biology and life sciences forum

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Short Proceeding paper

DEVELOPMENT OF POLYPHENOLICS EXTRACTS FROM MEXICAN CROPS AS NATURAL ANTIMICROBIAL AGENTS FOR POSTHARVEST TREATMENTS

Laura M. Aguilar-Veloz*, J. Arturo Olguín-Rojas, Diana Gómez-Flores, Cecilia Vázquez-González, Alfredo Salvador Castro-Díaz, Manuel González-Pérez, Montserrat Calderón-Santoyo and Juan Arturo Ragazzo-Sánchez

[1] Ingeniería en Procesos Bioalimentarios, Universidad Tecnológica de Tecamachalco. Avenida, Universidad Tecnológica 1, 75483 Tecamachalco, Puebla, México
[2] Laboratorio Integral de Investigación en Alimentos, Tecnológico Nacional de México/Instituto Tecnológico de Tepic, Av. Tecnológico #2595, Colonia Lagos del Country, Tepic C.P. 63175, Nayarit, México
* Correspondence: lauraguilarveloz@gmail.com

Abstract: Last decade, the use of natural antimicrobial agents, like polyphenolic extracts in postharvest applications has gained attention. However, a significant challenge lies ahead. Demonstrating commercial-scale production feasibility, practical applications, and economic viability compared to traditional agrochemicals is crucial. This review focuses on the achievements and obstacles in using polyphenolic extracts from Mexican crops as natural antimicrobial agents against postharvest phytopathogens and foodborne microorganisms. Comprehensive knowledge of the molecular mechanisms in vitro and in vivo, as well as plant systems, is essential for better results. Toxicity assessment and impact on fruit quality need evaluation. Incorporating coating and encapsulation techniques can enhance extract effectiveness. An integrated approach is needed for efficient, cost-effective control throughout the preharvest, harvest, and post-harvest phases. Successful commercialization depends on cost-benefit analysis, infrastructure, raw materials, local needs, and technical facilities, among other factors. Additionally, incorporating strategies related to circular economy can improve plant residue utilization and enhance technological and marketing approaches.

Keywords: polyphenolic extracts; natural antimicrobials; postharvest; Mexican crops

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

Mexico is a megadiverse country with a high potential of natural resources, occupying the fourth place in the world for its richness in plant species. However, high food losses, the intensive use of agrochemicals, agro-food waste dimension and the lack of infrastructure for their use and management, affect its agro-industrial development [1]. According to the circular economy principles, the valorization of agro-food waste has showed growing attention due to the possibilities to be a source of high biological active compounds (HBAC), with applications in food, pharmaceutical and cosmetic industries, among others. Furthermore, HBAC are environmental and human health friendly alternatives for pathogens control in different contexts. Particularly, the polyphenols (PPhs) are considered very attractive compounds because are responsible of the antioxidant and antimicrobial properties of some vegetable extracts [2–4]. Postharvest process is focused on food properties (nutritional, taste, aroma, and good appearance) and food safety. Them, the studies will be focused to phytopathogenic microorganisms and those foodborne bacteria, which threaten the health of consumers [5]. The present review aims to evidence the success and challenges of research on PPhs extracts from Mexican crops as NA, against phytopathogens and foodborne microorganisms on postharvest processes.

2. Mexican crops as potential sources of PPhs extracts

Among the main crops in Mexico, there are some traditional cultivars that serve as sources of PPhs extracts, which are known for their antimicrobial properties. The selection of the following crops (Table 1) was based on their native origin in Mexico (Habanero chili pepper, allspice, prickly pear), commercial importance (cinnamon), their impact on agricultural development in various Mexican states (broccoli and jackfruit), and the attention they have received from the Mexican and international scientific communities. In addition, a brief description of each crop is provided below:

Table 1. Antimicrobial effect of phenolic extracts of different origin on pathogenic microorganisms (in vitro).

