The in vitro antimicrobial and antioxidant activity of leaves of medicinal plants with phytobiotic potential in animal production

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Abstract

Little is known about which secondary metabolites are responsible for inhibiting pathogenic bacteria and reducing the pro-oxidant effect on the leaves of four medicinal plants used as phytobiotic in animal production. The aim of this study was to evaluate the antimicrobial and antioxidant activity of four medicinal plants (*Anacardium occidentale*, *Psidium guajava*, *Morinda citrifolia* and *Moringa oleifera*.) *in vitro*. A total of six bacterial strains were inoculated, then minimum bactericidal concentration (MBC) was evaluated in fine powder and minimum inhibitory concentration (MIC) and MBC were determined on the aqueous extract. Also, the *in vitro* antioxidant activity was evaluated through 1,1-diphenyl-2-picryl-hydrazyl, as well as the main secondary metabolites were identified and quantified by chromatographic analysis. The results showed that *Anacardium occidentale* and *Psidium guajava* leaves had higher antimicrobial activity against all bacterial strains. In addition, *Morinda citrifolia* inhibited *S. aureus* in the aqueous extract, although without *in vitro* bactericidal effect, while *Moringa oleifera* leaf did not show antimicrobial effect. All plants showed antioxidant capacity, standing out *Anacardium occidentale* and *Psidium guajava*. Mainly the leaves of *Anacardium occidentale* showed high concentrations of quercetin 3-O-glucoside-7-O-rhamnoside, kaempeferol-7-O-glucoside, quercetin, caffeic acid, and cinnamic acid. Apparently, the antimicrobial and antioxidant activity are due to the main polyphenolic compounds identified in medicinal plants (mainly *Anacardium occidentale* and *Psidium guajava*); however, further studies are necessary to elucidate the exact mechanism.

Introduction

The European Union totally eliminated the use of growth-promoting antibiotics in animal production on January 1st, 2006, prompting many countries to reduce or eliminate these synthetic products. Subtherapeutic antibiotics are known to cause microbial resistance and cross-resistance with other microorganisms that inhabit animals and humans. Therefore, there is a growing interest in research to find natural alternatives to antibiotics; especially medicinal plants with beneficial phytochemical compounds and with antimicrobial, anti-inflammatory and antioxidant properties (Martínez et al. 2020).

In that context, phytogenic additives have proven to be an important alternative to enhance the genetic expression of farm animals without the use of dietary antibiotics. Thus, phytogenic feed additives are included among supplements in order to positively affect feed quality, animal health and animal products caused by their specifically effective substances (Karásková et al. 2015). Likewise, approximately 80% of the population in developing countries use medicinal plants systematically for humans and animals, in Cuba 1,170 species of these plants are reported, where 56% are known for their curative and preventive properties (Ramírez et al. 2020). Plants for antibacterial purposes are used to heal wounds, relieve digestive and oral discomfort, and additives in the farm animal diet, among others (Martínez et al. 2013; Más et al. 2016; Aroche Ginarte et al. 2017; Salazar Bell et al. 2017; Aroche et al. 2018). Thus, plants such as *Anacardium occidentale* (*A. occidentale*), *Psidium guajava* (*P. guajava*), *Morinda citrifolia* (*M. citrifolia*), and *Moringa oleifera* (*M. oleifera*) are some of the most used as adjuvants to therapeutic treatment in different diseases in humans and animals.

Anacardium occidentale, (family *Anacardiaceae*) is commonly used in the infection treatment, hemorrhages, diarrheal processes, and diabetes in animals, and also have shown that small concentrations could increase the egg production and egg quality and could decrease pig's diarrheal syndrome (Sunderam et al. 2019; Khatib et al. 2020; Siracusa et al. 2020). Its antimicrobial activity has also been verified in the ethanolic extract of flowers, bark, and leaves, relating it to the alkaloid, saponin, phenolic acid and tannin contents (da Silva et al. 2016).

Several investigations have shown that leaves, fruits, bark and roots of *P. guajava* have been used to alleviate several illnesses, such as gastrointestinal diseases, diarrheal syndrome, stomach pain, diabetes mellitus, hypertension, wound healing, inflammations and obesity. Also, in animal production, *P. guajava* has been shown to promote egg production, eggshell thickness and reduce the liquid feces of pigs after weaning (Gupta et al. 2019; Salihu Abdallah et al. 2019; Weli et al. 2019; Ceballos-Francisco et al. 2020).

Morinda citrifolia are also popular for their variety of benefits in human health and animal production, such as antimicrobial, anticancer, antioxidant, anti-inflammatory, analgesic, cardiovascular, among others (Senthilkumar et al. 2016; Sunder et al. 2016; Thorat et al. 2017). Those properties made possible to include its leaves and fruits in poultry and pig diets with positive effects on egg production and body weight in order to increase the animal performance (Sunder et al. 2016; Aroche Ginarte et al. 2017; Salazar Bell et al. 2017; Aroche et al. 2018).

Moringa oleifera as a functional food in human health and animal production is very popular, especially for its high nutritional content of protein, minerals and vitamins (Zhang et al. 2018; Wang et al. 2018; Su and Chen, 2020). Likewise, beneficial effects of *M. oleifera* have been found due to its anticancer, anti-inflammatory, antidiabetic, antioxidant and antimicrobial activity (Siddhuraju and Becker, 2003; Dhakad et al. 2019). Regarding to animal use of *M. oleifera*, several authors recommend it as a feasible source of nutrients for ruminant and non-ruminant animals (Mahfuz and Piao, 2019; Su and Chen, 2020; Valdivie et al. 2020).

These four plants have a marked global interest for animal production, due to their nutraceutical properties to improving productive indicators, intestinal health, and quality of the final product (e.g., egg, meat and milk) in animals (Martínez et al. 2012, 2013; Más et al. 2015, 2016; Aroche Ginarte et al. 2017; Cañete Sera et al. 2017; Salazar Bell et al. 2017; Aroche et al. 2018; Ramírez et al. 2020). However, little is known about which of these plants has the highest antibacterial and antioxidant potential related to animal production; which would allow to elucidate the medicinal benefits reported animals of zootechnical interest; therefore, the objective of this investigation was to determine the antimicrobial and antioxidant effect of *A. occidentale*, *P. guajava*, *M. citrifolia* y *M. oleifera* leaves and aqueous extract *in vitro.*

Material And Methods

Plant Material

Leaves of *A. occidentale*, *P. guajava*, *M. oleifera* and *M. citrifolia* were collected in Granma province, Cuba, in February/2019, during the low rainy season; this zone is characterized by a flat topography and charcoal brown soil, authenticated by specialists from the Faculty of Agricultural Sciences of the University of Granma. The plants were more than one year old and without any sign of pathology. The leaves were dried in the shade, with free air circulation to constant weight and then dried in a stove (WSU 400, German) with air recirculation for 1 hour at 60°C. Subsequently, the leaves were crushed in a hammer mill with parallel blades, at 1 mm of size. The samples were stored at room temperature (26°C) in fully airtight plastic bags until further use.

In vitro experiments were performed at the Feed Research Institute of the Chinese Academy of Agricultural Sciences to determine the antibacterial and antioxidant activity of the leaves and their aqueous extracts.

Preparation of the Fine Powder and Aqueous Extract

To obtain the fine powder, the leaves were ground in a commercial grain crushing machine (Zhejiang Horus Industry and Trade Co., Ltd., Zhejiang, China) through a 40 mesh (0.45 mm) sieve (Yoston, China) and stored in completely airtight bags until use for microbiological tests.

Also, 16.67 g of the leaves of each plant were weighed and mixed with 500 mL of water (30:1, v/w) for aqueous extraction. The aqueous extract was obtained by the sonication method, using an ultrasonic extractor (model SY-1000E, China) for 50 minutes at 50°C, allowed to stand for 1 hour, and filtered through Whatman filter paper. No. 1. It was subsequently condensed through a rotary evaporator (model RE-2000, China), under reduced pressure at 45°C at 60 rpm. The extract was frozen at -80°C for at least 4 hours, and finally dried in a lyophilizing machine (model LGJ-18, China).

Minimum Bactericidal Concentration of Fine Powder

The MBC of the fine powder from leaves of the four plants was determined for triplicated. Bacterial culture was inoculated and incubated for 12 hours, later, 90 mm diameter petri dishes were prepared with Mueller-Hinton Agar (MHA) at different concentrations of the fine powder. Each bacterial culture of 100 µL of was inoculated, which consisted in strains of enterotoxigenic *Escherichia coli* (ETEC) $K88^+$, *Escherichia coli* ATCC 1515, *Staphylococcus aureus* (*S. aureus*): ATCC 43300 and ATCC 25923, *Salmonella enteritidis* (*S. enteritidis*): ATCC 3377, and *Salmonella typhimurium* (*S. typhimurium*): ATCC 14028. In the first period, concentrations of 5, 15 and 30 mg/mL of fine powder in the culture medium were tested to identify the minimum concentration of each plant in that range. Then, concentrations less than 5 mg/mL were used for leaves of *A. occidentale* and *P. guajava*; 5 to 15 mg/mL of fine powder in culture medium in the case of *M. citrifolia* and 15 to 30 mg/mL of fine powder of culture medium with *M. oleifera*.

