Looking inside Mexican Traditional Food as Sources of Synbiotics for Developing Novel Functional Products

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Review

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Abstract: Currently, emerging alimentary alternatives are growing, leading to the consumption of natural products including bio, fermented, and traditional foods. The studies over functional properties of food matrices and their derived compounds have resulted in the development of new functional alimentary items. However, most of the population still has limited access to, and information about, suitable foods. Analyzing traditional fermented products, we found fermented food matrices containing beneficial bacteria, with the possibility of exerting effects on different substrates enhancing the bioavailability of short-chain fatty acids (SFCAs), antioxidants, among other food-derived products. Maize (*Zea mays* L.), agave varieties, nopal (*Opuntia ficus-indica*), and beans (*Phaseolus vulgaris* L.) were key foods for the agricultural and nutritional development of Mesoamerica. We believe that the traditional Mexican diet has relevant ingredients with these functionalities and their association will allow us to develop functional food suitable for each population and their current needs. In this review, the functional properties of maize, agave, nopal, and frijol are detailed, and the functional food innovation and development opportunities for these food matrices are analyzed, which may be an important precedent for future basic and applied research.

Keywords: functional foods; probiotics; prebiotics; synbiotics

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1. Introduction

A breakthrough in functional food research has been made in the last decades. The identification and characterization of the fibers, antioxidants, vitamins, and microflora of these food matrices is the brick in the wall that will allow the understanding and developing of novel functional foods. In this context, there are two food components that stand out. In first place are the prebiotics, such as non-digestible fibers or other food-derived compounds (i.e., antioxidants), substrates selectively utilized by host microorganisms, which also confer a health benefit [1]. These substrates may stimulate the growth of beneficial microorganisms in several ways and promote some changes in the metabolites produced by these bacteria, namely, reduction in the colonic pH, changes in the stool mass, and improvements in intestinal and systemic health [2]. In second place are the probiotics, "microorganisms which, when administered at appropriate concentrations confer a positive effect to host health"; these health effects generally include the inhibition of harmful bacteria or the production of particular metabolites with other specific strain-dependent effects, and they have positive impacts on the host immune system [3]. The association of both probiotics and prebiotics leads to synbiotics. A panel of experts updated the definition of a synbiotic as "a mixture comprising live microorganisms and substrate(s) selectively utilized by host microorganisms that confers a health benefit on the host" [4].

The supplementation of non-fermentable carbohydrates, such as inulin and resistant starch (RS, mainly type R2), reduces the risk of chronic diseases, which can be partially attributed to the modulation of the intestinal microbiota via the prebiotic effect, with beneficial effects in vitro, in vivo, and in several clinical trials [5]. Short-chain fatty acids (SCFAs), particularly butyrate produced from the fermentation of complex carbohydrates as a part of its synbiotic activity, are essential nutrients for colonic epithelial cells and anti-inflammatory regulatory T lymphocytes [6,7]. Meanwhile, depletion of the gut SCFA-producing microbial species and/or their substrates can contribute to the disruption of the colonic epithelial barrier and subsequent inflammation [8] (Figure 1).