Source	Extract / PPhs concentration	Pathogen	Concentration	Inhibition	Reference
		Foodborne microorganisms			
Prickly pear (Opuntia ficus indica (L.) Mill.) (Cladode)	Aqueous PPhs extract 700 mg GAE/100g	Salmonella typhi Helicobacter pylori Escherichia coli Staphylococcus aureus	3.40 mg/mL 1.37 mg/mL 1.41 mg/mL, 1.41 mg/mL	> 50%	[19].
Piper dioica L.merril	Aqueous eugenol extract*	Streptococccus mutans	0.1-1mg/mL	15.9 mm a 24 h 18.6 mm a 48 h	[24].
Clove (Eugenia caryophyllata Thunb.) Mexican oregano (Lippia berlandieri Schauer)	Alcoholic extracts of eugenol and carvacrol*	Listeria monocytogenes ATCC 19114 Echerichia coli ATCC 25922		> than non encapsulated extracts	[25]
Habanero chili pepper (Capsicum chinense)	Habanero Pepper Peel Ethanolic Extract	C. albicans—ATCC 90028 C. tropicalis—CI C. glabrata—ATCC2001 C. krusei—ATCC 6258	3000 µg/mL 750 µg/mL 3000 µg/mL 3000 µg/mL	100%	[26]
		Phytopatogens			
Jackfruit leaf (Artocarpus heterophyllus Lam)	Hydroalcoholic PPhs extract	Alternaria alternate	1 mg/mL**	40 %	[4]
Jack ruit leaf (Artocarpus heterophyllus Lam)	Hydroalcoholic PPhs extract	Colletotrichum gloesporioides	1-5 mg/mL**	40-60 %	[5]
Pepper (Piper Dioica L. merril)	Nanoencapsulated eugenol*	Colletotrichum gloesporioides	0.5 % (p/p) de nanoformulación con eugenol incorporado	100%	[27]
Cinnamon (Cinnamomum zeylanicum J.Presl)	Methanolic extract	Fusarium spp.	300 ppm	31.8-45.6 %	[28]
Xoconostle (Opuntia oligacantha C.F. Först)	Nanoencapsulated emulsion 409.37 mg GAE/Ml	Colletotrichum gloesporioides		> that non encapsulated extracts	[29]

*pure compound. **concentration of PPhs.

2.1. Alslpice (Piper Dioica L. Merril)

Allpice is native from Mexico and Central America and has been domesticated and naturalized in various tropical countries. In Mexico, it is ecologically distributed on the slope of the Gulf of Mexico, from the north of Puebla and Veracruz to the south of the Yucatan, relating some similar climatic and edaphic characteristics [16]. Its national production is channeled mainly to the international market. Allspice production in the country is located under two contexts: the traditional backyard agriculture, family and manual labor, as an alternative crop, with a lack of support and technology; and another most sophisticated international trade system [17]. According the authors, the fruit contains 1.89% ± 0.94 of essential oil. The eugenol content in the leaves and fruit, varies from 38.23 to 46.52%, with respect to its origin and location.

2.2. Broccoli (Brassica oleracea var. Italica)

Broccoli is an annual crop, which falls within the cruciferous family and the genus *Brassica oleracea*. In Mexico, Guanajuato accounts for over 67% of the national broccoli production, alongside other contributing states [6] Within broccoli, the presence of HBAC has been empirically substantiated to exert antimicrobial properties. These compounds encompass vitamin C, carotenoids, PPhs, glucosinolates, sulforaphane, and enzymes, such as peroxidases and lyases, among others. Diverse extraction techniques facilitate the isolation of these NA agents. For instance, ethyl acetate and chloroform ethyl acetate extracts have exhibited discernible activity against *Escherichia coli* and *Candida albican*s, respectively. Furthermore, aqueous extracts derived from lyophilized broccoli have demonstrated efficacy against *Bacillus cereus, Streptococcus faecalis, Staphylococcus aureus, Listeria monocytogenes, Salmonella typhimurium, Pseudomonas aeruginosa, E. coli, Shigella sonnei, and C. albicans* [7]. Notably, the presence of NA is not confined solely to the broccoli florets but extends to agro-industrial byproducts, such as stems and leaves. Specifically, aqueous extracts derived from broccoli stems, at a concentration ratio of 1:20 w/v, have demonstrated antimicrobial activity against *L. monocytogenes*, with a minimum inhibitory concentration (MIC) of 102.4 mg/mL [8].

