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PHYTOCHEMICAL PROFILE AND ANTIMICROBIAL ACTIVITY OF PLANT EXTRACTS AGAINST PATHOGENIC MICROORGANISMS OF IMPORTANCE TO THE LIVESTOCK INDUSTRY

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ABSTRACT

Infections caused by pathogenic bacteria are a recurrent problem in the livestock sector, generating important economic losses in the livestock industry. One of the main strategies includes antibiotic therapy; however, its use is limited since pathogenic bacteria present resistance to these drugs, which makes treatment against microbial infections difficult. Therefore, the hypothesis proposed was that ethanolic extracts of native plants from the state of Sonora, Mexico, can inhibit the growth of Gram (+) and Gram (-) pathogenic bacteria related to common infections in the livestock industry. The objective was to evaluate the phytochemical and antimicrobial profile of native plants from the state of Sonora, Mexico. In this study, 17 ethanolic extracts were obtained from native plants of Sonora, and the antimicrobial activity was evaluated by the agar diffusion method and by the microdilution technique using reference bacteria from the ATCC collection. The phytochemical profile was evaluated by spectrophotometry and the experimental design used was completely randomized with three replicates per treatment at 95 % confidence. The results showed that extracts of *Prosopis velutina*, *Ibervillea sonorae*, *Populus alba*, *Ambrosia ambrosioides*, *Krameria sonorae*, and *Leucaena leucocephala* were effective in eliminating *Listeria monocytogenes* ATCC 19115, *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922 and *Salmonella enterica* serovar Typhimurium ATCC 14028 ($p \leq 0.05$). In addition, these extracts presented the highest concentration of total polysaccharides, flavones and flavonols, flavanones and dihydroflavonols, tannins and total chlorogenic acid ($p \leq 0.05$). Therefore, plant extracts from Sonora, Mexico, represent a natural alternative for the control of Gram (+) and Gram (-) pathogens of importance to the livestock industry.

Keywords: *Prosopis velutina*, *Ibervillea sonorae*, *Populus alba*, antimicrobial, plant extracts, livestock.

INTRODUCTION

In recent years, there has been increasing interest in evaluating the antimicrobial potential of plants to be used as a natural alternative in the treatment of human diseases or as a preservative in the food industry. However, few studies have focused on the use of plant extracts to treat diseases in domestic animals destined for livestock production. In this context, Kama-Kama *et al*. (2016) reported the antimicrobial activity of *Solanum aculeastrum*, *Albizia coriaria*, *Ekebergia capensis*, *Piliostigma thonningii,* and *Euclea divinorum* extracts against disease-causing strains of *Mycoplasma* in African livestock. In addition, another study showed that ethyl acetate extracted from *Terminalia chebula* plant exhibited antimicrobial activity against the pathogens *Staphylococcus aureus*, *Bacillus megaterium*, *Escherichia coli,* and *Pseudomonas aeruginosa*, which cause bovine mastitis (Kher *et al*., 2019). Likewise, Ndhlovu *et al*. (2017) reported that extracts of *Pterocarpus angolensis*, *Cissus quadrangularis* and *Catunaregam spinosa* were efficient in inhibiting the growth of *Dermatophilus congolensis*, which causes dermatological diseases in cattle; while extracts of *Caryocar brasiliense* and *Schinopsis brasiliensis* showed antimicrobial activity against *Staphylococcus aureus* and *Escherichia coli*, causative of gastrointestinal diseases in beef-producing cattle (de O Ribeiro *et al*., 2018).

Although evidence indicates that plant extracts have potential to control infection-causing pathogens in the livestock industry, not all plants possess this quality (Romulo *et al*., 2018), as bioactive phytochemical compounds, such as alkaloids, phenolic compounds, terpenes, and steroids may vary from plant to plant (Aminah *et al*., 2021; Vaou *et al*., 2021). Therefore, the search for new natural alternatives for this purpose is still at a premature stage due to the great biodiversity of existing plants worldwide, which highlights the need for further research in this area.