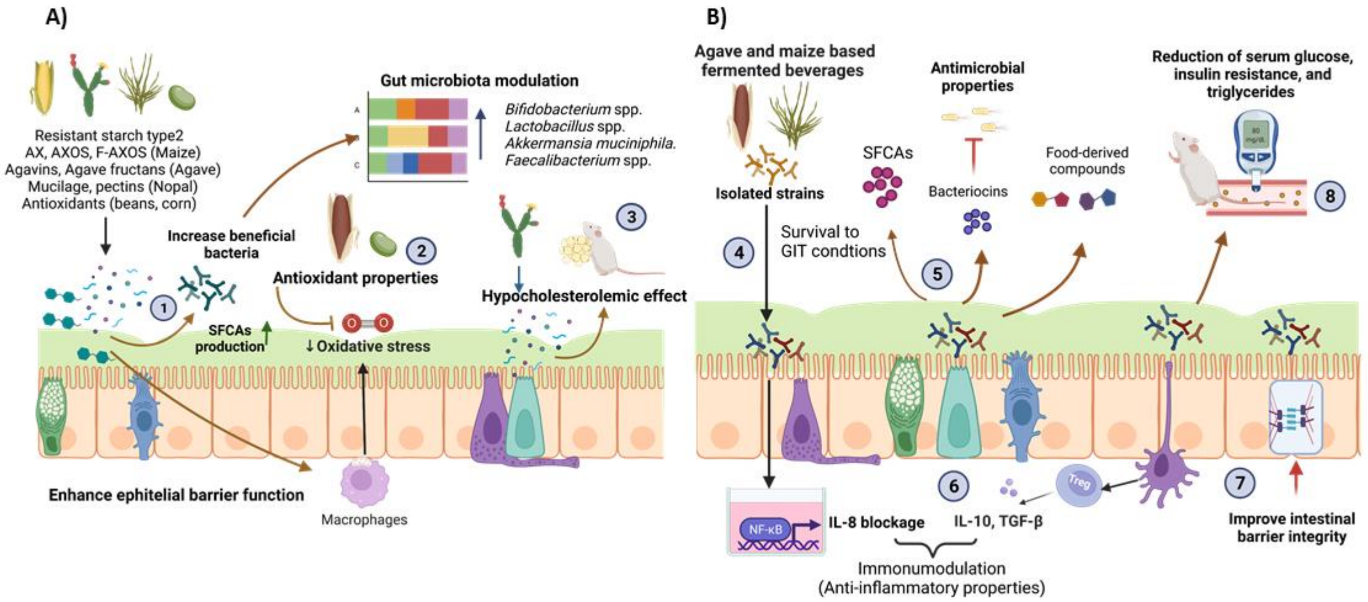

Figure 1. The general mechanisms by which Mexican traditional food can have a health effect are diverse and have been lately described: (**A**) Some of the components of Mexican traditional food, called prebiotics (non-digestible carbohydrates and antioxidants compounds) can exert positive effects on intestinal and systemic health: (1) enhancing the increase in numerous short-chain fatty acids (SCFAs) producing bacteria, butyrate, acetate, propionate, and gut microbiota modulation; (2) displaying antioxidant properties; and (3) improving metabolic syndrome markers such as a decrease in cholesterol. (**B**) The different fermented food containing a proportion of probiotic bacteria that are known to interact with the indigenous host microbiota also have health benefits. Isolated strains from maize and agave-based beverages are capable to survive gastrointestinal conditions, and (5) produce SCFAs and antimicrobial compounds against pathogen bacteria, (6) immune-modulate anti-inflammatory cytokines, (7) reinforce the colon barrier integrity, and (8) improve some metabolic syndrome markers. SCFAs: Short-chain fatty acids. RS: Resistant starch. AX: Arabinoxylans. XOS: Xylooligosaccharides. F-AXOS: Feruloylated arabinoxylan mono- and oligosaccharides. Created by BioRender.com (2022) (accessed on 6 March 2022).

The provision of healthy solutions for the population has not been accessible for everyone. This review proposes the identification and description of the properties of feasible alternatives in the traditional fermented or not, food matrices of regional Mexican food. Furthermore, promoting commerce via local markets and producing suitable ecological post-harvest methods that avoid the exploitation of the cultivation soils will be strategies to achieve successful food availability. Although several functional foods around the world are known to have important health effects [9–11], we decided to focus on Mexican food: corn (*Zea mays* L.), agave varieties, nopal (*Opuntia ficus-indica*), and beans (*Phaseolus vulgaris* L.) since their effects have not been summarized from this viewpoint and they have been crucial from the development of the ancient Mesoamerican civilization [12]. Important information from other countries that also produce and consume these four products are included in some sections, and this remarks on the importance of their high availability around the world.

To identify the information for its creation, the authors selected original research articles by using the keywords of the review in combination with the scientific name of the food (*Zea mays* L., *Agave* varieties, *Opuntia ficus-indica*, and *Phaseolus vulgaris* L.). Two important criteria for this selection were considered; that the information was up to date (2000–2022) and recovered from English language animal trials and in vitro studies.

The vast research findings in these food matrices have demonstrated functional and nutritional attributes due to their fiber-like type 2 RS, agavins [13]; fiber mucilage [14], water extractable polysaccharides [15], and antioxidants [16,17]. Furthermore, their microorganism content improves the shelf-life of the product, its sensorial characteristics, and probiotic properties [18,19]. The isolation, characterization and association of the prebiotics and probiotics from the food matrices has become a suitable alternative for the development of new products [19]. This review addresses the probiotic and prebiotic insights in corn, agave, nopal and beans, emphasizing the synbiotic capacities of each food and their opportunities for functional food development.

2. Maize

Corn (*Zea mays* L.) is an important source of carbohydrates, proteins, fiber, vitamins, and minerals such as calcium, magnesium, potassium, and sodium [20]; moreover, it is the main cereal produced worldwide followed by wheat and rice [21]. First domesticated in Mesoamerica, it is highly consumed in Mexico and on the American continent [22]. The anatomical corn kernel parts [23] and its tonalities, comprising bioactivities with compounds such as anthocyanins and flavonoids, make it a valuable food [22].

In Mexico, maize is traditionally consumed as tortilla, using an alkaline-thermic process called "nixtamalization" [24] that favors the release and absorption of bioactive compounds during the GIT passage [25]. However, some phytochemical bioactive compounds could be altered or degraded in this process [26]. Fermentation by lactic acid bacteria (LAB) improves the bioavailability of active compounds, which enhances its conservation and improves some sensorial attributes [27]. Chemical and thermal modifications of corn lead to the release and conformation of different polymer structures, such as type 2 resistant starch (RS2), arabinoxylans (AX), xylooligosaccharides (XOS), feruloylated arabinoxylan mono- and oligosaccharides (F-AXOS), high-amylose maize type 2 resistant starch (HAM-RS2), among other prebiotic fibers [28–30], which may provide several health benefits to the host.

2.1. Prebiotics in Maize

As prebiotic, corn-derived products have been tested in vitro, in vivo, and in clinical trials. Table 1 summarizes important information from these prebiotics. The by-products of nixtamalized corn may be a source of prebiotic compounds such as ferulated arabinoxylans [31], which can promote the growth of probiotic bacteria of the genus *Bifidobacterium* [32]. Moreover, XOS derived from corn cobs exhibits prebiotic properties and promotes the growth of *L. plantarum* S2, increasing the SCFAs and the anti-microbial effects of *L. plantarum* against *S. flexneri, E. coli, S. aureus*, and *S. typhimuriu*, maintaining the gut homeostasis [33].

Table 1. Prebiotics, probiotics and synbiotics in Maize.