Minimum Inhibitory Concentration and Minimum Bactericidal of Aqueous Extract from the Plants

For this study, aqueous extract of the four plants was used, thus a stock solution of 13 mg/mL was prepared, which was used to prepare in serial dilutions of 13, 6.5, 3.25, 1.63, 0.81, 0.41, 0.2, 0.1, 0.05, 0.03, and 0.01 mg/mL. The inoculum of *E. coli* (ETEC $K88^+$), *S. aureus* (ATCC 43300), and *S. typhimurium* (ATCC 14028) were prepared in culture medium at a concentration of approximately 15 x 10^7 CFU/mL compared to theoretical optical density (550 nm absorbance) that defines the level of 0.50 in the McFarland turbidimetric scale. Then, 200 µL/well of each dilution was placed in 96-well microplates and 2 µL of each bacterial culture was inoculated for triplicates, incubated for 12 hours at 37°C to determine its absorbance in a plate reader (ELISA, BIO-TEK, Synergy HT).

Determination of the MBC was carried out for triplicated, 100 µL of supernatant from those wells where bacterial growth was inhibited and seeded with a sterile glass triangular spatula in 90 mm diameter petri dishes with Mueller-Hinton Agar (MHA), and incubated for 12 hours at 37°C.

Antioxidant Activity

Antioxidant activity of aqueous extract of leaves from the four plants was evaluated with DPPH− (Shen et al. 2010) where a solution of 0.1 mM of DPPH− in methanol was prepared. Later, 1 mL of this solution was taken and vigorously mixed in a vortex with 3 mL of the different concentrations (10, 5, 2.5, 1.25, 0.625, 0.313, 1,156, 0.078, 0.039, 0.020 and 0.010 mg/mL) of the extract, and 200 µL of each concentration were placed in a 96-well microplate. The solutions were left to stand at room temperature in the dark for 30 min and then, the absorbance at 517 nm was measured with the use of a plate reader (ELISA brand, BIO-TEK, Synergy HT). BHT was used as reference. Low absorbance values indicate high free radical scavenging capacity, or high antioxidant capacity, which was calculated using the following formula:

Antioxidant effect of DPPH−(% inhibition) = [(A0 –A1) / A0 * 100]; where A0 is the absorbance of the control reaction, and A1 is the absorbance in the presence of the extracts and the reference. All samples were evaluated in triplicate and the results were averaged and shown as IC_{50} values (mg/mL).

Identification and Quantification of Major Compounds from Leaves of the Four Plants

Pretreatment Method

The sample leaves (40 mg) from *A. occidentale*, *P. guajava*, *M. citrifolia* and *M. oleifera* were added to 4 mL of extractant and were shaken under ultrasonic for 30 min. Then, centrifugation for 5 min to take the supernatant and the membrane was done.

1. *A. occidentale* leaves 41.93 mg + extractant (0.8 mL EDTA buffer solution + 3.2 mL methanol)
2. *P. guajava* leaves 41.94 mg + extractant (0.8 mL EDTA buffer solution + 3.2 mL methanol)
3. *M. citrifolia* leaves 44.50 mg + extractant (0.8 mL EDTA buffer solution + 3.2 mL methanol)
4. *M. oleifera* leaves 44.20 mg + extractant (0.8 mL EDTA buffer solution + 3.2 mL methanol)

EDTA buffer solution: weigh 7.10 g of anhydrous sodium hydrogen phosphate, 1.95 g of disodium edetate, 8.40 g of citric acid, and dissolve in 650 mL of water.

Chromatographic Method

The column used was an Agilent's Zorbax Eclipse Plus-C18 (3.0 x 150 mm, 1.8 µm). Mobile phase A: water (0.1% formic acid and 0.2 mmol/L ammonium acetate); mobile phase B: methanol (0.1% formic acid and 0.2 mmol/L ammonium acetate). Separation gradient (0-1 min: 10% B; 1-9 min: 10% B-90% B; 9-11 min: 90% B-100% B; 11-11.1 min: 100% B-10% B; 11.1-13 min: 10% B). The column temperature was 29.5 ° C, the injection volume was 2 µL and the flow rate 0.25 mL/min (Fang et al. 2007).

Mass spectrometry (MS)

Electrospray ionization (ESI) in positive/negative mode with a MS2 Scan was used in MS. The drying gas temperature was 250°C and dry gas flow rate of 7 L/min, with an atomizing gas pressure of 35 psi. Sheath gas temperature of 325°C and sheath gas flow of 11 L/min was used, and a fragmentor of 80 V; 100 V; 120 V with a cell accelerator voltage of 5 V was used.

Description

The pretreatment was separately extracted with methanol and acetonitrile. The results showed that the extraction with methanol was better. In the full scan of the parent ion, the positive and negative ion modes are used for simultaneous scanning, and the results can be mutually verified. The addition of formic acid to the mobile phase increased the sensitivity of the compound both in positive ions and in negative ion mode. The addition of ammonium acetate improved the peak shape of the chromatogram. There may be ions in positive ion mode: [M+H] +, [M+Na] +, [M+NH4] +, [2M+H] +; and there may be ions in the negative ion mode: [M+CH3COO]-, [M+COO]-.

Qualitative Method

Forty mg sample of leaves from *A. occidentale* and *P. guajava* were added to 4 mL of extractant and were shaken under ultrasonic for 30 min. Then, centrifugation for 5 min to take the supernatant and the membrane was done.

EDTA buffer solution: weight 7.1 g of anhydrous sodium hydrogen phosphate, 1.95 g of disodium edetate, 8.4 g of citric acid, and dissolve in 650 mL of water.

UHPLC-MS/MS Conditions

Chromatographic analysis was performed on a waters acquity ultrahigh-performance liquid chromatography system, using an Agilent Zorbax Eclipse Plus C18 column (3.0 x 150 mm, 1.8 µm). Mobile phase A: water (0.1% formic acid and 0.2 mmol/L ammonium acetate); mobile phase B: methanol (0.1% formic acid and 0.2 mmol/L ammonium acetate). Separation gradient (0-1 min: 10% B; 1-2 min: 10% B-60% B; 2-7.5 min: 60% B-90% B; 7.5-8.0 min: 90% B-100% B; 8.0-8.1 min: 10% B). The injection volume was 2 µL and the flow rate 0.30 mL/min (Fang et al. 2007).

MS was performed on a Sciex Triple Quad 4500 MS/MS, and electrospray ionization coupled with multiple reaction monitoring (MRM) model. The resulting optimized values were as follows: source temperature 450°C; ion spray voltage 4500 V; collision gas: 9 psi; curtain gas 10 psi; ion source gas (GS 1) 18 psi; and ion source gas (GS 2) 0 psi.

Statistical Analysis

Data were processed by simple classification ANOVA in a completely randomized design. Before this, the normality of the data was verified using the Kolmogorov-Smirnov test and for uniformity of variance, the Bartlett test. When the effects were significant, the means were separated using Duncan's test at the significance level of $P \leq 0.05$. All analyzes were carried out in accordance with the SPSS statistical software, version 21.0 (SPSS Inc., Chicago, IL, USA).

Results

The MBC of the leaves of *A. occidentale*; *P. guajava*; *M. citrifolia* and *M. oleifera* against six strains of pathogenic bacteria is showed in Table 1. Leaves of *A. occidentale* showed the greatest bactericidal effect in the study, mainly against *Escherichia coli* K88 and *Staphylococcus aureus* (ATCC 25923) with concentrations of 4 and 1 mg/mL, respectively. Likewise, the leaves of *P. guajava* showed a bactericidal effect by reducing the growth of Gram negative and Gram-positive bacteria with a concentration of 11 mg/mL for *E. coli* $K88^{+}$. Also, the leaves of *M. citrifolia* and *M. oleifera* only showed bactericidal activity against the strains of *S. aureus* (ATCC 43300; ATCC 25923) although with higher doses (8-16 mg/ml) than the inhibitory effects of the leaves of *A. occidentale* and *P. guajava*.

Table 1
MBC of the leaf powder of four plants against six bacterial strains (mg/mL)

Bacteria	AO	PG	MC	MO
E. coli K88^{+}	4.0	11.0	NI	NI
E. coli (ATCC 1515)	4.0	5.0	NI	NI
S. aureus (ATCC 43300)	1.0	1.0	8.0	16.0
S. aureus (ATCC 25923)	0.5	5.0	15.0	NI
S. enteritidis (ATCC 3377)	4.0	4.0	NI	NI
S. typhimurium (ATCC 14028)	2.0	2.0	NI	NI

AO: *Anacardium occidentale*. PG: *Psidium guajava*. MC: *Morinda citrifolia*. MO: *Moringa oleifera*. NI: No inhibition.

MIC and MBC of the aqueous extract of the leaves of the four plants in study are shown in table 2. Similar to the fine powder of the leaves, the aqueous extracts of *A. occidentale* and *P. guajava* had the highest bactericidal activity. It should be noted that MIC and MBC to inhibit the growth of *E. coli* K88^{+} is the same in both medicinal plants (6.5 mg/ml).

Table 2
MIC and MBC of the aqueous extract of the leaves of the plants (mg / mL)

Extracts	*E. coli* (K88^{+})		*S. aureus* (43300)		S. *typhimurium* (14028)	
	MIC	MBC	MIC	MBC	MIC	MBC
AO	6.5	6.5	0.81	0.81	3.25	3.25
PG	6.5	6.5	0.81	1.63	6.5	6.5
MC	NI	NI	6.5	NI	NI	NI
MO	NI	NI	NI	NI	NI	NI

MIC: Minimum Inhibitory Concentration. MBC: Minimum Bactericidal Concentration. AO: *Anacardium occidentale*. PG: *Psidium guajava*. MC: *Morinda citrifolia*. MO: *Moringa oleifera*. NI: No inhibition.