In Mexico, it is estimated that there are about 26 000 plant species, of which about 4000 species are used to treat human diseases in a traditional way (Ruiz-Bustos *et al*., 2009; Robles-Zepeda *et al*., 2011). Particularly, some plants native to the state of Sonora, Mexico, have been reported to show antimicrobial potential against *Helicobacter pylori*, *Mycobacterium tuberculosis*, *Escherichia coli*, *Shigella flexneri*, and *Salmonella* spp. (Ruiz-Bustos *et al*., 2009; Robles-Zepeda *et al*., 2013; Sosa-Castañeda *et al*., 2022), and about 400 plants of Sonora are used by local native groups to treat disease (Moreno-Salazar *et al*., 2008; Morales-Figueroa *et al*., 2022). However, the biological effects of a large amount of these plants still lack scientific support. Therefore, it is of great importance to evaluate the phytochemical profile and efficacy of native plants from Sonora, Mexico, to eliminate pathogenic bacteria that cause recurrent infections in animals destined for human consumption in the livestock industry.

MATERIALS AND METHODS

Preparation of ethanolic extracts

Extracts were obtained from 17 plants native of Sonora, Mexico (Table 1), which belong to the Botanical Garden of the Department of Agriculture and Livestock (DAG)

Table 1. Identification and parts of plants species used in ethanolic extracts.

Key	Common name	Family	Scientific name	Part of the plant
E1	Álamo	Salicaceae	*Populus alba*	Leaves
E2	Batamote	Asteraceae	*Baccharis glutinosa*	Stems
E3	Chicura	Asteraceae	*Ambrosia ambrosioides*	Stems
E4	Cosahui	Krameriaceae	*Krameria sonorae*	Root
E5	Guaje	Fabaceae	*Leucaena leucocephala*	Leaves
E6	Guamúchil	Fabaceae	*Pithecellobium dulce*	Bark
E7	Jojoba	Simmondsiaceae	*Simmondsia chinensis*	Leaves
E8	Mezquite	Fabaceae	*Prosopis velutina*	Leaves
E9	Palo verde	Fabaceae	*Parkinsonia microphylla*	Stems and leaves
E10	Palo verde azul	Fabaceae	*Cercidium floridum*	Stems and leaves
E11	Rama blanca	Asteraceae	*Encelia farinosa*	Leaves
E12	Sangregado	Euphorbiaceae	*Jatropha cardiophylla*	Stems
E13	Tepehuaje	Fabaceae	*Lysiloma watsonii*	Leaves
E14	Torote	Burseraceae	*Bursera microphylla*	Leaves
E15	Vinorama	Fabaceae	*Acacia constricta*	Leaves
E16	Wereke	Cucurbitaceae	*Ibervillea sonorae*	Tuber
E17	Zamota	Fabaceae	*Coursetia glandulosa*	Stems

*Plants collected at the Botanical Garden of the DAG-UNISON.

of the University of Sonora (UNISON). Each plant was dehydrated at 34 °C in a hot air oven (Thelco, Precision Science, model 28, USA). The dehydrated plant material was pulverized in a mill (Pulvex Mini 100, Mexico) to a particle size of 100 microns. Then 100 g of the pulverized plant material was mixed with 100 mL of 99 % pure ethanol (Sigma-Aldrich, St. Louis, MO, USA) in a glass bottle and stored for 5 days in the dark at 25 °C (Khan *et al*., 2017). Finally, the extracts were filtered with filter paper Whatmanâ no. 41 and the plant material was dehydrated again. The difference in weight of plant material before and after storage was considered as the amount of soluble compounds extracted from the plants. Ethanolic extracts were adjusted to 50 mg mL^{-1} and stored in the dark at 4 °C until use.

Phytochemical profile of ethanolic extracts

Total polysaccharide content was determined according to DuBois *et al*. (1956), data were expressed as mg of glucose equivalent per gram of extract (mg GE g^{-1}). The content of flavones and flavonols, as well as the content of total flavanones and dihydroflavonols was determined using the methodology reported by Popova *et al*. (2004), the data were expressed as mg of hesperetin equivalent per gram of extract (mg HE g^{-1}). Total tannin content was determined according to Price and Butler (1977), the results were expressed in mg of catechin equivalent per gram of extract (mg CE g^{-1}). Finally, the chlorogenic acid content was determined by the methodology suggested by Griffiths *et al*. (1992) and the results were expressed as mg of chlorogenic acid

per gram of extract (mg CA g^{-1}). Calibration curves were used for all determinations of phytochemical profiles of the extracts and the absorbances were read in a spectrophotometer (Spectro Max MD, USA).