	Prebiotic, Probiotic or Synbiotic	General Effect	Reference
Prebiotics	Arabinoxylans (AX)	Promote the growth of probiotic bacteria of the genus Bifidobacterium.	[31]
	Xylooligosaccharides (XOS)	Promote the growth of L. plantarum S2, increasing short-chain fatty acids (SCFA) and the anti-microbial effect of L. plantarum against *S. flexneri*, *E. coli*, *S. aureus*, and *S. typhimurium*.	[32]
	High-amylose maize type 2 resistant starch (HAM-RS2)	Reduction in the concentrations of blood urea nitrogen, IL-6, TNFα, and malondialdehyde, and increase in the relative abundance of Faecalibacterium genus.	[33]
	Dietary fibers K1 and K2	Increase in SCFA content and stimulate the growth of Bifidobacterium genus and Bacteroidetes and Actinobacteria phyla.	[29]
	Feruloylated arabinoxylan mono- and oligosaccharides (F-AXOS)	Selectively stimulate Bifidobacterium and Lactobacillus.	[30,34]
Probiotics	*Streptococcus genera*, *Weissella paramesenteroides*, *Lactococcus lactis* and *L. paramesenteroides*	Functional probiotic properties: resistance to low pH and bile salts conditions, ability to adhere to HEp2 cell line	[35]
	Pediococcus pentosaceus, *Weissella confusa*, *Weissella paramesenteroides*, *Lactiplantibacillus plantarum*, *Lactobacillus acidophilus*, *Levilactobacillus brevis*, *Lactobacillus coryniformis*, *Leuconostoc pseudomesenteroides* and *Lactococcus lactis*	Antimicrobial properties against Enterobacteriaceae, and yeasts	[36,37]
	Weissella cibaria and *Leuconostoc citreum*	Antagonistic activity towards foodborne pathogens, short-chain fatty acids production and adhesion to HT-29 cell line	[38,39]
Synbiotics	Hi-maize 958 or Hi-maize 260 resistant starch (RS), in combination with *Bifidobacterium lactis*	Modulation over the microbiota composition, re-inforced the innate immune system, and decreased blood lipids levels in hypercholesterolemic patients	[40]
	XOS and *Lacticaseibacillus paracasei* HII01	Reduction in gut inflammation and restoration of dybiosis in obese rats.	[41]
	Promitor™ Soluble Corn Fiber and *L. rhamnosus* LGG	Increase in NK cell activity and decreased serum total cholesterol and LDL cholesterol in patients with dyslipidemia, and also increases in Ruminococcaceae and Parabacteroides.	[42]

Supplementation with the prebiotic HAM-RS2 led to a significant serum reduction in the concentrations of blood urea nitrogen, IL-6, TNFα, and malondialdehyde. Moreover, the *Faecalibacterium* genus was significantly increased in relative abundance following HAM-RS2 supplementation in patients with chronic kidney disease (CKD), but not *Bifidobacteria*, *Prevotella*, *Parabacteroides*, or *Ruminococcus* [29]. The thermolysis of starch modification and chemical modification of dietary fibers K1 and K2 increased the SCFA content in obese children feces, which proves that these preparations provide a beneficial fermentation substrate for the enteric microbiota [30]. Consumption of prebiotic substances stimulate the growth not only at the *Bifidobacterium* genus, but also of strains belonging to the *Bacteroidetes* and *Actinobacteria* phyla, while inhibiting *Firmicutes* strains, particularly, *Clostridium* species, consistent with the presented results of dietary preparations with K1 and K2 fibers [30].

Fiber-like carbohydrates are not the only substrates considered prebiotics, it has also been reported that antioxidant compounds can modulate the growth and metabolism of microorganisms from the gut microbiota [43]. Broekaert, Courtin, Verbeke, Van de Wiele, Verstraete, and Delcour [34] reported that cereal derived feruloylated arabinoxylan mono- and oligosaccharides (F-AXOS) isolated and identified in cereal samples, including maize, exerted antioxidant properties, also displaying prebiotic colonic effects in animals and humans through selective stimulation of *Bifidobacterium* spp. and *Lactobacillus* spp.

2.2. Probiotic Candidates in Maize-Based Fermented Foods

Many maize-based beverages that are found in Mexico: pozol, tejuino, and atole agrio (a corn-based beverage), harbor particular microorganisms such as yeast and bacteria (i.e., *Lactobacillus* spp., *Enterococcus* spp., *Leuconostoc* spp., and *Lactococcus* spp.) [19], as well as derived products from fermentation with beneficial effect to gastrointestinal tract (GIT), and enzymes with industrial applications. Table 1 gather important information from these probiotics.

The traditional beverage pozol contains some strains such as *Enterococcus, Exiguobacterium, Pediococcus, Lactococcus, Leuconostoc, Lactotreptococcus,* and *Weisella* [44–46]; and also *Streptococcus genera*, *Weissella paramesenteroides, Lactococcus lactis*, and *L. paramesenteroides* with functional probiotic properties such as resistance to low pH and bile salts conditions and ability to adhere to HEp2 cell line [35]. Atole agrio beverage also harbors a diverse microflora: *Pediococcus pentosaceus, Weissella confusa, Weissella paramesenteroides, Lactiplantibacillus plantarum, Lactobacillus acidophilus, Levilactobacillus brevis*, *Lactobacillus coryniformis*, *Leuconostoc pseudomesenteroides,* and *Lactococcus lactis,* which have antimicrobial properties against *Enterobacteriaceae*, and yeasts [36,37].

Recently, bacterial strains *Limosilactobacillus fermentum, Lactiplantibacillus plantarum, Enterococcus faecium*, *Enterococcus durans,* and *Enterococcus hirae* were identified in commercial and artisanal tejuino, a beverage elaborated with germinated maize [38]. According to Silva, Ramos et al. 2017, when analyzing the survival of bacterial strains isolated from this food matrix on a human gastrointestinal model, only *Weissella cibaria* and *Leuconostoc citreum* displayed antagonistic activity towards foodborne pathogens, short-chain fatty acids production, and adhesion to HT-29 human colon cell line [38,39]. In other world regions such as Africa, "koko and ogi" also maize-based preparations, have been observed for their bacterial contents (*Lactiplantibacillus plantarum,* Limosilactobacillus fermentum, *Limosilactobacillus reuteri, Enterococcus faecium, Pediococcus acidilactici, Pediococcus pentosaceus, Enterococcus faecalis,* and *Levilactobacillus brevis*), which are able to survive the GIT conditions, inhibiting pathogenic bacteria and reducing diarrhea [47]. Another example is chicha from Argentina, a corn-based product containing LAB (*Lactiplantibacillus plantarum, Lactobacillus rossiae, Leuconostoc lactis*, *Weissella viridescens*, *Enterococcus hirae*, *Enterococcus faecium*, *Leuconostoc mesenteroides,* and *Weissella confusa*), which are known to improve the production of riboflavin and folate. Hence, the microflora signature from maize-based beverages is a positive indicator that promising pre- and probiotics are involved in fermentation.