2.3. Cinnamon (Cinnamomum Zeylanicum J.Presl)

The *Cinnamomum* genus includes *C. zeylanicum* and *C. cassia*, they are widely used spice worldwide and belongs to the *Lauraceae* family. In Mexico, cinnamon bark serves various purposes, with its prominent role as an aromatic ingredient in foods. Its application in ethnobotanical medicine due to its antimicrobial properties, as well as its antioxidant and antimutagenic capabilities [9]. *C. cassia* contains a higher cumarin concentration, up to 1% [10]. This characteristic is linked to the fact that isocoumarin, a secondary metabolite found in cinnamon, is hepatotoxic to humans. The European Food Safety Authority (EFSA) regulates the tolerable daily intake (TDI) of coumarin, setting limits between 0.1 mg to 2.0 mg/kg of body weight for general food products.

2.4. Habanero chili pepper (Capsicum chinense Jacq.)

Habanero chili pepper represents an integral part of Mexican cultural tradition and identity, having left its mark on Mexican cuisine for at least eight centuries [11]. Besides, it holds substantial economic importance, in 2019, global production reached approximately 42 million tons [1]. The increase in demand for habanero peppers and their products has led to a growth in waste generation (peduncles, stems, and leaves) [12]. Different researchers explored the HBAC profile of habanero chili pepper, Mokhtar *et al*. [13] evaluated the *in vitro* antimicrobial activity of pepper PPhs and capsaicinoids against thirteen pathogenic bacteria. The principal PPhs present are caffeic acid, quercetin, rutin, kaempferol, coumarin, and narangin. Vuerich *et al*. [14] analyzed the antifungal activity of the ethyl acetate extract against some of the major fungal and *Oomycetes pathogens* of grapevine, the total concentration of PPhs in the oleoresin accounted for 268.5±15.4 mg g^{-1} (dw), with vanillic acid (65%) being the predominant compound, followed by protocatechuic acid (13%), both of which are hydroxycinnamic derivatives. Habanero chili and its by-products present an interesting alternative as potential sources of PPhs extracts as natural antimicrobial agents for postharvest treatments.

2.5. Jackfruit (Artocarpus heterophyllus Lam.)

Jackfruit is exhibiting applications in traditional medicine, agriculture and industry in some geographical areas, and in Mexico its major economic impact has been in Nayarit state [15]. It is one of the most common evergreen trees found in the tropical regions, which must periodically be pruned to facilitate fruit harvest. A considerable volume of this biomass (about 10,500 tons/ha of leaf per year), its high phytochemical and protein content. Regarding the PPhs extracts recovery, some advantages of the emerging solid–liquid techniques such as high hydrostatic pressure, ultrasound-assisted extraction, and microwave-assisted extraction have been demonstrated by Mexican authors. Extracts containing mainly flavonoids, tannins, glycosides, phenolic and organic acids, with antimicrobial action against different foodborne and phytopathogenic microorganisms were tentatively identified [4,5].

2.6. Prickly pear (Opuntia ficus indica (L.) Mill.)

Opuntia is a diverse family that predominates in the arid and semi-arid regions of the Americas. About 1400–1800 cacti´s species have been described in the world, and Mexico is the country with the greatest diversity (850 species, 84% endemic) [18]. PPhs in different parts (fruit, cladode, and pulp) of prickly pear are known to contribute to its antioxidant and antimicrobial activities. The studies indicated that cladode possessed a higher quantity of phenolics compared with that observed in fruit and pulp. Gallic acid was the most abundant phenolic compound (66.19 μg/g) [19].