Likewise, a higher concentration of the aqueous extract of *P. guajava* (compared to the aqueous extract of *A. occidentale* leaves) is necessary to inhibit and eliminate *S. typhimurium* (ATCC 14028), similar occurred for the bactericidal effect of this product against *S. aureus* (ATCC 43300). The aqueous extract of *M. citrifolia* only inhibited the growth of *S. aureus* (ATCC 43300) at doses of 6.5 mg/mL, however, it did not show bactericidal activity at the concentrations studied (maximum concentration of 13 mg/mL). Also, the *M. oleifera* extract did not show inhibitory or bactericidal activity.

Table 3 shows the IC_{50} of the aqueous extract of the leaves of the four plants. *A. occidentale* plant with the highest free radical trapping activity compared to the other three plants, as it reflects the lower IC_{50}, being even lower ($P<0.001$) than the positive control butylated hydroxytoluene (BHT). Furthermore, *P. guajava* did not show ($P>0.05$) statistical differences with *A. occidentale* and BHT. However, *M. oleifera* and *M. citrifolia* had the lowest results in antioxidant activity, as they require the highest concentration to inhibit the 1,1-diphenyl-2-picryl-hydrazyl (DPPH−) reaction.

Table 3
IC_{50} of the aqueous extract of the leaves of the four plants

Extracts	IC_{50} (mg/mL)
Anacardium occidentale	0.028 ± 0.0006^{a}
Psidium guajava	0.069 ± 0.0061^{ab}
Morinda citrifolia	6.269 ± 0.0665^{d}
Moringa oleifera	0.603 ± 0.0102^{c}
BHT	0.093 ± 0.0101^{b}
P-value	<0.001

IC_{50}: Extract concentration required to inhibit the DPPH− reaction by 50%. Data are mean ± SD (n = 3). Values followed by different letters within a column are significantly different ($P<0.05$) according to the Duncan. BHT used as a positive control.

The phytochemical compounds identified in the four plants and compared with those reported in the literature are shown in Table 4, where the information on antibacterial and antioxidant activity was compared based on the scientific literature.

Table 4
Phytochemical compounds identified in the plants

Phytochemical subclass	Name	AO	PG	MC	MO	Properties		References
						Antibacterial	Antioxidant	
Flavonoids								
Anthocyanins	Cyanidin 3-O-xylosyl-rutinoside	X	X	X	X		X	(Diaconeasa et al. 2020)
Anthocyanins	Cyanidin 3-O-(6"-acetyl-galactoside)	X	X				X	(Diaconeasa et al. 2020)
Anthocyanins	Cyanidin 3-O-(6"-acetyl-glucoside)	X	X				X	(Einbond et al. 2004)
Anthocyanins	Petunidin 3-O-rhamnoside	X	X				X	(Diaconeasa et al. 2020)
Anthocyanins	Delphinidin 3-O-galactoside	X	X	X			X	(Einbond et al. 2004)
Anthocyanins	Delphinidin 3-O-glucoside	X	X	X			X	(Einbond et al. 2004)
Anthocyanins	Pelargonidin 3-O-galactoside	X	X				X	(Martínez et al. 2020)
Anthocyanins	Pelargonidin 3-O-glucoside	X	X				X	(Martínez et al. 2020)
Anthocyanins	Delphinidin 3-O-sambubioside		X				X	(Einbond et al. 2004)
Anthocyanins	Malvidin 3-O-glucoside		X		X		X	(Diaconeasa et al. 2020)
Anthocyanins	Peonidin 3-O-(6"-p-coumaroyl-glucoside)			X			X	(Salehi et al. 2019)
Anthocyanins	Peonidin 3-O-rutinoside			X			X	(Salehi et al. 2019)
Dihydrochalcones	Phloretin				X		X	(Zamroziewicz and Barbey, 2016)
Dihydroflavonols	Dihydroquercetin 3-O-rhamnoside	X	X				X	(Hajimahmoodi et al. 2014)
Flavanones	Eriodictyol 7-O-glucoside	X	X	X			X	(Chotphruethipong et al. 2019)
Flavanones	Eriocitrin		X				X	(Hajimahmoodi et al. 2014)
Flavanones	Pinocembrin			X	X	X	X	(Sangweni et al. 2020)
Flavanones	Didymin				X	X	X	(Samarakoon et al. 2012)
Flavanones	Poncirin				X		X	(Bannour et al. 2017)
Flavones	Diosmin	X	X	X			X	(Hajimahmoodi et al. 2014)
Flavones	Apigenin 6-C-glucoside	X	X	X	X		X	(Martínez et al. 2020)
Flavones	6-Hydroxyluteolin 7-O-rhamnoside	X	X				X	(Martínez et al. 2020)
Flavones	Luteolin 6-C-glucoside	X	X	X			X	(Martínez et al. 2020)
Flavones	Luteolin 7-O-glucoside	X	X	X			X	(Martínez et al. 2020)
Flavones	7,3',4'-Trihydroxyflavone		X			X	X	(Dsouza and Nanjaiah, 2018)
Flavones	Baicalein		X				X	(Liu et al. 2016)
Flavones	Nepetin			X		X	X	(Osman et al. 2014)

AO: *Anacardium occidentale*. PG: *Psidium guajava*. MC: *Morinda citrifolia*. MO: *Moringa oleifera*.

Phytochemical subclass	Name	AO	PG	MC	MO	Properties		References
						Antibacterial	Antioxidant	
Flavones	Cirsimaritin				X	X	X	(Ren et al. 2019)
Flavones	Apigenin 6,8-di-C-glucoside				X	X	X	(Călinoiu and Vodnar, 2020)
Flavones	Chrysoeriol 7-O-apiosyl-glucoside				X		X	(Bannour et al. 2017)
Flavones	Luteolin 7-O-rutinoside				X	X	X	(Pereira et al. 2016)
Flavones	Luteolin 7-O-malonyl-glucoside				X	X	X	(Pereira et al. 2016)
Flavonols	Quercetin 3-O-(6"-acetyl-galactoside) 7-O-rhamnoside	X	X		X	X	X	(Hajimahmoodi et al. 2014)
Flavonols	Methylgalangin	X	X			X	X	(Echeverría et al. 2017)
Flavonols	3-Methoxynobiletin	X	X	X		X	X	(Bannour et al. 2017)
Flavonols	Kaempferol 7-O-glucoside	X	X			X	X	(Salehi et al. 2019)
Flavonols	Quercetin 3-O-rhamnoside	X	X	X		X	X	(Hajimahmoodi et al. 2014)
Flavonols	Kaempferol 3-O-galactoside	X	X	X		X	X	(Almeida et al. 2019)
Flavonols	Kaempferol 3-O-glucoside	X	X			X	X	(Salehi et al. 2019)
Flavonols	Quercetin 3-O-arabinoside	X	X			X	X	(Hajimahmoodi et al. 2014)
Flavonols	Quercetin 3-O-xyloside	X	X			X	X	(Hajimahmoodi et al. 2014)
Flavonols	Myricetin 3-O-galactoside	X	X			X	X	(Marín et al. 2018)
Flavonols	Myricetin 3-O-glucoside	X	X			X	X	(Marín et al. 2018)
Flavonols	Myricetin 3-O-arabinoside	X	X			X	X	(Marín et al. 2018)
Flavonols	Quercetin 3-O-glucosyl-xyloside		X			X	X	(Hajimahmoodi et al. 2014)
Flavonols	3-Methoxysinensetin			X			X	(Biswas et al. 2019)
Flavonols	Isorhamnetin			X		X	X	(Gong et al. 2020)
Isoflavonoids	Biochanin A	X				X	X	(Rufatto et al. 2018)
Isoflavonoids	Glycitein	X					X	(Doughari, 2012)
Isoflavonoids	6"-O-Acetylgenistin	X	X				X	(Bannour et al. 2017)
Isoflavonoids	Genistin	X	X			X	X	(Devi et al. 2009)
Isoflavonoids	6"-O-Acetylglycitin		X				X	(Iqbal et al. 2018)
Isoflavonoids	Glycitin			X			X	(Iqbal et al. 2018)
Lignans								
Lignans	Sesamol		X			X	X	(Alshahrani et al. 2020)
Lignans	Dimethylmatairesinol			X		X	X	(Chiodelli et al. 2017)
Phenolic acids								
Hydroxycinnamic acids	Schottenol ferulate	X	X				X	(Biswas et al. 2019)
Hydroxycinnamic acids	Sitosterol ferulate	X	X				X	(Moussa et al. 2020)

AO: *Anacardium occidentale*. PG: *Psidium guajava*. MC: *Morinda citrifolia*. MO: *Moringa oleifera*.