2.3. Synbiotic Effects of Maize

A few, but promising, studies on supplementation with both corn-derived prebiotics and probiotics have been performed and resumed in Table 1. The Hi-maize 958 or Hi-maize 260 resistant starch (RS), in combination with *Bifidobacterium lactis* showed encouraging results in a colorectal cancer rat model. The synbiotic modulated the microbiota composition, reinforced the innate immune system and decreased blood lipids levels in hypercholesterolemic patients [40]. In this same line, a synbiotic combination of *Lacticaseibacillus paracasei* HII01 and XOS reduced gut dysbiosis and gut inflammation in obese rats [41]. A randomized, double-blind, placebo-controlled, crossover study performed by Costabile, Bergillos-Meca, Rasinkangas, Korpela, de Vos, and Gibson [42] using *L. rhamnosus* LGG combined with Promitor™ Soluble Corn Fiber, increased natural killer (NK) cell activity and decreased serum total cholesterol and LDL cholesterol in patients with dyslipidemia. In addition, the synbiotic combined with corn soluble fiber increased *Ruminococcaceae* and *Parabacteroides* suggesting that the treatment may positively affect the microbiota in elderly persons experiencing microbiota diversity decreases [42].

3. Agave

Mexico is reported to be the place of origin of *Agave*, mainly used for the production of distilled and non-distilled alcoholic beverages, including tequila, mezcal, bacanora, raicilla, and pulque, all of which have special connections to Mexican history and culture, and economy [48]. Dietary fiber obtained from *Agave tequilana*, is rich in fructans and insoluble fiber (IDF); however, during their extraction process, an IDF-rich by-product (about 30%) is generated and usually discarded [49]. Agave cell wall composition is structured mainly by cellulose and hemicelluloses, and this plant is a carrier of the fructan-type carbohydrates, with multiple ascribable health benefits [50]. Since this plant is an excellent source of sugars, minerals, and phenolic compounds, biotechnology research has been focusing on development of several agave-based sub-products [51].

Agavins (from *Agave*) are structured by linear fructans linked by fructosyl chains with β (1–2) linkages, whereas branched fructans are linked by both β (1–2) and β (2–6) [13]. All these fiber components favor the growth of LAB [52], *Bifidobacterium* and yeast communities, which are able to ferment fructans by the expression β-fructofuranosidase enzyme that catalyze fructo-oligosaccharides (FOS) hydrolysis [53]. Saponins obtained from *Agave americana* were also studied as an additive in animal feeding [54]. Several studies reported that these LAB strains participated during agave fermentation [17,18,55,56]. For this reason, agave is both a prebiotic and probiotic promising source for the development of novel functional food products.

3.1. Derived Prebiotics from Agave

Agave should be considered a valuable alternative for the addition of nutritionally relevant dietary fiber in healthier food. Particularly, plants of the *Agave* genus are rich in fructans [57], considered prebiotics because they are not digestible by intestinal tract enzymes, and their structure and type of link by common β (2-1)-like inulins plus β (2-6) linkages of whole molecules allows them to pass into the colon without degradation by endogenous GIT enzymes, where they can be fermented by beneficial bacteria [58]. Some important aspects of *Agave* prebiotics are condensed in Table 2. Inulin-type fructans are the most studied prebiotic compounds because of their broad range of health benefits related to hormonal modulation involved in food intake [58]. Agavins are known to reverse metabolic disorders in several ways that include the gut microbiota changes and or other systemic health effects like the increase in SCFA concentrations in the gut and the endocrine modulation [58–60]. Agave was recognized as a new and potential source of sapogenins and saponins, which are glycosides of triterpenes or steroids with a high number of bioactivities [61]. Branched agave fructans are also known as prebiotics that enhance barrier function and reduce epithelial barrier permeability [62].

The potential of ashen and green *Agave* bagasse as functional ingredients in supplemented cookies has been studied for the application of the chemical and functional properties of this plant noticing that it possesses mainly FOS and simple sugars [50]. *Agave* boles are rich in sugars and contains inulin with a similar degree of polymerization to those extracted from other sources such as *Agave tequilana* or *Agave atrovirens* [63]. The powder of *A. sisalana* bole extract, recently identified as a rich source of inulin, exhibited higher potential of fermentation compared with crude polysaccharides when it was used for several LAB fermentations [63]. Morán-Velázquez, Monribot-Villanueva, Bourdon, Tang, López-Rosas, Maceda-López, Villalpando-Aguilar, Rodríguez-López, Gauthier, Trejo, Azadi, Vilaplana, Guerrero-Analco and Alatorre-Cobos [64] evaluated the composition of *A. fourcroydes* spines includes hemicellulose, pectins, and monolignol subunits, flavonoids, and condensed tannins. The phenylpropanoid-derived compounds, specifically from lignocellulosic matrix, identified flavonoids (quercetin, kaempferol) and condensed tannins ((+)-catechin and (−)-epicatechin) as the predominant metabolites in spines. Agave fourcroydes has shown high concentrations of fructans in their stems; however, there is no information on new products derived from this plant that might enhance its benefit.

Table 2. Prebiotics, probiotics, and synbiotics in *Agave*.