Antimicrobial activity of ethanolic extracts

Listeria monocytogenes ATCC 19115, *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, and *Salmonella enterica* serovar Typhimurium ATCC 14028 were obtained from the culture collection of the Microbiology Laboratory of the Department of Chemical and Biological Sciences of the UNISON. All strains were reactivated in BHI broth culture medium (brain-heart infusion, BD Difco, Sparks, MD, USA). Then, 2 plates were prepared with BHI agar (brain-heart infusion, BD Difco, Sparks, MD, USA) for each strain. Four sterile filter paper discs Whatmanâ no. 41 of 6 mm diameter were placed on each plate, and 20 µL of each ethanolic extract were added to each disk. Finally, the plates were incubated at 37 °C for 24 h. Halos greater than 3 mm were considered as inhibition according to the criteria used by Heredia-Castro *et al*. (2015).

Determination of the minimum inhibitory concentration

The minimum inhibitory concentration (MIC) of each of the extracts was determined by the microdilution technique. Bacteria from the ATCC collection were propagated in BHI broth culture medium (brain-heart infusion, BD Difco, Sparks, MD, USA). A stock solution of 50 mg mL^{-1} of each ethanolic extract was used and 10 dilutions were obtained with concentrations ranging from 5 mg mL^{-1} to 50 mg mL^{-1} for each of the extracts. The MIC was defined as the minimum concentration of extract at which the pathogen did not show visible growth (Mahfuzul *et al*., 2007).

Statistical analysis

A completely Randomized Design with one-way ANOVA was used at 95 % of confidence with three replicates per treatment. The mean comparison test was performed by Tukey-Kramer at a significance level of 0.05 using NCSS statistical software version 11.

RESULTS AND DISCUSSION

The antimicrobial activity of phytochemical compounds derived from plant extracts has attracted strong attention in the scientific community; therefore, the search for new plants with biological potential to control pathogenic microorganisms continues. The results of the phytochemical profile of the ethanolic extracts derived from plants from Sonora, Mexico (Table 2) showed that extract E16 presented the highest concentration of total polysaccharides (250.32 ± 2.12 mg GE g^{-1}) ($p \leq 0.05$), while, extracts E6, E7, and E11 showed the lowest concentration (100.51 ± 1.25, 102.71 ± 1.49 and 103.36 ± 2.65 mg GE g^{-1}, respectively) ($p \leq 0.05$).

Extract E16 presented a higher content of flavones and flavonols (100.65 ± 2.14 mg HE g^{-1}) ($p \leq 0.05$); on the contrary, extracts E6, E7, and E11 showed the lowest concentration of these compounds (34.62 ± 1.20, 32.14 ± 2.12 and 32.82 ± 2.86 mg HE g^{-1}, respectively)

Table 2. Phytochemical profile of ethanolic extracts derived from plants species analyzed.