Phytochemical subclass	Name	AO	PG	MC	MO	Properties		References
						Antibacterial	Antioxidant	
Hydroxycinnamic acids	Chicoric acid	X	X				X	(Zhu et al. 2018)
Hydroxybenzoic acids	Ellagic acid acetyl-arabinoside	X	X			X	X	(Arifuzzaman et al. 2018)
Hydroxybenzoic acids	Ellagic acid acetyl-xyloside	X	X			X	X	(Arifuzzaman et al. 2018)
Hydroxycinnamic acids	Sinapic acid	X	X	X	X	X	X	(Kim et al. 2017)
Hydroxycinnamic acids	Cinnamic acid	X	X	X	X	X	X	(Ruwizhi and Aderibigbe, 2020)
Hydroxycinnamic acids	Caffeic acid		X	X	X	X	X	(Liu et al. 2016)
Hydroxycinnamic acids	Hydroxycaffeic acid		X			X	X	(Amato et al. 2018)
Hydroxyphenylacetic acids	Homoveratric acid		X				X	(Rocchetti et al. 2019)
Hydroxybenzoic acids	2-Hydroxybenzoic acid		X			X	X	(Martínez et al. 2020)
Hydroxybenzoic acids	3-Hydroxybenzoic acid		X			X	X	(Martínez et al. 2020)
Hydroxybenzoic acids	4-Hydroxybenzoic acid		X			X	X	(Martínez et al. 2020)
Hydroxybenzoic acids	Ellagic acid		X			X	X	(Wong et al. 2012)
Hydroxybenzoic acids	Gallic acid		X			X	X	(Martínez et al. 2020)
Hydroxycinnamic acids	p-Coumaroyl malic acid			X	X	X	X	(Mouterde et al. 2020)
Hydroxycinnamic acids	Stigmastanol ferulate			X			X	(Odhiambo et al. 2018)
Hydroxyphenylacetic acids	Methoxyphenylacetic acid			X	X		X	(Bannour et al. 2017)
Hydroxyphenylpropanoic acids	Dihydro-p-coumaric acid			X	X	X	X	(Casadey et al. 2021)
Hydroxycinnamic acids	5-5'-Dehydrodiferulic acid			X			X	(Bannour et al. 2017)
Hydroxycinnamic acids	5-8'-Benzofuran dehydrodiferulic acid			X			X	(Bannour et al. 2017)
Hydroxycinnamic acids	5-8'-Dehydrodiferulic acid			X		X	X	(Bannour et al. 2017)
Hydroxycinnamic acids	8-O-4'-Dehydrodiferulic acid			X		X	X	(Bannour et al. 2017)
Hydroxycinnamic acids	Avenanthramide 2c			X	X	X	X	(Jágr et al. 2020)
Hydroxycinnamic acids	Avenanthramide K			X	X	X	X	(Jágr et al. 2020)
Hydroxybenzoic acids	Protocatechuic acid 4-O-glucoside			X		X	X	(Sánchez-Maldonado et al. 2011)
Hydroxybenzoic acids	Gallic acid 4-O-glucoside				X	X	X	(Martínez et al. 2020)
Hydroxybenzoic acids	Galloyl glucose				X	X	X	(Bouarab-Chibane et al. 2019)
Hydroxycinnamic acids	Cinnamoyl glucose				X	X	X	(Arifuzzaman et al. 2018)
Hydroxycinnamic acids	Sinapine				X	X	X	(Mouterde et al. 2020)
Triterpenoids								

AO: *Anacardium occidentale*. PG: *Psidium guajava*. MC: *Morinda citrifolia*. MO: *Moringa oleifera*.

Phytochemical subclass	Name	AO	PG	MC	MO	Properties		References
						Antibacterial	Antioxidant	
jacoumaric acid			X			X	X	(Egharevba et al. 2010)
isoneriucoumaric acid			X			X	X	(Ngbolua, 2018)
2α-hydroxyursolic acid			X			X	X	(Ngbolua, 2018)
Stilbenes								
Stilbenes	Pinosylvin		X			X	X	(Plumed-Ferrer et al. 2013)
Stilbenes	Resveratrol		X			X	X	(Florence et al. 2018)
Stilbenes	Pterostilbene			X	X	X	X	(Lee et al. 2017)
Other polyphenols								
Hydroxyphenylpropenes	Acetyl eugenol	X	X	X	X	X	X	(Shankar et al. 2018)
Alkylphenols	5-Tricosylresorcinol	X	X				X	(Kamal-Eldin et al. 2001)
Tyrosols	Oleuropein	X	X			X	X	(Amini et al. 2017)
Hydroxyphenylpropenes	Anethole	X	X	X	X	X	X	(Ponte et al. 2012)
Hydroxyphenylpropenes	Estragole	X	X	X	X	X	X	(Song et al. 2016)
Tyrosols	p-HPEA-AC		X	X	X		X	(Ma et al. 2019)
Furanocoumarins	Psoralen		X			X	X	(Li et al. 2018)
Alkylmethoxyphenols	4-Vinylguaiacol		X	X	X		X	(Ahmed et al. 2019)
Hydroxybenzoketones	3-Methoxyacetophenone		X	X	X	X	X	(Türkkan et al. 2017)
Phenolic terpenes	Carvacrol		X	X	X	X	X	(Du et al. 2015)
Phenolic terpenes	Thymol		X	X	X	X	X	(Shankar et al. 2018)
Other polyphenols	Pyrogallol		X	X	X	X	X	(Florence et al. 2018)
Tyrosols	3,4-DHPEA-AC		X				X	(Ma et al. 2019)
Alkylphenols	4-Ethylcatechol		X		X		X	(Sova and Saso, 2020)
Hydroxybenzaldehydes	Protocatechuic aldehyde		X			X	X	(Takos and Rook, 2013)
Tyrosols	Tyrosol		X	X		X	X	(Casadey et al. 2021)
Hydroxybenzoketones	2,3-Dihydroxy-1-guaiacylpropanone		X			X	X	(Zemek et al. 1987)
Tyrosols	Hydroxytyrosol 4-O-glucoside			X		X	X	(Amini et al. 2017)
Phenolic terpenes	Carnosic acid				X	X	X	(Park et al. 2019)
Alkylphenols	3-Methylcatechol				X	X	X	(Capasso et al. 1995)
Other polyphenols	Phlorin				X	X	X	(Miyake and Hiramitsu, 2011)

AO: *Anacardium occidentale*. PG: *Psidium guajava*. MC: *Morinda citrifolia*. MO: *Moringa oleifera*.

Is remarkable the presence of powerful antibacterial compounds (Table 4) such as quercetin 3-O-(6"-acetyl-galactoside) 7-O-rhamnoside, methylgalangin, 3-methoxynobiletin, kaempferol 7-O-glucoside, quercetin 3-O-rhamnoside, kaempferol 3-o-galactoside, kaempferol 3-O-glucoside, quercetin 3-O-arabinoside, quercetin 3-O-xyloside, quercetin 3-O-glucosyl-xyloside, myricetin 3-O-galactoside, myricetin 3-O-glucoside, and myricetin 3-O-arabinoside, where mainly present in *A. occidentale* and *P. guajava* leaves. This is consistent with the results obtained in the antimicrobial experiment shown in Table 1 and 2.

Also, the content of principal compounds from *A. occidentale* and *P. guajava* leaves are shown on Table 5, where it is observed the higher concentration of quercetin 3-O-glucoside-7-O-rhamnoside, kaempferol-7-O-glucoside, quercetin, caffeic acid and cinnamic acid from *A. occidentale* leaves compared to *P. guajava*.

Table 5
Quantification of majority compounds from leaves of *A. occidentale* and *P. guajava*

Compounds	*A. occidentale* (µg/g)	*P. guajava* (µg/g)
Quercetin 3-O-glucoside-7-O-rhamnoside	0.54	0.12
Chicorid acid	0.62	1.3
Kaempeferol-7-O-glucoside	1.95	<0
Quercetin	10.25	<0
Caffeic acid	0.22	<0
Cinnamic acid	0.25	0.07

Discussion

A. occidentale is known for its antibacterial properties, mainly in its flowers, bark and leaves (da Silva et al. 2016). In addition, it has been used in the prevention and treatment of oral diseases (being the first contact of the digestive system with the food) by inhibiting the bacteria in this cavity and therefore the formation of biofilm (Anand et al. 2015). Also, Melo Menezes et al. (2014) found that both crude extract and isolated tannins of *A. occidentale* have inhibitory activity against microorganisms that are part of the composition of oral biofilm. Therefore, they hypothesized that the mechanisms of the antimicrobial action of tannins, the enzymatic inhibition, the modification of cellular metabolism by its action on the membranes and binding with metal ions, decrease the access to metabolism to the microorganisms that are outside the biofilm. The present study results showed a potent antimicrobial and antioxidant activity, which is related to the high content of polyphenols and flavonoids contained in its leaves, in addition to other medicinal compounds.

Souza et al. (2017) observed the antioxidant and anti-inflammatory activity *in vitro* in *A. occidentale* leaves extract when used in RAW 264.7 macrophage cells due to the lower oxidative damage of these cells and the decrease in inflammatory parameters induced by LPS stimulation. Additionally, Brito et al. (2020), pointed out that pentagalloil hexoside, a precursor to the formation of hydrolyzed tannins such as ellagitannins and gallotanins, was found in all the organs of *A. occidentale*, these chemical compounds are responsible for several functional properties, with higher emphasis on the antimicrobial activity. Thus, the present study showed that *A. occidentale* was the plant with the highest antimicrobial and antioxidant capacity compared to the other three plants studied.

Regarding the effect of *A. occidentale* in animal production, specifically in poultry and pig production, Aroche-Ginarte et al. (2017) found that dietary supplementation with 1.0% of a mixed powder made from 40% of *A. occidentale* leaves powder increased growth performance and decreased the diarrhea incidence in weaned piglets. Furthermore, Más et al. (2016) showed that the dietary inclusion in low concentrations of *A. occidentale* and *P. guajava* leaves powder promoted growth and reduced dehydration in pigs before and after weaning. In this sense, Aroche et al. (2018) showed positive results in feed efficiency and IgG production when they added 0.5% of a mixture of plants representing 60% of *A. occidentale* in broiler diets.