	Probiotic, Prebiotic, or Synbiotic	General Effect	Reference
Prebiotics	*Agavins*	Reverse the metabolic disorders including microbiota changes	[46]
	Powder of *A. sisalana* bole extract (rich in inulin)	Important source of substrate for the higher fermentation potential with LAB	[63]
	Agave fourcroydes	Phenolic compounds including quercetin, kaempferol, (+)-catechin, and (−)-epicatechin exhibit possible prebiotic potentional.	[64]
Probiotics	*L. mesenteroides* P45	Antibacterial activity against the pathogens *Listeria monocytogenes*, enteropathogenic *Escherichia coli*, *Salmonella* enterica serovar *Typhi* and *S. enterica* serovar *Typhimurium*	[56]
	Leuconostoc mesenteroides subsp. *mesenteroides*	Survival on the in vitro GIT simulated conditions and exhibited antimicrobial activity against some pathogens	[65]
	Leuconostoc SD23	Reduction in serum glucose, the homeostasis model assessment of insulin resistance, and triglycerides in maternal obesity rats	[66]
	L. sanfrancensis LBH1068	Anti-inflammatory properties on an HT-29 cells TNF-α model and improvement of symptoms in the DNBS-colitis model	[17]
	L. plantarum LM17	Significant reduction in weight loss and improvement in the intestinal permeability using the DNBS-colitis model	[18]
Synbiotics	Agave fructans (*Agave salmiana*) and probiotic bacteria, *Lacticaseibacillus casei* SACCO BGP93 and *Bifidobacterium lactis* SACCO BLC1	Stimulation of the intestinal host defense. Antagonic activity to pathogens.	[67]
	Agave inulin and *L. reuteri* DSM 17,938	Improved stool characteristics in children with cerebral palsy and chronic constipation	[58]

3.2. Probiotics from Agave Sources

Previous studies characterized and described the microflora present in agave-based fermented beverages. *Agave* bagasse (fibrous-like material) is in contact with the indigenous microbiota of the plant, as abovementioned agave sugars and fibers promoting bacterial growth. In Table 2, some summarized information is available. In fact, studies performed by Escalante, et al. [55] reported that aguamiel (*Agave* sap) contains more than 32 microorganism species, including LAB. The inherent microbiota fermentation process of *Agave* sap produced pulque, a Mexican traditional fermented beverage. One of the characteristics of this beverage is the viscosity, conferred by bacterial exopolysaccharides produced by *Leuconostoc* spp. Different *Leuconostoc* strains have been isolated from aguamiel, and have probiotic properties. *L. mesenteroides* P45 displayed antibacterial activity against the pathogens *Listeria monocytogenes*, enteropathogenic *Escherichia coli*, *Salmonella* enterica serovar *Typhi*, and *S. enterica* serovar *Typhimurium* in in vitro and murine models. *Leuconostoc mesenteroides* subsp. *mesenteroides*, isolated from aguamiel (sap, from *Agave salmiana*) survived the in vitro GIT simulation conditions and exhibited antimicrobial activity against some pathogens [65]. The genome analysis showed that P45 encoded a pre-bacteriocin coding gene and six peptidoglycan hydrolase enzymes [56]. Oral administration of *Leuconostoc* SD23 (strain isolated from aguamiel) was tested in a maternal obesity (MO) model in Wistar rats. Although it did not affect the weight, percentage of body fat was lower than in control obesity groups. Moreover, serum glucose, the homeostasis model assessment of insulin resistance, and triglycerides were higher in MO than in groups treated with probiotic strain [66]. Torres-Maravilla, et al. [17] isolated *L. sanfrancensis* LBH1068 from pulque (*Agave salmiana*) with anti-inflammatory properties on an HT-29 cells TNF-α model and improved symptoms in the DNBS-colitis model. In the other hand, in *Agave* bagasse (*Agave atrovirens*) for mezcal production, *Lactiplantibacillus plantarum* strains with antioxidant properties were isolated, particularity *L. plantarum* LM17 that improved the health of the mice, as observed by reduced weight loss, and significantly decreased intestinal permeability on a colitis mice model [18].

3.3. Synbiotic Effects of Agave

The general synbiotic effects of *Agave* have been incorporated in Table 2. Moreno-Vilet, et al. [67] evaluated the synbiotic effect of *Agave* fructans (*Agave salmiana*) and probiotic bacteria, *Lacticaseibacillus casei* SACCO BGP93 and *Bifidobacterium lactis* SACCO BLC1. This combination produced an early activation of the lymphocyte population CD69+ cells, cell proliferation, and nitric oxide (NO) production in peripheral blood mononuclear cells (PMBC) in vitro. Moreover, fructans from *Agave* increased the expression of *Tbet* and *FOXP3* transcription factors, suggesting that this prebiotic stimulate indirectly the intestinal host defense by T helper cell regulation. The synbiotic effect of *Agave* and probiotics has been also tested in animal health generating beneficial effects against pathogens, such as *Salmonella typhimurium* and *Clostridium perfringens*, particularly in those cases where the use of antibiotics during poultry production was excluded. Either through the generation of short-chain fatty acids (SCFA) that contribute to mucosal cells proliferation or growth-promotion of beneficial gut bacteria, synbiotics could favor a microenvironment that improves the activity of the poultry immune system [68]. Finally, in a clinical model, the synbiotic effect of *L. reuteri* DSM 17,938 and/or agave inulin significantly improved stool characteristics in children with cerebral palsy and chronic constipation [59].