Key	Total polysaccharides	Total flavones and flavonols	Flavanones and total dihydroflavonols	Total tannins	Total chlorogenic acid
E1	200.32 ± 2.12 e	75.87 ± 2.27 e	10.57 ± 1.87 c	3.05 ± 0.21 d	25.33 ± 1.25 d
E2	185.65 ± 1.33 f	62.33 ± 1.68 g	7.12 ± 1.01 d	3.33 ± 0.14 d	15.85 ± 1.04 e
E3	210.32 ± 2.12 d	80.14 ± 1.25 d	12.25 ± 1.65 c	4.89 ± 0.69 b	27.57 ± 1.65 c
E4	230.32 ± 2.12 c	86.54 ± 3.23 c	15.89 ± 1.25 b	4.58 ± 0.74 bc	29.33 ± 1.14 bc
E5	230.32 ± 2.12 c	88.62 ± 2.11 c	15.25 ± 1.14 b	4.32 ± 0.21 c	28.36 ± 2.25 bc
E6	100.51 ± 1.25 h	34.62 ± 1.20 h	3.55 ± 0.12 e	2.11 ± 0.07 f	10.57 ± 1.14 f
E7	102.71 ± 1.49 h	32.14 ± 2.12 h	3.77 ± 0.14 e	2.01 ± 0.20 f	9.96 ± 1.06 f
E8	240.32 ± 2.12 b	92.32 ± 2.33 b	18.58 ± 2.86 a	5.02 ± 0.58 a	30.59 ± 1.23 b
E9	182.36 ± 2.98 g	65.96 ± 2.35 f	6.98 ± 0.87 d	3.42 ± 0.09 d	14.89 ± 1.61 e
E10	184.42 ± 2.87 g	64.36 ± 2.38 f	6.64 ± 0.48 d	3.21 ± 0.06 d	14.81 ± 1.21 e
E11	103.36 ± 2.65 h	32.82 ± 2.86 h	3.33 ± 0.16 e	2.02 ± 0.10 f	9.88 ± 1.02 f
E12	180.25 ± 2.28 g	63.25 ± 2.58 g	6.72 ± 0.42 d	3.02 ± 0.02 d	15.81 ± 1.51 e
E13	183.42 ± 2.78 g	64.69 ± 1.57 f	6.84 ± 0.37 d	3.26 ± 0.03 d	15.38 ± 1.21 e
E14	181.81 ± 2.31 g	61.19 ± 2.54 g	6.81 ± 0.33 d	3.28 ± 0.02 d	14.14 ± 1.11 e
E15	184.01 ± 2.69 g	65.95 ± 3.25 f	7.00 ± 0.16 d	3.15 ± 0.02 d	14.15 ± 1.17 e
E16	250.32 ± 2.12 a	100.65 ± 2.14 a	20.68 ± 1.59 a	5.24 ± 0.18 a	35.57 ± 1.01 a
E17	182.95 ± 1.99 g	62.47 ± 1.58 g	6.99 ± 0.19 d	3.04 ± 0.03 d	15.17 ± 1.51 e

Total polysaccharides = mg GE g^{-1}; Flavones and flavonols = mg HE g^{-1}; Total flavanones and dihydroflavonols = mg HE g^{-1}; Total tannins = mg CE g^{-1}; Total chlorogenic acid = mg CA g^{-1}. Different letter indicates significant difference between data in the same column ($p \leq 0.05$). E1 to E17 are according to Table 1.

($p \leq 0.05$). Regarding total flavanones and dihydroflavonols content, extracts E8 and E16 showed the highest concentration (18.58 ± 2.86 and 20.68 ± 1.59 mg HE g^{-1}, respectively) ($p \leq 0.05$); on the other hand, extracts E6, E7, and E11 showed the lowest concentration of these phytochemicals (3.55 ± 0.12, 3.77 ± 0.14 and 3.33 ± 0.16 mg HE g^{-1}, respectively) ($p \leq 0.05$). The content of total tannins was higher in extracts E8 and E16 (5.02 ± 0.58 and 5.24 ± 0.18 mg CE g^{-1}, respectively) ($p \leq 0.05$), while extracts E6, E7, and E11 presented the lowest concentration of these compounds (2.11 ± 0.07, 2.01 ± 0.20 and 2.02 ± 0.10 mg CE g^{-1}, respectively) ($p \leq 0.05$). Finally, extract E16 presented a higher content of total chlorogenic acid (35.57 ± 1.01 mg CA g^{-1}) ($p \leq 0.05$), while extracts E6, E7 and E11 presented the lowest concentration of that phytochemical (10.57 ± 1.14, 9.96 ± 1.06 and 9.88 ± 1.02 mg CA g^{-1}, respectively) ($p \leq 0.05$).

Other studies have also evaluated the phytochemical profile of some plants from Sonora, Mexico. In this context, Vidal-Gutiérrez *et al*. (2020) identified 11 phenolic compounds (4 phenolic acids, 6 flavonoids and 1 flavan-3-ols) in the extract of *Bursera microphylla*, while Estrada-Zúñiga *et al*. (2012) reported the presence of total phenols in the extract of *Ibervillea sonorae*. The presence of phenols and total flavonoids in the extract of *Krameria erecta* has also been reported (Jiménez-Estrada *et al*., 2013). Other studies evaluated different *Prosopis* species and found the presence of alkaloids, phenolic compounds, flavonoids, phenolic acids, glycosides, steroids, tannins, and

triterpertenoids (Sharifi-Rad *et al*., 2019). In the extract of *Leucaena leucocephala*, native to northwestern Mexico and cultivated in Egypt, the presence of terpenes, flavonoids, coumarins, and sterols was found (Hassan *et al*., 2014). In addition, the presence of phytochemical compounds in plants can vary from one species to another (Sharifi-Rad *et al*., 2019) due to various factors, one of them being the stress to which the plant is subjected (Vidal-Gutiérrez *et al*., 2020).