P. guajava has also shown strong bactericidal activity on its leaves and aqueous extract, as it requires a small amount to eliminate bacteria such as *E. coli*, *S. aureus*, and *Salmonella*. Similarly, Salihu Abdallah et al. (2019) verified that the aqueous and methanolic extracts of *P. guajava* leaves have antimicrobial activity against *S. aureus* and *S. typhi*. The aqueous extract was effective with MIC of 12.5 mg/mL for both bacteria and MBC between 25 and 50 mg/mL for *S. aureus* and *S. typhi* respectively. In this study, the concentrations of aqueous extract were necessary to obtain the MIC and MBC against these bacteria, and were lower than those aforementioned, which may be due to the variety of the plant used, the origin, the extraction methods, among other factors. Also, Chero Nepo and Ruiz Barrueto (2016) determined that the alcoholic extract of *P. guajava* inhibits the growth of *Streptococcus mutans* due to its bactericidal power.

Regarding the antioxidant activity, Flores et al. (2015) identified the chemical composition of seven cultivars of *P. guajava* and founded a high content of flavonoids, in addition of anthocyanins, proanthocyanins, triterpenes and other compounds. Likewise, Feng et al. (2015) and Flores et al. (2015) showed that there is high correlation between flavonoid content and the antioxidant capacity of the plant, which agree with our findings, where *P. guajava* was the second plant to show a high antioxidant power.

On the other hand, *M. oleifera* is a multipurpose plant with multiple nutritional benefits, but also has been studied for its antimicrobial and antioxidant effects, since its use in human and animal nutrition is increasingly popular (Wang et al. 2018). Likewise, *M. citrifolia* has innumerable health benefits, however, when these two plants are compared with *A. occidentale* and *P. guajava*, they may be at a disadvantage due to the lower content of secondary metabolites responsible for the aforementioned activity. This research demonstrated the marked difference for antimicrobial and antioxidant effect of both the leaves and the aqueous extract of *A. occidentale* and *P. guajava* compared to *M. citrifolia* and *M. oleifera*.

However, in the case of *M. oleifera*, researchers such as Siddhuraju and Becker (2003), determined that this plant presents high antioxidant power in its ethanolic and methanolic extracts, which was related to abundant flavonoid content, especially quercetin and kaempferol. Shih et al. (2011) found high antioxidant activity in the ethanolic extract of various parts of this plant, where the leaves showed the highest activity, with an IC_{50} of 0.287 mg/mL, which is less than that found in this study (0.603 mg/mL). This difference could be due to the difference on the extraction (aqueous) method used this study. In

relation to animal production, authors such as Zhang et al. (2018) found positive effects of *M. oleifera* on performance of fattening pigs, with a marked effect due to increased activity of the enzyme superoxide dismutase and decreased serum malondialdehyde concretion.

M. citrifolia only inhibited the growth of staphylococcal strains, in both forms, as fine powder and as aqueous extract, however, did not show any antimicrobial effect with the other bacterial strains. These results agree with Almeida et al. (2019), whom reported several studies that probe the antimicrobial and antioxidant properties of *M. citrifolia* based on its chemical compounds in the plant parts. Also, antibacterial activity was found by Pandiselvi et al. (2019) and Sunder et al. (2012) specifically with *Staphylococcus aureus*. The difference in terms of the least antimicrobial effect in this study could be due to the use of methanolic extract. The antioxidant activity of the leaves of *M. citrifolia* was the lowest of among the four plants. Very little literature has been published about the antioxidant capacity of the leaves of this plant. Besides, there are several investigations that show this quality in its fruits (Senthilkumar et al. 2016; Sunder et al. 2016; Thorat et al. 2017). Sunder et al. (2016) demonstrated the multiple uses of *M. citrifolia* in livestock and poultry as a natural growth promoter due to its immunomodulatory, antioxidant, and hypocholesterolemic properties.

Polyphenols are the major secondary metabolites distributed in all plants, with higher emphasis on isoflavonoids, anthocyanins, flavonols, and flavones in *A. occidentale* and *P. guajava*. The quantification of the main secondary metabolites in these two plants (*A. occidentale* and *P. guajava*) such as quercetin 3-O-glucoside-7-O-rhamnoside, chicoric acid, kaempeferol-7-O-glucoside, caffeic acid, and cinnamic acid could support the antibacterial and antioxidant effects found in this study.

Theoretically, authors such as Sharaf et al. (2000) and Roepke and Bozzo (2013) have mentioned that 3-O-glucoside-7-O-rhamnoside is a rare secondary metabolite in plants with proven antioxidant and antimicrobial properties against *E. coli*. Furthermore, caffeic and chicoric acids have potential as antidiabetic agents (Tousch et al. 2008), already demonstrated by Kamtchouing et al. (1998) and Mukhtar et al. (2004) who found a reduction in glucose concentration in laboratory mice when they used extracts of *A. occidentale* and *P. guajava*, respectively. In addition, the flavonoid kaempferol-7-O-glucoside was identified and quantified in the leaves of *A. occidentale*, which is a phytochemical widely studied for its antimicrobial properties (Singh et al. 2011). Moreover, cinnamic acid is an organic acid that occurs naturally in many medicinal plants and quantified in both medicinal plants, it has low toxicity and a wide spectrum of functional activities, this secondary metabolite has antibacterial, antiviral and antifungal properties (Sova, 2012), which supports the effect antimicrobial found in the leaves of the plant in study (Tables 1 and 2). Although positive results have been found for the secondary metabolites quantified in the leaves of the plant under study (mainly *A. occidentale*), the results in farm animals are not conclusive. Thus, these results could contribute to understand how medicinal plants (mainly leaves of *A. occidentale* and *P. guajava* and their extracts), due to their antimicrobial and antioxidant function, can completely replace growth-promoting antibiotics in farm animals, as demonstrated by Martínez et al. (2013), Más et al. (2016), Aroche et al. (2017), Salazar et al. (2017) and Aroche et al. (2018) in poultry and pigs.

Conclusions

It is concluded that *A. occidentale* and *P. guajava* are the plants with the highest antimicrobial and antioxidant activity in their leaves and aqueous extract. *M. oleifera* has good antioxidant *in vitro* activity, although it does not have high antimicrobial power; and *M. citrifolia* is the plant that has the least antioxidant activity in its aqueous extract.

Declarations

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References

Ahmed AF, Shi M, Liu C, Kang W (2019) Comparative analysis of antioxidant activities of essential oils and extracts of fennel (*Foeniculum vulgare* Mill.) seeds from Egypt and China. Food Sci Hum Wellness 8:67–72. https://doi.org/10.1016/j.fshw.2019.03.004

Almeida ÉS, Oliveira D, Hotza D (2019) Properties and applications of *Morinda citrifolia* (Noni): A Review. Compr Rev Food Sci Food Saf 18:883–909. https://doi.org/10.1111/1541-4337.12456

Alshahrani S, Sreaya AA, Mashyakhi MY, Alqahtani S, Sivakumar SM, Alhazmi HA, Rehman Z, Alam F (2020) Chemical characterization and antibacterial efficacy of Saudi sesame oil against human pathogenic bacteria. Environ Conserv J 21:19–29. https://doi.org/10.36953/ECJ.2020.211203

Amato A, Migneco LM, Martinelli A, Pietrelli L, Piozzi A, Francolini I (2018) Antimicrobial activity of catechol functionalized-chitosan versus Staphylococcus epidermidis. Carbohydr Polym 179:273–281. https://doi.org/10.1016/j.carbpol.2017.09.073

Amini A, Liu M, Ahmad, Z (2017) Understanding the link between antimicrobial properties of dietary olive phenolics and bacterial ATP synthase. Int J Biol Macromol 101:153–164. https://doi.org/10.1016/j.ijbiomac.2017.03.087

Anand G, Ravinanthan M, Basaviah R, Shetty V (2015) *In vitro* antimicrobial and cytotoxic effects of *Anacardium occidentale* and *Mangifera indica* in oral care. J Pharm Bioallied Sci 7:69–74. https://doi.org/10.4103/0975-7406.148780

Arifuzzaman M, Islam MM, Rahman MM, Rahman MA, Kawsar SMA (2018) An efficient approach to the synthesis of thymidine derivatives containing various acyl groups: characterization and antibacterial activities. Acta Pharm Sci 56:7–22. https://doi.org/10.23893/1307-2080.APS.05622

Aroche Ginarte R, Martínez Aguilar Y, Ayala González L, Rodríguez Bertot R, Rodríguez Fraga Y (2017) Growth performance and diarrhea incidence in postweaning pigs, supplemented with plants mixed leaves powder, with nutraceutical properties. Rev Cien Agri 14:19–26. https://doi.org/10.19053/01228420.v14.n2.2017.7145

Aroche R, Martínez Y, Ruan Z, Guan G, Waititu S, Nyachoti CM, Más D, Lan S (2018) Dietary inclusion of a mixed powder of medicinal plant leaves enhances the feed efficiency and immune function in broiler chickens. J Chem 2018:1–6. https://doi.org/10.1155/2018/4073068

Bannour M, Fellah B, Rocchetti G, Ashi-Smiti S, Lachenmeier DW, Lucini L, Khadhri A (2017) Phenolic profiling and antioxidant capacity of Calligonum azel Maire, a Tunisian desert plant. Food Res Int 101:148–154. https://doi.org/10.1016/j.foodres.2017.08.069

Biswas S, Talukdar P, Talapatra DSN (2019) Presence of phytochemicals in fruits and leaves of guava (*Psidium guajava* Linn.) for cancer prevention: A mini review. J Drug Deliv Ther 9:726–729. https://doi.org/10.22270/jddt.v9i4-s.3290

