <i>et al.</i> 2004; Fernández-Pavía <i>et al.</i> 2015

Table 1: Continued

Table 1: Continued

	<i>Neocosmospora solani</i> (= <i>Fusarium solani</i>)	Crown and root rot	Raspberry, strawberry	Estado de México, Guanajuato, Jalisco, Michoacán	Mendoza-Zamora and Romero-Cova 1989; Ceja-Torres <i>et al.</i> 2008; López- Aranda <i>et al.</i> 2016; Mariscal-Amaro <i>et al.</i> 2017	
Pestalotiopsidaceae	<i>Neopestalotiopsis rosae</i> <i>Pestalotiopsis</i> spp.	Crown and root rot	Strawberry	Michoacán	Rebollar-Alviter <i>et al.</i> 2020	
		Crown and root rot	Blueberry, strawberry	Michoacán, Puebla	Fraire-Cordero <i>et al.</i> 2003; Mondragón-Flores <i>et al.</i> 2012; Morales-Mora <i>et al.</i> 2019	
Phyllostictaceae	<i>Phyllosticta</i> spp.	<i>Phyllosticta</i> leaf spot	Blueberry, strawberry	Baja California, Estado de México, Michoacán,	García-Álvarez 1976; Mendoza- Zamora and Romero-Cova 1988; Mondragón-Flores <i>et al.</i> 2012	
Plectosphaerellaceae	<i>Verticillium albo-atrum</i> <i>Verticillium dahliae</i> <i>Verticillium</i> spp.	<i>Verticillium</i> wilt	Raspberry, strawberry	Guanajuato, Jalisco, Michoacán, México, does not specify locality.	García-Álvarez 1976, 1981; Ceja- Torres <i>et al.</i> 2008; Fernández-Pavía <i>et al.</i> 2015; López-Aranda <i>et al.</i> 2016	
		<i>Verticillium</i> wilt	Strawberry	Estado de México, Guanajuato, Michoacán	Téliz-Ortíz <i>et al.</i> 1986; Castro-Franco and Dávalos 1990; Mendoza 1992;	
		<i>Verticillium</i> wilt	Raspberry, strawberry	Guanajuato, Michoacán, México, does not specify locality	Narro-Sánchez <i>et al.</i> 2006; López- Aranda <i>et al.</i> 2016	
Pleosporaceae	<i>Alternaria alternata</i> <i>Alternaria</i> spp.	Leaf Spot	Strawberry	Guanajuato	Mariscal-Amaro <i>et al.</i> 2017	
		Leaf spot, dry wilt, soft fruit rot, root rot	Blueberry, raspberry, strawberry, blackberry	Aguascalientes, Baja California, Durango, Estado de México, Guanajuato, Jalisco, Michoacán, Oaxaca	García-Álvarez 1976, 1981; Fraire- Cordero <i>et al.</i> 2003; Narro-Sánchez <i>et al.</i> 2006; Mondragón <i>et al.</i> 2012; Fernández-Pavía <i>et al.</i> 2015; López- Aranda <i>et al.</i> 2016	
Sclerotiniaceae	<i>Bipolaris</i> spp.	Blueberry blight	Blueberry	Michoacán	Mondragón <i>et al.</i> 2012	
	<i>Curvularia</i> spp.	Stem scab	Blueberry	Michoacán	Mondragón <i>et al.</i> 2012	
	<i>Stemphylium</i> spp.	Silver stain	Blueberry	Michoacán	Mondragón <i>et al.</i> 2012	
	<i>Botrytis cinerea</i>	Gray mold, <i>Botrytis</i> blossom blight	Strawberry, blackberry	Colima, Estado de México, Guanajuato, Jalisco, México, does not specify locality, Michoacán, Morelos	García-Álvarez 1976, 1981; Mendoza- Zamora and Romero-Cova 1988; Tejera and Ochoa 2004; Narro- Sánchez <i>et al.</i> 2006; Agustín and García 2007; Fernández-Pavía <i>et al.</i> 2017	
Venturiaceae	<i>Botrytis</i> spp. <i>Coleroa chaetomium</i>	Gray mold	Strawberry	Michoacán	Fraire-Cordero <i>et al.</i> 2003	
		Leaf spot	Blackberry	Estado de México	Romero-Cova 1990	
Xylariaceae	<i>Rosellinia</i> spp.	Root rot	Raspberry, blackberry	Durango	García-Álvarez 1976	
		Root rot	Strawberry	Michoacán	Ceja-Torres <i>et al.</i> 2008	
Ceratobasidiaceae	<i>Rhizoctonia fragariae</i> <i>Rhizoctonia solani</i>	Root rot, fruit rot	Raspberry, strawberry	Estado de México, Guanajuato, Jalisco, México, does not specify locality, Michoacán, Morelos, Nayarit, Sonora	García-Álvarez 1976, 1981; Téliz- Ortíz <i>et al.</i> 1986; Mendoza-Zamora and Romero-Cova 1989; Castro-Franco and Dávalos 1990; Mendoza 1992; López-Aranda <i>et al.</i> 2016	
		Root rot	Strawberry	Guanajuato, Michoacán	Narro-Sánchez <i>et al.</i> 2006	
Basidiomycota	Phragmidiaceae	<i>Gerwasia pittieriana</i>	Rust	Raspberry, blackberry	Morelos, México, does not specify locality	León-Gallegos and Cummins 1981
			Rust	Raspberry, blackberry	Michoacán, Morelos, Veracruz, México, does not specify locality,	López <i>et al.</i> 1980; León-Gallegos and Cummins 1981; López 1984
		<i>Gymnoconia nitens</i>	Rust	Raspberry, blackberry	Puebla, México, does not specify locality	León-Gallegos and Cummins 1981
			Rust	Blackberry	México, does not specify locality	León-Gallegos and Cummins 1981
		<i>Kuehneola loeseneriana</i>	Rust	Raspberry, blackberry	Veracruz, México, does not specify locality,	López <i>et al.</i> 1980; León-Gallegos and Cummins 1981; López 1984; Hernández and Hennen 2003
			Rust	Raspberry, blackberry	México, does not specify locality, Puebla, Veracruz	Watson 1971; García-Álvarez 1976; Farr and Rossman 2019
		<i>Phragmidium mexicanum</i> (= <i>Frommea mexicana</i>)	Rust	Strawberry	México, does not specify locality	Cummins and Stevenson 1956; Watson 1971; García-Álvarez 1976; Fernández-Pavía <i>et al.</i> 2015