The results of the antimicrobial activity of the ethanolic extracts against bacteria from the ATCC collection (Table 3) showed that 14 of the 17 extracts evaluated exhibited activity against at least one bacterium ($p \leq 0.05$), while, three of the extracts assessed showed no activity (E6, E7 and E11) against any pathogen evaluated. Extract E16 presented the highest antimicrobial activity against *S. aureus* (18.50 ± 0.70 mm) ($p \leq 0.05$) and, on the contrary, E12 and E13 presented the lowest activity (4.00 ± 1.41 mm and 4.50 ± 0.70 mm, respectively) ($p \leq 0.05$). On the other hand, extract E8 presented the highest inhibition against *L. monocytogenes* (16.50 ± 2.12 mm) ($p \leq 0.05$), while E12 presented the lowest antimicrobial activity (3.50 ± 0.70 mm) ($p \leq 0.05$). The E4 extract showed the highest antimicrobial activity against *E. coli* (14.50 ± 2.12 mm) ($p \leq 0.05$); conversely, E12 and E13 showed the lowest activity (3.50 ± 0.70 mm and 3.50 ± 0.70 mm)

Table 3. Antimicrobial activity of ethanolic extracts obtained from plant species analyzed, against pathogenic bacteria from the ATCC collection.

Extracts	Gram (+)		Gram (-)	
	Staphylococcus aureus	*Listeria monocytogenes*	*Escherichia coli*	*Salmonella enterica* serovar Thyphimurium
E1	7.00 ± 1.41 e	11.50 ± 2.12 df	11.00 ± 1.41 d	7.00 ± 1.41 c
E2	5.50 ± 0.70 g	8.00 ± 1.41 g	6.50 ± 2.12 f	n.p.
E3	10.50 ± 2.12 d	10.50 ± 0.70 f	12.50 ± 0.70 bc	7.50 ± 0.70 bc
E4	12.50 ± 2.12 c	13.50 ± 2.12 c	14.50 ± 2.12 a	8.00 ± 1.41 b
E5	13.00 ± 2.82 c	12.50 ± 0.70 cd	11.50 ± 2.12 cd	12.00 ± 1.41 a
E6	n.p.	n.p.	n.p.	n.p.
E7	n.p.	n.p.	n.p.	n.p.
E8	14.00 ± 1.41 b	16.50 ± 2.12 a	13.00 ± 1.41 b	13.00 ± 1.41 a
E9	6.50 ± 0.70 f	5.50 ± 0.70 h	5.50 ± 0.70 f	3.50 ± 0.70 e
E10	5.50 ± 0.70 g	8.00 ± 1.41 g	n.p.	n.p.
E11	n.p.	n.p.	n.p.	n.p.
E12	4.00 ± 1.41 h	3.50 ± 0.70 i	3.50 ± 0.70 h	n.p.
E13	4.50 ± 0.70 h	5.50 ± 0.70 h	3.50 ± 0.70 h	n.p.
E14	7.00 ± 2.82 e	5.50 ± 0.70 h	4.0 ± 0.41 g	n.p.
E15	7.50 ± 2.12 e	10.50 ± 2.12 f	8.50 ± 0.70 e	13.00 ± 1.4 a
E16	18.50 ± 0.70 a	14.00 ± 1.41 b	10.00 ± 1.4 d	5.50 ± 0.70 d
E17	6.50 ± 0.70 f	7.50 ± 0.70 g	4.50 ± 0.70 fg	n.p.

*Data expressed in mm of inhibition halos. Concentration of extracts = 50 mg mL^{-1}; n.p.: no activity. Different letter indicates significant difference between data in the same column ($p \leq 0.05$).

($p \leq 0.05$), and the E10 extract showed no activity. Likewise, extracts E5, E8, and E15 showed higher antimicrobial activity against *Salmonella enterica* serovar Typhimurium (12.00 ± 1.41 mm, 13.00 ± 1.41 mm and 13.00 ± 1.41 mm, respectively) ($p \leq 0.05$); in contrast, E9 showed the lowest activity (3.50 ± 0.70 mm) ($p \leq 0.05$) and extracts E2, E10, E12, E13, E14, and E17 showed no antimicrobial activity against this pathogen.