4. Nopal

Opuntia ficus-indica, also known by its common name, nopal, is a cactus plant from the family *Cactaceae*. This is a widely distributed [69] and nutritious plant, high in amino acids and vitamins such as carotenoids and other antioxidant bioactive compounds [70,71], and an excellent source of minerals [72,73]. Its cladodes are regularly consumed in Mexico and the surrounding area since ancient times, being the symbol of the foundation of Tenochtitlan, and used by the Aztecs for the treatment of some colon cancer forms [74]. The fruit of nopal, also called the pear, is also valued because of its flavor, and frequently consumed. One of the most valuable characteristics of this plant, is its carbohydrate content; fibers and mucilages have already been analyzed as bioactive components with important health roles [14]. Several aspects have been yet described, like the mucilage viscosity and elasticity [75] as long as its highly branched formation and a backbone with rhamnosyl-, galactosyl- and galacturonic acid residues and branching side chains of xylosyl- and arabinosyl- residues [76,77]. Mucilage has been pointed as an anti-inflammatory component on topical, and mucosal injuries [78,79]. On the other hand, pectins are another important component of nopal. These fibers are commonly composed by a backbone chain structure of α (1-4)-linked D-galacturonic acid units and (1-2) linked L-rhamnopyranosyl residues with linear segments of homogalacturonans [80].

Although fibers can differ in their chemical composition and physical structure, they can exert different biological functions and impact the host gut microbiome [81]. Nopal has known to have multiple benefits studied in experimental models [82–84]. From all the positive health benefits, the prebiotic effect has been highly described in previous years.

4.1. Prebiotic Effect in Nopal

The general information of nopal prebiotics, potential synbiotics, and synbiotics can be found in Table 3.

Table 3. Prebiotics and Synbiotics in Nopal.

	Prebiotic, Probiotic, or Synbiotic	General Effect	Reference
Prebiotics	Opuntia pear peel	Specific bacterial growth and higher organic acid production than glucose in in vitro assays	[85,86]
	Opuntia pear peel	Higher counts of lactic acid bacteria and Bifidobacteria species	[87]
	Opuntia ficus indica fruit juice	Specific bacterial growth (*Limosilactobacillus fermentum* ATCC 9338), decreased sugar components and decreased risky volatile components	[88]
	Opuntia ficus indica fruit juice	Changes in the growth speed and density of microorganisms of the intestinal microbiota	[89]
	Nopal	Modification on the gut microbiota profile, metabolic changes, and an important reduction in circulating lipopolysacharide levels	[90,91]
	Nopal fiber	Higher intestinal bacterial diversity in specific phyla and cecal fermentation. Modulation of inflammatory intestinal markers and oxidative stress	[92]
Synbiotics	Cactus pear peel flour and LAB (*Lactiplantibacillus plantarum* UAM17, *Enterococcus faecium* UAM18, Aerococcus viridans UAM21b and *Pediococcus pentosaceus* UAM22a) (potential synbiotic)	Increased bacterial viability and resistance to acidic conditions by co-encapsulation with pear peel flour	[93]
	Cactus pear peel flour with wheat flour and *Pediococcus pentosaceus* UAM22a (potential synbiotic)	More water retention, increased yield and reduction on the oxidative rancidity on a formulated sausage.	[94]
	Cactus pear peel flour as co-encapsulant of probiotic *Enterococcus faecium* UAM1 or *Pediococcus pentosaceus* UAM2 (potential synbiotic)	Prevention of food spoilage from coliforms and decreased oxidative rancidity	[95]
	Cactus fruit juice and *Lactiplantibacillus plantarum* S-811, *L. plantarum* S-TF2, *Fructobacillus fructosus* S-22, and *F. fructosus* S-TF7	Organoleptic characteristics guaranteed, inocuity preservation, and protection from pathogens	[96]
	Cactus fruit juice and *Lactiplantibacillus plantarum* S-811	Improvement of stress tolerance in Sacharomyces cerevisiae Decrease in adipose index, weight, and intestinal inflammatory parameters in C57-BL6 obese mice	[97]
	Cactus cladodes pulp and LAB (*L. brevis* POM2 and POM4)	Increased synthesis of GABA Preservative effects on vitamin C and carotenoids Increased radical scavenging activity	[98]
	Cactus fruit puree *Leuconostoc mesenteroides*	Anti-inflammatory effects and tight junctions integrity Decreased oxidative stress	[99]

The prebiotic effect has been analyzed for Opuntia pear peel, with a similar composition to nopal. As a carbon source, the peel was tested on two LAB (*Pediococcus pentosaceus* and *Aerococcus viridans).* Diaz-Vela, Totosaus, Cruz-Guerrero, and de Lourdes Pérez-Chabela [85] showed prebiotic potential through the increases in specific bacterial growth and higher organic acid production than with glucose in in vitro assays. In a similar way, in 2015, the combinatory effect of this two thermotolerant strains and nopal was also tested [86]. Both strains were reproductively fermentable as carbon sources and showed good growth kinetics, and *Pediococcus* acetic acid production was significantly higher than in control groups when compared with other agro-industrial by-products. Perez-Chabela, et al. [87] used cactus pear peel flour as an alternative fiber alternative for intestinal bacteria of Wistar rats for analyzing the prebiotic and systemic metabolic effects on the host. They assessed an increase in cecal lactic acid bacteria and *Bifidobacteria*, also allowing the growth of *Bacteroides* and *Enterobacteria* and on the systemic level, they noticed the same hypocholesterolemic effect than in the control diet containing inulin as a non-digestible carbohydrate.

The juice of the pear (the nopal fruit) has already been assessed to determine its qualities after fermenting with *Limosilactobacillus fermentum* ATCC 9338. Panda, et al. [88], reported that the lacto-juice was biochemically and microbiologically analyzed, and later analyzed by spectroscopy and gas chromatography mass spectrometry, noticing how the fermentation decreased the sugars in the beverage by action of the bacteria but after fermentation, the total phenolic content did not change. In addition, the chromatograms of the lacto-juice showed how fermentation modified or eliminated several risky volatile components associated with the fresh juice.