Table 1: Continued

Table 1: Continued

		<i>Phragmidium occidentale</i>	Rust	Raspberry	Veracruz	Carrion and Galvan 1987
		<i>Phragmidium</i> spp.	Rust	Raspberry, blackberry	Puebla	García-Álvarez 1981
Pucciniastraceae		<i>Naohidemycetes vaccinii</i> (= <i>Pucciniastrum vaccinii</i> , <i>Naohidemycetes vacciniorum</i>)	Late leaf rust	Blueberry	Durango, México, does not specify locality	León-Gallegos and Cummins 1981
		<i>Pucciniastrum americanum</i>	Leaf rust	Raspberry	Estado de México, Jalisco, Michoacán	Rebollar-Alviter <i>et al.</i> 2001a, b; Marín <i>et al.</i> 2019
		<i>Pucciniastrum</i> spp.	Leaf rust	Blueberry	Michoacán	Mondragón-Flores <i>et al.</i> 2012
		<i>Thekopsora minima</i>	Leaf rust	Blueberry	Jalisco, Michoacán, México, does not specify locality	Rebollar-Alviter <i>et al.</i> 2011; Horst 2013
Mucoromycota	Mucoraceae	<i>Mucor</i> spp.	Soft fruit rot	Strawberry	Michoacán	Fraire-Cordero <i>et al.</i> 2003
	Rhizopodaceae	<i>Rhizopus stolonifer</i> (= <i>Rhizopus nigricans</i>)	Soft fruit rot	Strawberry, blackberry	Estado de México, Guanajuato, México, does not specify locality, Michoacán	García-Álvarez 1976; Fraire-Cordero <i>et al.</i> 2003; Chávez-Díaz <i>et al.</i> 2014; Fernández-Pavía <i>et al.</i> 2015

Table 2: Species of pathogenic microorganisms reported affecting berries, organized by Kingdom

	Bacteria	Stramenopila	Fungi	Pathogenic species by crop
Blue berry	1	0	15	16
Rasp berry	2	2	25	29
Straw berry	5	5	43	53
Black berry	2	1	23	26
Total pathogenic species by group	5	8	75	88

Table 3: Berry plant species reported to be affected for plant pathogens microorganism in Mexico