Bouarab-Chibane L, Forquet V, Lantéri P, Clément Y, Léonard-Akkari L, Oulahal N, Degraeve P, Bordes C (2019) Antibacterial properties of polyphenols: characterization and QSAR (Quantitative Structure–Activity Relationship) models. Front Microbiol 10:829. https://doi.org/10.3389/fmicb.2019.00829

Brito E, Mendes L, Garruti D, Zocolo G, Lima M (2020) Structure astringency relationship of anacardic acids from cashew apple (*Anacardium occidentale* L.). ChemRxiv https://doi.org/doi.org/10.26434/chemrxiv.12336704.v1

Călinoiu LF, Vodnar DC (2020) Thermal processing for the release of phenolic compounds from wheat and oat bran. Biomolecules 10:21. https://doi.org/10.3390/biom10010021

Cañete Sera N, Martínez Aguilar Y, Escalona Rosabal A, Más Toro D (2017) Antidiarrheal effects of *Anacardium occidentale* L. leaf powder on newborn birds. Rev Prod Anim 29:47–54. https://www.researchgate.net/publication/321302749

Capasso R, Evidente A, Schivo L, Orru G, Marcialis MA, Cristinzio G (1995) Antibacterial polyphenols from olive oil mill waste waters. J Appl Bacteriol 79:393–398. https://doi.org/10.1111/j.1365-2672.1995.tb03153.x

Casadey R, Challier C, Altamirano M, Spesia MB, Criado S (2021) Antioxidant and antimicrobial properties of tyrosol and derivative-compounds in the presence of vitamin B2. Assays of synergistic antioxidant effect with commercial food additives. Food Chem 335:127576. https://doi.org/10.1016/j.foodchem.2020.127576

Ceballos-Francisco D, Castillo Y, De La Rosa F, Vásquez W, Reyes-Santiago R, Cuello A, Cuesta A, Esteban MÁ (2020) Bactericidal effect on skin mucosa of dietary guava (*Psidium guajava* L.) leaves in hybrid tilapia (*Oreochromis niloticus* × *O. mossambicus*). J Ethnopharmacol 259:112838. https://doi.org/10.1016/j.jep.2020.112838

Chero Nepo DA, Ruiz Barrueto MÁ (2016) Antibacterial effect *in vitro* of the alcoholic extract of *Psidium guajava* (guayaba) and *Medicago sativa* (alfalfa) on *Streptococcus mutans* ATCC 25175. Rev de Salud & Vida Sipanense 3:6–12.

Chiodelli G, Pellizzoni M, Ruzickova G, Lucini L (2017) Effect of different aloe fractions on the growth of lactic acid bacteria. J Food Sci 82:219–224. https://doi.org/10.1111/1750-3841.13568

Chotphruethipong L, Benjakul S, Kijroongrojana K (2019) Ultrasound assisted extraction of antioxidative phenolics from cashew (*Anacardium occidentale* L.) leaves. J Food Sci Technol 56:1785–1792. https://doi.org/10.1007/s13197-019-03617-9

da Silva RA, Liberio SA, do Amaral FM, Fernandes do Nascimento FR, Brandão Torres LM, Monteiro Neto V, Meireles Guerra RN (2016) Antimicrobial and antioxidant activity of *Anacardium occidentale* L. flowers in comparison to bark and leaves extracts. JBM 4:87–99. http://dx.doi.org/10.4236/jbm.2016.44012

Devi MKA, Gondi M, Sakthivelu G, Giridhar P, Rajasekaran T, Ravishankar GA (2009) Functional attributes of soybean seeds and products, with reference to isoflavone content and antioxidant activity. Food Chem 114:771–776. https://doi.org/10.1016/j.foodchem.2008.10.011

Dhakad AK, Ikram M, Sharma S, Khan S, Pandey VV, Singh A (2019) Biological, nutritional, and therapeutic significance of *Moringa oleifera* Lam. Phytother Res 33:2870–2903. https://doi.org/10.1002/ptr.6475

Diaconeasa Z, Stirbu I, Xiao J, Leopold N, Ayvaz Z, Danciu C, Ayvaz H, Stanila A, Nistor M, Socaciu C (2020) Anthocyanins, vibrant color pigments, and their role in skin cancer prevention. Biomedicines 8:336. https://doi.org/10.3390/biomedicines8090336

Doughari JH (2012) Phytochemicals: Extraction methods, basic structures and mode of action as potential chemotherapeutic agents. In V. Rao (Ed.), Phytochemicals—A Global Perspective of Their Role in Nutrition and Health. InTech. https://doi.org/10.5772/26052

Dsouza D, Nanjaiah L (2018) Antibacterial activity of 3,3',*4*'-Trihydroxyflavone from *Justicia wynaadensis* against diabetic wound and urinary tract infection. Braz J Microbiol 49:152–161. https://doi.org/10.1016/j.bjm.2017.05.002

Du E, Gan L, Li Z, Wang W, Liu D, Guo Y (2015) *In vitro* antibacterial activity of thymol and carvacrol and their effects on broiler chickens challenged with *Clostridium perfringens*. J Anim Sci Biotechnol 6:58–69. https://doi.org/10.1186/s40104-015-0055-7

Echeverría J, Opazo J, Mendoza L, Urzúa A, Wilkens M (2017) Structure-activity and lipophilicity relationships of selected antibacterial natural flavones and flavanones of Chilean flora. Molecules 22:608. https://doi.org/10.3390/molecules22040608

Egharevba HO, Iliya I, Ibekwe N, Abdullahi MS, Okwute SK, Okogun JI (2010) Broad spectrum antimicrobial activity of *Psidium guajava* Linn. leaf. Nat Sci 8:43–50.

Einbond LS, Reynertson KA, Luo XD, Basile MJ, Kennelly EJ (2004) Anthocyanin antioxidants from edible fruits. Food Chem 84:23–28. https://doi.org/10.1016/S0308-8146(03)00162-6

Fang F, Li J, Pan Q, Huang W (2007) Determination of red wine flavonoids by HPLC and effect of aging. Food Chem 101:428–433. https://doi.org/10.1016/j.foodchem.2005.12.036

Feng X, Wang Z, Meng DL, Li X (2015) Cytotoxic and antioxidant constituents from the leaves of *Psidium guajava*. Bioorg Med Chem Lett 25:2193–2198. http://dx.doi.org/10.1016/j.bmcl.2015.03.058

Florence I, Hery S, Akhmad D (2018) Antibacterial and antioxidant activities of pyrogallol and synthetic pyrogallol dimer. Res J Chem Environ 22:39–47.

Flores G, Wu SB, Negrin A, Kennelly EJ (2015) Chemical composition and antioxidant activity of seven cultivars of guava (*Psidium guajava*) fruits. Food Chem 170:327–335.

Gong G, Guan Y, Zhang ZL, Rahman K, Wang SJ, Zhou S, Luan X, Zhang H (2020) Isorhamnetin: A review of pharmacological effects. Biomed Pharmacother 128:110301. https://doi.org/10.1016/j.biopha.2020.110301

Gupta R, Malik P, Das N, Singh M (2019) Antioxidant and physicochemical study of *Psidium guajava* prepared zinc oxide nanoparticles. J Mol Liq 275:749–767. https://doi.org/10.1016/j.molliq.2018.11.085

Hajimahmoodi M, Moghaddam G, Mousavi S, Sadeghi N, Oveisi M, Jannat B (2014) Total antioxidant activity, and hesperidin, diosmin, eriocitrin and quercetin contents of various lemon juices. Trop J Pharm Res 13:951. https://doi.org/10.4314/tjpr.v13i6.18

Iqbal N, Zhang Q, Wu H, Yang C, Deng J, Qin W, Zhang J, Yang W, Liu J (2018) Soybean (*Glycine Max* L.) Germplasm screening and geographical determination based on targeted isoflavone metabolomics. Appl Ecol Environ Res 16:3933–3953. https://doi.org/10.15666/aeer/1604_39333953

Jágr M, Dvořáček V, Čepková PH, Doležalová J (2020) Comprehensive analysis of oat avenanthramides using hybrid quadrupole-orbitrap mass spectrometry: Possible detection of new compounds. Rapid Commun Mass Spectrom 34:e8718. https://doi.org/10.1002/rcm.8718

Kamal-Eldin A, Pouru A, Eliasson C, Åman P (2001) Alkylresorcinols as antioxidants: Hydrogen donation and peroxyl radical-scavenging effects. J Sci Food Agric 81:353–356. https://doi.org/10.1002/1097-0010(200102)81:3<353::AID-JSFA826>3.0.CO;2-X

Kamtchouing P, Sokeng S, Moundipa P, Watcho P, Jatsa H, Lontsi D (1998) Protective role of *Anacardium occidentale* extract against streptozotocin-induced diabetes in rats. J Ethnopharmacol 62:95–99. https://doi.org/10.1016/S0378-8741(97)00159-1

Karásková K, Suchý P, Straková E (2015) Current use of phytogenic feed additives in animal nutrition: A review. Czech J Anim Sci 60:521–530. https://doi.org/10.17221/8594-CJAS

Khatib SK, Bullón J, Vivas J, Bahsas A, Rosales-Oballos Y, Marquez R, Forgiarini A, Salager JL (2020) Synthesis, characterization, evaluation of interfacial properties and antibacterial activities of dicarboxylate anacardic acid derivatives from cashew nutshell liquid of *Anacardium occidentale* L. J Surfact Deterg 23:503–512. https://doi.org/10.1002/jsde.12384