3. Antimicrobial properties vs. antioxidant effect of PPhs

The antioxidant capacity of these crops, depend on the variavility of PPhs and other phytochemicals concentration and composition, and mechanisms of action. High antioxidant capacities related with scavenging hydroxyl radical action mesure by ABTS and DPPH methods were exhibited [5]. The relationship between the antimicrobial action of PPhs and antioxidant capacity, it is barely analyzed during postharvest studies [4,5]. In fact, PPhs favor increase of permeability of cellular wall and membrane causing their disintegration, and delay of lipid peroxidation, and free radical scavenging [5]. Furthermore, antimicrobial action of PPhs is associated with the presence of a free hydroxyl group, bonded to a C6 aromatic ring as a system for electron delocalization. It provokes modification of the microbial membrane and has a key role in the inactivation of microbial enzymes. These changes disturb cellular respiration and may cause cell death [20]. At the same time, potassium ion leakage and reduction of H_2O_2 decomposition is observed, and highly reactive oxygen species, promote oxidative damage and act as proton exchangers. It causes collapse of proton motive force and eventually leads to cell death [21]. For instance, the antioxidant activity of in prickly pear and minimum inhibitory concentration (MIC) responses had a significant negative correlation with each other [19].

4. Challenges in research and use of NA in postharvest systems

NA technologies will present a major challenge in next decades, because some technical problems must be analized [22]. In fact, the standardization of the commercial NA depends of various factors such as: variety and cultivation conditions, climatic factors; plant maturity and agronomic practices, the part of the plant used, methods of extraction and conservation, and techniques of chemical characterization [23].

Meanwhile, some technical problems can be considered as opportunities to develop the industrial applications of NA in postharvest processes and commercialization [5,22,30–33] of methods for pathogen and metabolites identification, and the study about mechanisms of pathogens and NA compounds will promote the compound's registration and improve the use of these technologies. Furthermore, the *in vivo* practices, whether conducted under semi-controlled or real conditions, must consider the composition of the microbiota in fruits and vegetables. Additionally, research on the relationship between physiological changes in food products and genetic control will enhance the optimization of treatments. On the other hand, it is crucial to investigate the impact of nanotechnology on preservation strategies and safety [5,22,30–33]. In fact, micro and nanocapsules have been employed as effective components in coatings, edible films, and PPh formulations. Various methods, utilizing either natural biopolymers or synthetic polymeric materials, have been employed based on their specific use. They improve the physicochemical properties of the capsules or fibers to guarantee their technofunctional properties and applications [27,29,32,33]. For successful technological development, the selection of efficient emerging methods is needed. Furthermore, the implementation of multipurpose biorefineries is proposed, accompanied by the evaluation of their feasibility, according to the cost of materials, energy sustainability and environmental impact, considering the circular economy principles. The production of AN is a trigger for agro-food waste revaluation, so it is essential to identify and strengthen the research lines that enhance their study and applications, especially from endemic sources. Furthermore, support for primary producers in aspects of training and infrastructure must be ensured.

5. Conclusions

Mexican agroindustry has the challenge of technologically ensuring the management and use of large volumes of agro-food waste. This involves the development of agricultural programs at the local, regional and national level based on viable crops and the redesign of linkage strategies with other industries. The production of HBVC is a trigger for the revaluation of this biomase, so it is essential to identify and strengthen the investigations and applications, especially from endemic sources. Some technical problems can be considered as opportunities to develop the industrial applications of NA in postharvest processes and commercialization. Greater attention should be given to the development of nanotechnologies, due to its socioeconomic impact. Furthermore, the implementation of multipurpose biorefineries is proposed, accompanied by the evaluation of their feasibility, according to the cost of materials, energy sustainability and environmental impact, considering the circular economy principles.

Author Contributions: Conceptualization, L.M.A.V, J.A.O.R.; investigation, L.M.A.V., J.A.O.R., D.G.F., C.V.G., M.G.P, M.C.S, J.A.R.S data curation, L.M.A.V.; J.A.O.R. writing—original draft preparation, L.M.A.V.; writing—review and editing, L.M.A.V., J.A.O.R., J.A.R.S. visualization, L.M.A.V., J.A.O.R.; supervision, L.M.A.V.; J.A.O.R; project administration, L.M.A.V, J.A.O.R. ; funding acquisition, M.G.P, M.C.S, J.A.R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors express their gratitude to CONAHCYT and Technological University of Tecamachalco. To Ms. Paulina Aguirre-Lara for audiovisual material.

Conflicts of Interest: The authors declare no conflict of interest.

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