Other studies, trying the juice of the fruit of *Opuntia ficus-indica* from the Meknes in Morocco showed significant stimulatory effect on the intestinal bacterial growth, including *E. coli, Sacharomyces cerevisiae, Sacharomyces boulardii,* and *Bifidibacterium* spp. [89]. Both mucilage and pectic-derived oligosacharides from Opuntia prickly pear cactus stems have already been reported as prebiotics when tried in vitro in human colonic microbial communities. As reported by Guevara-Arauza, et al. [90], the mucilage effects were higher than the ones from the oligosaccharides, and induced an increase in lactobacilli and bifidobacteria, and a minor pathogen inhibitory effect.

When analyzing its prebiotic effect on an obesity rat model [91], several interesting parameters were assessed. The animals had a high fat diet added with sucrose for 7 months and then the researchers tried a 5% nopal treatment. An important increase in *Ruminococcus bromii*, *Rumminococcus flavefaciens*, *Limosilactobacillus reuteri*, *Bacteroides fragilis,* and *Akkermansia muciniphila* was assessed by gut microbiota sequencing. Some others such as *Bacteroides acidifaciens*, *Blautia producta*, *Faecalibacterium prausnitzii*, *Butyricicoccus pullicaecorum,* and *Clostridium citroniae* were decreased after nopal consumption. Some metabolic changes and an important reduction in circulating lipopolysaccharide levels and consequently the endotoxemia were consequently assessed. In a similar way, Moran-Ramos, et al. [92] tested the effect of 4% dietary fiber from nopal for 6 weeks on an experimental rat model, after a high fat diet. This treatment avoided the induced adiposity and adipocyte hypertrophy. The consumption of this substance increased the intestinal bacterial diversity in specific phyla such as Deferibacteres, Bacteroidetes, and Firmicutes, and the increased fermentation in the cecum, led to the modulation of inflammatory intestinal markers and oxidative stress related to the positive changes over hepatic steatosis.

4.2. Synbiotic Effects in Nopal

All these major findings point to the positive effects of *Opuntia ficus indica* over the growth, nutrition, and metabolism of several species. However, synbiotic formulations with nopal have not yet been fully explored. To our knowledge, there are just few papers exploring the prebiotic effects in specific bacterial species. This could eventually constitute synbiotic effects when identifying the specific health benefits from in vivo models or clinical trials and their application for nutritional or alimentary products. In this section we outlined the potential synbiotic and synbiotic effects of nopal (Table 3), which have been analyzed in several countries around the world, particularly in America where it is highly consumed.

In the case of potential synbiotic formulations, Serrano-Casas, Pérez-Chabela, Cortés-Barberena, and Totosaus [93] studied the combinatory effect between cactus pear peel flour and LAB (*Lactiplantibacillus plantarum* UAM17, *Enterococcus faecium* UAM18, *Aerococcus viridans* UAM21b, and *Pediococcus pentosaceus* UAM22a) on an alginate co-encapsulation. The bacterial viability was improved with the technique, as well as their resistance to acidic conditions. However, since 2015, cactus pear peel flour (3% w/w) was used with wheat flour (2% w/w) added to lean pork and lard, with *P. pentosaceus* UAM22, to formulate a sausage. The cactus flour made the product retain more water, increased yield and reduced the oxidative rancidity on cooked product. Although the mixture changed the texture of the sausage, this was considered a viable alternative for the creation of synbiotic meat products [94]. In 2020, Barragán-Martínez explored the addition of cactus pear peel flour as co-encapsulant of probiotic *Enterococcus faecium* UAM1 or *Pediococcus pentosaceus* UAM2 in cooked lean pork and lard meat sausages. This increased total moisture and enhanced the bacterial populations protecting them from coliforms after storage, and decreased oxidative rancidity, finding it to be a great alternative as nondairy food matrixes [95].

In 2017, Verón, Di Risio, Isla, and Torres [96] isolated seventeen autochtonous strains from *Opuntia ficus-indica* fruits from the arid regions of Argentina for the preparation of a fermented cactus fruit juice. They selected four of them with good qualities as starters; *Lactiplantibacillus plantarum* S-811, *L. plantarum* S-TF2, *Fructobacillus fructosus* S-22, and *F. fructosus* S-TF7. These strains guaranteed the expected organoleptic characteristics, as the acidity preserved the safety and healthy features of the juice and protected it from pathogen contamination. *L. plantarum* S-811 was later used [97] to test the functional features of a nopal fruit juice. The nutritional parameters of the juice were analyzed, along with its ability to improve oxidative stress tolerance in *Sacharomyces cerevisiae* on exposure to 4 mM H_2O_2. Furthermore, the effect of the fermented juice was also evaluated in obese C57-BL6 mice, showing a decrease in adipose index, weight, and intestinal inflammatory parameters.

In another study performed by Filannino, Cavoski, Thligene, Vincentini, De Angelis, Silano, Gobbetti, and Di Cagno [98], thirteen strains of LAB (isolated from fruits and vegetables) were singly used as starter cultures of *Opuntia ficus* L. cladodes pulp. The fermentation increased the functionality of the vegetable compounds and the synthesis of several metabolites; after the fermentation with *L. brevis* POM2 and POM4, a greater concentration of γ-amino butyric acid (GABA) was identified. In addition, preservative effects on vitamin C and carotenoid levels were caused by the lactic acid fermentation and by the flavonoid aglycone derivatives, kaempferol and isorhamnetin, which generated an increase in radical scavenging activity. The effects on inflammatory biomarkers were assessed in Caco-2/TC7 cells treated with TNFα (whose level was particularly affected by *L. brevis* POM4 and *L. rossiae* 2LC8) and with IL-1β and IFN-γ. Another intestinal effect was the contribution to the maintenance of tight junctions' integrity.

In a similar way, another study evaluated different *Leuconostoc mesenteroides* strains from the same fruit and selected according to their growth and metabolism so they could efficiently ferment *Opuntia ficus-indica* L. fruit puree. The mixture decreased Caco-2/TC7 inflammation, protecting the tight junctions and limiting the cellular oxidative stress caused by the reactive oxygen species [99].