Kim JH, Yu D, Eom SH, Kim SH, Oh J, Jung WK, Kim YM (2017) Synergistic antibacterial effects of chitosan-caffeic acid conjugate against antibiotic-resistant acne-related bacteria. Mar Drugs 15:167. https://doi.org/10.3390/md15060167

Lee WX, Basri DF, Ghazali AR (2017) Bactericidal effect of pterostilbene alone and in combination with gentamicin against human pathogenic bacteria. Molecules 22:463. https://doi.org/10.3390/molecules22030463

Li X, Yu C, Hu Y, Xia X, Liao Y, Zhang J, Chen H, Lu W, Zhou W, Song Z (2018) New application of psoralen and angelicin on periodontitis with anti-bacterial, anti-inflammatory, and osteogenesis effects. Front Cell Infect Microbiol 8:178. https://doi.org/10.3389/fcimb.2018.00178

Liu WC, Pi SH, Kim IH (2016) Effects of *Scutellaria baicalensis* and *Lonicera japonica* extract mixture supplementation on growth performance, nutrient digestibility, blood profiles and meat quality in finishing pigs. Ital J Anim Sci 15:446–452. https://doi.org/10.1080/1828051X.2016.1202736

Ma C, Dunshea FR, Suleria HAR (2019) LC-ESI-QTOF/MS characterization of phenolic compounds in palm fruits (jelly and fishtail palm) and their potential antioxidant activities. Antioxidants 8:483. https://doi.org/10.3390/antiox8100483

Mahfuz S, Piao XS (2019) Application of moringa (*Moringa oleifera* L) as natural feed supplement in poultry diets. Animals 9:431. https://doi.org/10.3390/ani9070431

Marín L, Gutiérrez I, Entrialgo-Cadierno R, Villar CJ, Lombó F (2018) De novo biosynthesis of myricetin, kaempferol and quercetin in *Streptomyces albus* and *Streptomyces coelicolor*. PLOS ONE 13(11):e0207278. https://doi.org/10.1371/journal.pone.0207278

Martínez Y, Martínez O, Liu G, Ren W, Rodríguez R, Fonseca Y, Olmo C, Isert M, Aroche R, Valdivié M, Nyachoti CM (2013) Effect of dietary supplementation with *Anacardium occidentale* on growth performance and immune and visceral organ weights in replacement laying pullets. J Food Agric Environ 13:1352–1357. www.world-food.net

Martínez Y, Martínez O, Olmos E, Siza S, Betancur C (2012) Nutraceutical effect of *Anacardium occidentale* (AO) in diets of replacement laying pullets. Rev MVZ Cordoba 17:3125–3132.

Martínez Y, Más D, Betancur C, Gebeyew K, Adebowale T, Hussaine T, Lan W, Ding X (2020) Role of the phytochemical compounds like modulators in gut microbiota and oxidative stress. Curr Pharm Des 26:1–15. https://doi.org/10.2174/1381612826666200515132218

Más D, Martínez Y, Rodríguez R, Betancur C, Rosabal O (2015) Effect of dietary supplementation with *Morinda citrifolia* on productivity and egg quality of laying hens. Rev Cien Agri 12:7–12.

Más D, Martínez Y, Rodríguez R, Salazar I, Aroche R, López B, Marcella D (2016) Effect of the dietetic supplementation with powder of leaves of guava (*Psidium guajava*) and cashew (*Anacardium occidentale*) on the productive performance and the diarrhea incidence in pigs before and after weaning. RCPP 23:106–113. https://www.researchgate.net/publication/313821208_Efecto_de_la_suplementacion_dietetica_de_polvos_de_hojas_de_Psidium_guajava_y_Anacardium_destete#fullTextFileContent

Melo Menezes K, Vieira Pereira J, de Medeiros Nóbrega DR, Ramos de Freitas AF, Vieira Pereira MS, Vieira Pereira A (2014) Antimicrobial and anti-adherent *in vitro* activity of tannins isolated from *Anacardium occidentale* Linn. (Cashew) on dental biolfilm bacteria. Pesqui Bras Odontopediatria Clin Integr 14:191–198. http://dx.doi.org/10.4034/PBOCI.2014.143.03

Miyake Y, Hiramitsu M (2011) Isolation and extraction of antimicrobial substances against oral bacteria from lemon peel. J Food Sci Technol 48:635–639. https://doi.org/10.1007/s13197-011-0330-3

Moussa AY, Sobhy HA, Eldahshan OA, Singab ANB (2020) Caspicaiene: A new kaurene diterpene with anti-tubercular activity from an Aspergillus endophytic isolate in *Gleditsia caspia* Desf. Nat Prod Res 1–12. https://doi.org/10.1080/14786419.2020.1824222

Mouterde LMM, Peru AAM, Mention MM, Brunissen F, Allais F (2020) Sustainable straightforward synthesis and evaluation of the antioxidant and antimicrobial activity of sinapine and analogues. J Agric Food Chem. https://doi.org/10.1021/acs.jafc.0c02183

Mukhtar H, Ansari S, Ali M, Naved T, Bhat Z (2004) Effect of water extract of *Psidium guajava* leaves on alloxan-induced diabetic rats. Pharmazie 59(9):734–735.

Ngbolua JPKN, Lufuluabo LG, Moke LE, Bongo GN, Liyongo CI, Ashande CM, Sapo BS, Zoawe BG, Mpiana PT (2018) A review on the phytochemistry and pharmacology of *Psidium guajava* L. (*Myrtaceae*) and future direction. Disc Phytomed 5:7–13. https://doi.org/10.15562/phytomedicine.2018.58

Odhiambo RS, Kareru PG, Mwangi EK, Onyango DW (2018) Antioxidant activity, total phenols, flavonoids and LCMS profile of *Chamaecrista hildebrandtii* (Vatke) lock and *Clerodendrum rotundifolium* (Oliv.). European J Med Plants 26:1–11. https://doi.org/10.9734/ejmp/2018/v26i330093

Osman W, Mothana R, Basudan O, Salih M, Sudan M (2014) Antibacterial effect and radical scavenging activity of hispidulin and nepetin; two flavones from *Tarconanthus camphoratus* L. World J Pharm Res 4:424–433. https://www.researchgate.net/publication/270189223

Pandiselvi P, Manohar M, Thaila M, Sudha A (2019) Pharmacological activity of *Morinda citrifolia* L (Noni). In Pharmacological benefits of natural products (First edition, pp. 213–237). JPS Scientific Publications.

Park J, Rho S, Kim Y (2019) Enhancing antioxidant and antimicrobial activity of carnosic acid in rosemary (*Rosmarinus officinalis* L.) extract by complexation with cyclic glucans. Food Chem 299:125119. https://doi.org/10.1016/j.foodchem.2019.125119

Pereira C, Barros L, Alves MJ, Santos-Buelga C, Ferreira ICFR (2016) Artichoke and milk thistle pills and syrups as sources of phenolic compounds with antimicrobial activity. Food Funct 7:3083–3090. https://doi.org/10.1039/C6FO00512H

Plumed-Ferrer C, Väkeväinen K, Komulainen H, Rautiainen M, Smeds A, Raitanen JE, Eklund P, Willför S, Alakomi HL, Saarela M, von Wright A (2013) The antimicrobial effects of wood-associated polyphenols on food pathogens and spoilage organisms. Int J Food Microbiol 164:99–107. https://doi.org/10.1016/j.ijfoodmicro.2013.04.001

Ponte EL, Sousa PL, Rocha MVAP, Soares PMG, Coelho AN, Leal-Cardoso JH, Assreuy AMS (2012) Comparative study of the anti-edematogenic effects of anethole and estragole. Pharmacol Rep 64:984–990. https://doi.org/10.1016/S1734-1140(12)70895-2

Ramírez MI, Dranguet D, Morales JA (2020) Anti-inflammatory activity of medicinal plants. Rev Granmense Desarro Local 16:320–332. https://revistas.udg.co.cu/index.php/redel/article/view/1450

Ren X, Bao Y, Zhu Y, Liu S, Peng Z, Zhang Y, Zhou G (2019) Isorhamnetin, hispidulin, and cirsimaritin identified in *Tamarix ramosissima* barks from Southern Xinjiang and their antioxidant and antimicrobial activities. Molecules 24:390. https://doi.org/10.3390/molecules24030390

Rocchetti G, Senizza B, Putnik P, Kovačević DB, Barba FJ, Trevisan M, Lucini L (2019) Untargeted screening of the bound / free phenolic composition in tomato cultivars for industrial transformation. J Sci Food Agric 99:6173–6181. https://doi.org/10.1002/jsfa.9889

Roepke J, Bozzo G (2013) Biocatalytic synthesis of quercetin 3-O-Glucoside-7-O-rhamnoside by metabolic engineering of *Escherichia coli*. Chembiochem 14:2418–2422. https://doi.org/10.1002/cbic.201300474

Rufatto LC, Luchtenberg P, Garcia C, Thomassigny C, Bouttier S, Henriques JAP, Roesch-Ely M, Dumas F, Moura S (2018) Brazilian red propolis: Chemical composition and antibacterial activity determined using bioguided fractionation. Microbiol Res 214:74–82. https://doi.org/10.1016/j.micres.2018.05.003

Ruwizhi N, Aderibigbe BA (2020) Cinnamic acid derivatives and their biological efficacy. Int J Mol Sci 21:5712. https://doi.org/10.3390/ijms21165712

Salazar Bell I, Martínez Aguilar Y, Rodríguez Bertot R, Olmo González C, Aroche Ginarte R, Pupo Torres G, Rosabal Nava O, Más Toro D (2017) Effects of supplementation with powder from various medicinal plants on production and quality of eggs of laying hens. Rev Prod Anim 29:1–5.