Few studies have demonstrated the antimicrobial potential of plants from Sonora, Mexico. In this regard, Moreno-Salazar *et al*. (2008) evaluated the antimicrobial effect of 30 native plants from northwestern Mexico against *E. coli*, *Shigella flexneri*, and *Salmonella enterica* serovar Typhimurium, and reported that *Lysiloma watsonii* and *Acacia constricta* presented antimicrobial activity against the 3 pathogens tested, which coincides with the findings of this study. However, the authors reported that *Pithecellobium dulce* was able to inhibit the growth of *E. coli, Shigella flexneri*, and *Salmonella enterica* Typhimurium, which differs with the results found in this study, since *Pithecellobium dulce* did not present antimicrobial activity against any of the pathogens evaluated. In addition, the authors found that *Baccharis glutinosa* and *Coursetia glandulosa* did not show antimicrobial activity against any of the pathogens tested, whereas in this study antimicrobial activity was found against *E. coli*. These contradictory results may be due to the type of solvent used to obtain the phytochemical compounds from the plants, since methanol and ethanol are solvents that have different polarity, which allows the extraction of different types of phytochemical compounds from the plants. On the other hand, Ruiz-Bustos *et al.* (2009) evaluated the antimicrobial potential of 6 methanolic extracts of plants from northwestern Mexico, and reported that *Ibervillea sonorae* did not show antimicrobial activity against *E. coli* and *S. aureus*, which differs from what was found in this study, since *Ibervillea sonorae* did show antimicrobial activity against these two pathogens. This could be due to the type of solvent used (methanol), the storage time (10 days) or the period of exposure to light of the plant material mixed with the solvent during storage. In the study, it was mentioned that the extracts were stored in amber colored bottles after they were obtained and not during storage prior to obtaining them, which could have affected their bioactivity. Likewise, it has been reported that the methanolic extract of *Ambrosia ambrosioides* presented antimicrobial activity against *Mycobacterium tuberculosis* (Robles-Zepeda *et al*., 2013), and that the methanolic extract of *Ibervillea sonorae* was efficient in inhibiting the growth of *Helicobacter pylori* (Robles-Zepeda *et al*., 2011), which demonstrates the antimicrobial potential of plants from Sonora, Mexico, to eliminate Gram (+) and Gram (-) bacteria. Their activity is related to the interaction of antimicrobial compounds with the outer peptidoglycan layer of the cell wall of Gram (+) bacteria and with the outer lipopolysaccharide layer of Gram (-) bacteria.

Plant-derived phytochemicals exhibiting antimicrobial activity can be classified into several groups according to their chemical structure, the main compounds being alkaloids, terpenoids, sulfur compounds, and polyphenols (Radulovic *et al*., 2013; Khameneh *et al*., 2019). Alkaloids are heterocyclic nitrogenous compounds containing extremely variable chemical structures and their antibacterial activity has been

demonstrated in some studies, where it has been observed that reserpine, piperine, tomatidine, berberine, among others, can inhibit the efflux pump and ATP synthase, or atrophy the cell membrane of bacteria, causing them to die (Khameneh *et al*., 2019). On the other hand, organosulfur compounds are molecules that contain sulfur, among which are lycine, ajoene, berteroin, among others. This group of molecules can inhibit the synthesis of ATP synthase, destroy the membrane of bacteria, and inhibit the synthesis of DNA and microbial proteins. Phenolic compounds are molecules having one or more unsaturated rings with one or more hydroxyl groups, which constitute a ubiquitous group of secondary metabolites found in some species of the plant kingdom. Phenolic compounds include phenolic acids, flavonoids and tannins, which can inhibit bacterial efflux pump and DNA gyrase, while terpenes are a very broad group of aromatic compounds derived from isopropene, Terpenes include molecules such as farnesol, neronidol, carvacol, menthol, among others, and these molecules can cause cell membrane atrophy and bacterial death (Radulovic *et al*., 2013; Khameneh *et al*., 2019).