Family	Berry	Scientific name	Characteristics and distribution
Ericaceae	Blueberry	<i>Vaccinium corymbosum</i> L.	Widely cultivated species. E.U. and North Hemisphere*
		<i>Vaccinium geminiflorum</i> Kunth	Mexican blueberry. Dwarf blueberry, Distributed from Alaska to Guatemala**
Rosaceae	Raspberry	<i>Rubus idaeus</i> L.	Widely cultivated species. Native of Europe and North Asia*
		<i>Rubus trilobus</i> Moc. & Sessé ex Ser.	Guatemala and southern and central Mexico*
Rosaceae	Strawberry	<i>Fragaria x ananassa</i> (Weston) Duchesne	North America to Patagonia.
Rosaceae	Blackberry	<i>Fragaria mexicana</i> Schldtl.	Wild Mexican strawberry. Mexico*
		<i>Rubus adenotrichos</i> Schldtl.	Wild blackberry. Distributed from central Mexico to Ecuador. The fruits are highly collected in Michoacan***
		<i>Rubus fruticosus</i> L.	Cultivated species. North and south Hemisphere*
		<i>Rubus humistratus</i> Steud	Wild blackberry. Endemic species of Mexico***
		<i>Rubus ulmifolius</i> Schott	Cultivated species. Europe, North Africa, America and Oceania*

Source: *GBIF Secretariat (2019), ** González-Elizondo and González-Elizondo (2014), *** Rzedowski and Calderón (2005)

Discussion

Berries plant protection include several strategies, but one of them is to know the pathogens that potentially affect the crops, especially considering that pest (understood as pathogens, animals, and weed) in global level, could cause annual crop yield losses from 20 to 40% of the production (Oerke 2006; Savary *et al.* 2012).

In this compilation of phytopathogens affecting berries in Mexico, fungi were the largest group reported with 75 of a total of 88 species of microorganism. The most common fungal pathogens included *Botrytis cinerea*, *Fusarium oxysporum* and *Colletotrichum* spp.; while the bacterium *Agrobacterium rhizobacter*, and the oomycete *Peronospora sparsa* and *Phytophthora cactorum*, were some of the most common pathogens reported. These fungi and bacteria are considered amongst the top plant pathogens due to the severe economic losses that cause

worldwide, and their scientific importance (Dean *et al.* 2012; Mansfield *et al.* 2012). Other reported pathogens such as *Thekopsora minima* in blueberry (Rebollar-Alviter *et al.* 2011), and *Rhizoctonia solani* in strawberry (Mouden *et al.* 2016; Amrutha and Vijayaraghavan 2019; Errifi *et al.* 2019) should also be considered as highly important due to the reductions on yields that cause (Ahmed *et al.* 2017).

A major deficiency in 35% of the reports that were analyzed was the lack of identification to the species level. More recent studies have included molecular techniques to assess the taxonomic species (Boyzo-Marin *et al.* 2016; Serret-López *et al.* 2017; Contreras-Pérez *et al.* 2019). However, in the cases of *Colletotrichum* and *Fusarium*, the presence of species complexes makes difficult to establish the correct identification of the involved species due to the probable presence of cryptic species. To identify species in these species complexes is necessary to use several molecular markers (Pastrana *et al.* 2017; Hernández-Cruz *et*

al. 2020). The use of multilocus identification may detect new species such as *Neopestalotiopsis rosae* reported in strawberry (Rebollar-Alviter *et al.* 2020).

Although pathogens in wild species of berries in Mexico have been scarcely studied, some wild hosts were referenced (Table 3). These plants might be capable of harboring pathogens that could serve as inoculum source reservoirs for the infection of nearby crops (Grünwald *et al.* 2001; Pak *et al.* 2017).

The information of phytopathogens affecting berries in Mexico will allow to researchers to detect areas of opportunity to focus on, and for technicians to have a benchmark about all the pathogens in each berry crop that have been reported. Knowing the pathogens will help to plant management strategies to combat infection caused by phytopathogens.

Conclusion

Records of bacteria, oomycetes and pathogenic fungi reported in berries in Mexico since 1956 to 2020 added up to a total of 88 species. Phytopathogenic bacteria are represented by 5.7% of the species, 9.1% correspond to oomycetes and 85.2% to fungi. Still there are phytopathogenic species that need more in-depth taxonomic studies, coupled with this, there are several lineages integrating species complex that need to delve into molecular, genetic and physiological studies to understand in a better way the strategies to control the field diseases.

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Author Contributions

EG and SC generated the idea of the study. EG, SC, SPF, and NG collected the data. EG prepared the initial manuscript; performed the tables. SC, SPF, GR analyzed the data to be considered. All authors commented on the manuscript, reviewed drafts of the paper, and approved the final draft.

Conflicts of Interest

All other authors declare no conflicts of interest

Data Availability

Not applicable.

Ethics Approval

Not applicable.

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