Salehi B, Gültekin-Özgüven M, Kırkın C, Özçelik B, Morais-Braga MFB, Carneiro JNP, Bezerra CF, Silva TG, Coutinho HDM, Amina B, Armstrong L, Selamoglu Z, Sevindik M, Yousaf Z, Sharifi-Rad J, Muddathir AM, Devkota HP, Martorell M, Jugran AK, Martins N, Cho WC (2019) *Anacardium* plants: chemical, nutritional composition and biotechnological applications. Biomolecules 9:465. https://doi.org/10.3390/biom9090465

Salihu Abdallah M, Nas F, Ali M (2019) Antibacterial activity of *Psidium guajava* leaf and stem bark extracts against clinical isolates of *Staphylococcus aureus* and *Salmonella typhi*. International Journal of Research in Pharmacy and Biosciences 6:11–17. https://www.researchgate.net/publication/333669708

Samarakoon K, Senevirathne M, Lee W, Kim Y, Kim J, Oh M, Jeon Y (2012) Antibacterial effect of citrus press-cakes dried by high speed and far-infrared radiation drying methods. Nutr Res Pract 6:187. https://doi.org/10.4162/nrp.2012.6.3.187

Sánchez-Maldonado AF, Schieber A, Gänzle MG (2011) Structure–function relationships of the antibacterial activity of phenolic acids and their metabolism by lactic acid bacteria. J Appl Microbiol 111:1176–1184. https://doi.org/10.1111/j.1365-2672.2011.05141.x

Sangweni NF, Moremane M, Riedel S, van Vuuren D, Huisamen B, Mabasa L, Barry R, Johnson R (2020) The prophylactic effect of pinocembrin against doxorubicin-induced cardiotoxicity in an *in vitro* H9c2 cell model. Front Pharmacol 11:1172. https://doi.org/10.3389/fphar.2020.01172

Senthilkumar S, Deepa K, Suganya T, Janakarajan M, Muralidharan J, Vasanthakumar P (2016) Therapeutic properties of noni (*Morinda citrifolia*) and its products. Int J Sci Environ Technol 5:1496–1502. www.ijset.net

Shankar R, Jyoti, Dheer D, Singh D, Kumar G, Karnatak M, Prakash Verma V (2018) Thymol chemistry: A medicinal toolbox. Curr Bioact Compd 14. https://doi.org/10.2174/1573407214666180503120222

Sharaf M, El-Ansari MA, Saleh NAM (2000) Quercetin triglycoside from *Capparis spinosa*. Fitoterapia 71:46–49. https://doi.org/10.1016/S0367-326X(99)00116-1

Shen Q, Zhang B, Xu R, Wang Y, Ding X, Li P (2010) Antioxidant activity *in vitro* of selenium-contained protein from the Se-enriched *Bifodobacterium animalis* 01. Anaerobe 16:380–386. https://doi.org/10.1016/j.anaerobe.2010.06.006

Shih M, Chang C, Kang S, Tsai M (2011) Effect of different parts (leaf, stem, and stalk) and seasons (summer and winter) on the chemical compositions and antioxidant activity of *Moringa oleifer*a. Int J Mol Sci 12:6077–6088. https://doi.org/10.3390/ijms12096077

Siddhuraju P, Becker K (2003) Antioxidant properties of various solvent extracts of total phenolic constituents from three different agroclimatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. J Agric Food Chem 51:2144–2155. https://doi.org/10.1021/jf020444+

Singh D, Sharma S, Rani R, Mishra S, Sharma RA (2011) Kaempferol-7-o-glucoside and their antimicrobial screening isolate from *Cassia renigera* wall. Int J Pharm Clin Res 3:30–34.

Siracusa R, Fusco R, Peritore AF, Cordaro M, D'Amico R, Genovese T, Gugliandolo E, Crupi R, Smeriglio A, Mandalari G, Cuzzocrea S, Di Paola R, Impellizzeri D (2020) The antioxidant and anti-inflammatory properties of *Anacardium occidentale* L. cashew nuts in a mouse model of colitis. Nutrients 12:834. https://doi.org/10.3390/nu12030834

Song Y, Choi M, Choi G, Park I, Oh C (2016) Antibacterial activity of cinnamaldehyde and estragole extracted from plant essential oils against *Pseudomonas syringae* pv. *actinidiae* causing bacterial canker disease in kiwifruit. Plant Pathol J 32:363–370. http://dx.doi.org/10.5423/PPJ.NT.01.2016.0006

Souza NC, de Oliveira JM, Morrone MS, Albanus RD, Amarante MSM, Camillo CS, Langassner SMZ, Gelain DP, Moreira JCF, Dalmolin RJS, Pasquali MAB (2017) Antioxidant and anti-inflammatory properties of *Anacardium occidentale* leaf extract. Evid Based Complement Alternat Med 2017:8. https://doi.org/10.1155/2017/2787308

Sova M, Saso L (2020) Natural sources, pharmacokinetics, biological activities and health benefits of hydroxycinnamic acids and their metabolites. Nutrients 12:2190. https://doi.org/10.3390/nu12082190

Sova M (2012) Antioxidant and antimicrobial activities of cinnamic acid derivatives. Mini Rev Med Chem 12:749–767. https://doi.org/10.2174/138955712801264792

Su B, Chen X (2020) Current status and potential of *Moringa oleifera* leaf as an alternative protein source for animal feeds. Front Vet Sci 7. https://doi.org/10.3389/fvets.2020.00053

Sunder J, Singh DR, Sakthivel J, Kundu A, Srivastava R (2012) Antimicrobial activity of *Morinda citrifolia* solvent extracts Indian Vet J 89:9–11.

Sunder J, Sujatha T, Kundu A (2016) Effect of *Morinda citrifolia* in growth, production and immunomodulatory properties in livestock and poultry: A review. J Exp Biol Agric Sci 4:249–265. https://doi.org/10.18006/2016.4(3S).249.265

Sunderam V, Thiyagarajan D, Lawrence AV, Mohammed SS, Selvaraj A (2019) *In-vitro* antimicrobial and anticancer properties of green synthesized gold nanoparticles using *Anacardium occidentale* leaves extract. Saudi J Biol Sci 26:455–459. https://doi.org/10.1016/j.sjbs.2018.12.001

Takos AM, Rook F (2013) Towards a molecular understanding of the biosynthesis of amaryllidaceae alkaloids in support of their expanding medical use. Int J Mol Sci 14:11713–11741. https://doi.org/10.3390/ijms140611713

Thorat B, Kambale A, Patil K (2017) Noni fruit crop is a versatile medicinal plant. J Med Plants Stud 5:247–249. www.PlantsJournal.com

Tousch D, Lajoix A, Hosy E, Azay-Milhau J, Ferrare K, Jahannault C, Cros G, Petit P (2008) Chicoric acid, a new compound able to enhance insulin release and glucose uptake. Biochem Biophys Res Commun 377:131–135. https://doi.org/10.1016/j.bbrc.2008.09.088

Türkkan E, Sayin U, Erbilen N, Pehlivanoglu S, Erdogan G, Tasdemir HU, Saf AO, Guler L, Akgemci EG (2017) Anticancer, antimicrobial, spectral, voltammetric and DFT studies with Cu(II) complexes of 2-hydroxy-5-methoxyacetophenone thiosemicarbazone and its N(4)- substituted derivatives. J Organomet Chem 831:23–35. https://doi.org/10.1016/j.jorganchem.2016.12.020

Valdivie M, Martínez Y, Mesa O, Botello León A, Hurtado C, Velázquez-Martí B (2020) Review of *Moringa oleifera* as forage meal (leaves plus stems) intended for the feeding of non-ruminant animals. Anim Feed Sci Technol 260:114338.

Wang P, Chen T, Sun J, Xu Q, Zhang Y (2018) Research progress in the application of *Moringa oleifera* in animal feed. Chin J Anim Nutr 30:2488–2495. https://doi.org/10.3969/j.issn.1006-267x.2018.07.008

Weli A, Al-Kaabi A, Al-Sabahi J, Said S, Hossain MA, Al-Riyami S (2019) Chemical composition and biological activities of the essential oils of *Psidium guajava* leaf. J King Saud Univ Sci 31:993–998. https://doi.org/10.1016/j.jksus.2018.07.021

Wong K, Hag Ali DM, Boey P (2012) Chemical constituents and antibacterial activity of *Melastoma malabathricum* L. Nat Prod Res 26:609–618. https://doi.org/10.1080/14786419.2010.538395

Zamroziewicz MK, Barbey AK (2016) Nutritional cognitive neuroscience: innovations for healthy brain aging. Front Neurosci 10:10. https://doi.org/10.3389/fnins.2016.00240

Zemek J, Valent M, Pódová M, Košíková B, Joniak D (1987) Antimicrobial properties of aromatic compounds of plant origin. Folia Microbiol 32:421–425. https://doi.org/10.1007/BF02887573

Zhang T, Zhang B, Si B, Zhang N, Tu Y, Zhou C, Diao Q (2018) Effects of Moringa leaf on growth performance, slaughter performance, antioxidant function and meat quality of finishing pigs. Chin J Anim Nutr 30:255–261. https://doi.org/10.3969/j.issn.1006-267x.2018.01.031

Zhu X, Huang F, Xiang X, Fan M, Chen T (2018) Evaluation of the potential of chicoric acid as a natural food antioxidant. Exp Ther Med 16:3651-3657. https://doi.org/10.3892/etm.2018.6596