In this study, the extracts from Sonora plants showed the presence of antimicrobial compounds such as flavones, flavonols, flavanones, dihydroflavonols, and tannins; however, the variability in the results of the antimicrobial activity found could be due to the presence and concentration of other phytochemical compounds not evaluated, such as sulfur compounds, terpenoids or alkaloids.

On the other hand, the MIC was evaluated in the 14 extracts that showed antimicrobial activity (Table 4). The results showed that dilutions of the extracts with concentrations

Table 4. Minimum inhibitory concentration of ethanolic extracts obtained from the plant species analyzed, against pathogenic bacteria from the ATCC collection.

Extract	Gram (+)		Gram (-)	
	Staphylococcus aureus	*L.isteria monocytogenes*	*Escherichia coli*	*Salmonella enterica* serovar Typhimurium
E1	50	35	30	50
E2	50	45	50	n.p.
E3	30	30	30	50
E4	35	30	25	50
E5	30	40	45	40
E8	30	15	35	30
E9	50	50	50	50
E10	50	50	n.p.	n.p.
E12	50	50	50	n.p.
E13	50	50	50	n.p.
E14	50	50	50	n.p.
E15	50	35	45	30
E16	15	25	30	50
E17	50	50	50	n.p.

*Concentrations of the extracts expressed in mg mL^{-1}. n.p.: no inhibitory activity.

between 5 and 10 mg mL^{-1} did not show activity against any pathogen evaluated. However, *S. aureus* was most susceptible to extract E16 (15 mg mL^{-1}), followed by extracts E3, E5, and E8 (30 mg mL^{-1}), whereas, *L. monocytogenes* was most susceptible to E8 (15 mg mL^{-1}), followed by E16 (25 mg mL^{-1}), E3, and E4 (30 mg mL^{-1}). Likewise, *E. coli* showed to be most susceptible to extract E4 (25 mg mL^{-1}), followed by extracts E1, E3, and E16 (30 mg mL^{-1}). Finally, *Salmonella enterica* serovar Typhimurium was most susceptible to extracts E8 and E15 (30 mg mL^{-1}), followed by extract E5 (40 mg mL^{-1}).

In a study conducted by Elisha *et al*. (2017), different concentrations of plant extracts were evaluated against *E. coli* and *Salmonella enterica* serovar Typhimurium, where it was reported that *Hypericum roeperianum* extract presented higher antimicrobial activity when used at a concentration of 0.13 mg mL^{-1} against *E. coli* and 0.26 mg mL^{-1} against *Salmonella enterica* serovar Typhimurium. Furthermore, *Heteromorpha arborescens* extract showed its highest antimicrobial activity at a concentration of 0.18 and 0.31 mg mL^{-1} against those two pathogens, respectively. Similarly, Ramli *et al*. (2017) reported that *E. coli* and *Salmonella enterica* serovar Typhimurium were susceptible to *Syzygium polyanthum* extract when exposed to a concentration of 1.25 mg mL^{-1}, while *S. aureus* and *L. monocytogenes* presented higher susceptibility when the concentration of the extract was adjusted to 0.63 mg mL^{-1}.

The variability of the concentration at which the highest antimicrobial activity of the plant extracts occurs could be due to the types of biomolecules present, as well as their quantity. To date, it has been reported that not all chemical compounds that are part of the flavonoid group can act with the same intensity against Gram (+) and Gram (-) bacteria, so their antimicrobial action could depend on the amount and type of flavonoids present in the extracts (Echeverría *et al*., 2017).

CONCLUSIONS

The ethanolic extract of *Prosopis velutina* was the most efficient in eliminating Gram (+) bacteria *Listeria monocytogenes* ATCC 19115 and *Staphylococcus aureus* ATCC 25923, and Gram (-) bacteria *Escherichia coli* ATCC 25922 and *Salmonella enterica* serovar Typhimurium ATCC 14028. However, extracts of *Ibervillea sonorae Populus alba*, *Ambrosia ambrosioides*, *Krameria sonorae*, and *Leucaena leucocephala* also showed significant antimicrobial activity against the same pathogens. In addition, these extracts presented the highest concentration of the phytochemical flavones and flavonols, total flavanones and dihydroflavonols, total tannins, and total chlorogenic acid. Therefore, extracts from native plants of Sonora, Mexico, can be considered as an alternative and natural treatment to control infections caused by Gram (+) and Gram (-) bacteria that affect animal production in the livestock industry.

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