5. Beans

Phaseolus vulgaris L., commonly called bean, is the most known plant from the family *Leguminosae.* Across the world, specifically Eastern Africa and Latin America, it is highly consumed in a wide range of varieties produced throughout the year and considered a major protein dietarian source [100] appreciated for its price and versatility. Numerous health benefits have been attributed to beans [101–105] and different varieties have been studied because of their phenolic and antioxidant content [106–109]. Beans are high in micronutrients such as minerals like iron, magnesium, zinc, potassium and vitamins [110]. They also have variable amounts of carbohydrates as starches and fibers, depending on the varieties and even the cooking method, which may change the nutritional quality of the products that contain them [111,112].

Prebiotic Effect in Beans

Several authors have explored the prebiotic potential of this bean components. Some of the general effects are condensed in Table 4.

Table 4. Prebiotics in Beans.

	Prebiotic	General Effect	Reference
Prebiotics	Bean flours containing of indigestible carbohydrates	Increase SCFA's production in Wistar rats feeding with bean flours fractions	[113]
	Non-digestible fraction from cooked bean (Negro and Bayo Madero beans varieties)	In vitro increase in SCFA's production by fermentation with an inoculum of human gut microbiota	[114]
	Non-digestible fractions of *Phaseolus vulgaris*	SCFAs production on intestinal cell lines	[15,115]
	Crude water extractable polysaccharides from *Phaseolus vulgaris*	Increase in the growth of in vitro *L. plantarum* and *L. fermentum*	[116]
	Soluble extract of carioca beans (*Phaseolus vulgaris* L.)	Increase in *Lactobacillus* and *Bifidobacterium* and decrease in pathogenic bacteria. Increase zinc and iron bioavailability (in vivo model)	[117]
	Pinto bean variety	Changes in gut microbiota, increase in butyrate content, and improvement in anti-inflammatory and lipid profiles (C57BL/6J mice model and clinical trial)	[118]

In 2001, Henningsson, and collaborators, Henningsson, Nyman, and Björck [113], worked with Wistar rats analyzing different diets from various bean flours containing two levels of indigestible carbohydrates (90 and 120 g/kg). Then, the fermentation of the rat hindgut was assessed, along with the distribution of SCFA's and cecal pH. In the distal colon, there was a significant increase in the diet with 120 g/kg (this diet also having the highest RS proportion). In another study, four raw and cooked *Phaseolus vulgaris* L. cultivars were analyzed by polysaccharide in vitro fermentation, incubating with a fecal inoculum of human gut microbiota under anaerobic conditions and then evaluating with gas chromatography the SCFA's production. Fermentation changed the pH by means of SCFA's production at 6 and 24 h, the Negro and Bayo Madero varieties being the ones with highest SCFA's production [114]. In a similar way, this fermentation of the indigestible fraction of Phaseolus vulgaris has been tested on intestinal cell cultures, detecting the SCFAs production as important players in cancer cells apoptosis [115,119]. Jayamanohar, Devi, Kavitake, Priyadarisini, and Shetty [15] studied the prebiotic capacity of the crude water extractable polysaccharides from *Phaseolus vulgaris*. They assessed an increase in the growth of *L. plantarum* and *L. fermentum*, which were seen to use the polysaccharides as a carbon source, producing organic acids in exchange. Furthermore, through the analysis of in vitro fecal fermentation, they also assessed a significant promotion of bifidobacterial counts. The activity of *Lactobacillus* and *Bifidobacterium* was also increased after the intra-amniotic administration of soluble extract of carioca beans (*Phaseolus vulgaris* L.) in an in vivo *Gallus gallus* model, and it limited the relative abundance of *Clostridium* and *E. coli* on the treated groups. Furthermore, the soluble bean extracts increased the expression of brush border membrane iron related proteins Znt1, AP, FPN, and DcytB, implying that it can also increase zinc and iron bioavailability [116]. Specifically, the pinto bean variety supplementation was analyzed on gut variables of C57BL/6J mice with metabolic changes after following a Western-style diet. This treatment reduced *Bilophilia* and increased *Lachnospiraceae* and *Bacteroidales,* also increasing fecal concentrations of butyrate and, consequently, induced an anti-inflammatory gut microenvironment also assessed in the upregulation of the Il-10 gene. Finally, the supplementation also improved metabolic features such as fasting blood glucose and tolerance, suppressing TNF-α, and, thus, impacting obesity-induced low-grade inflammation [117]. This same variety and its effects were also analyzed in humans in 2017 by Finley, Burrell, and Reeves [118]. Volunteers were stratified in two dietary intervention groups including bean consumption in one of them. This 12-week intervention was preceded by an equilibration phase. Although there were no clear trends in the bacterial population shifts, in the analysis of the fermentation patterns, the propionate production and total fatty acids did significantly change when they consumed the bean soup. Furthermore, an important improvement in the lipid profile was also assessed on the bean consumption group. Although no synbiotic foods or products, including any variety of *Phaseolus vulgaris*, have yet been examined to our knowledge, it remains a real area of opportunity because of the beneficial functional characteristics of this food.

6. Discussion

Dietary changes have negatively affected the health-related parameters; unfortunately, the adverse health outcomes may precede several pathologies, such as obesity, chronic entities such as vascular diseases, or cancer [120]. This is the most important justification for the recent interest in production and/or consumption of new alimentary products providing nutritive and functional substances isolated or in functional foods [121]. For the food industry, this has been considered a challenge that involves several areas related to health and food technology and implies the development of foods with higher nutrient content and functional properties that maintain strict safety standards. In addition, the interest in, and demand for, functional foods around the world and in Latin America and Mexico is still growing [122].

Mexican traditional food, such as the matrices we have described in this review, can promote diverse health effects acting as prebiotics, exerting specific activities on microbiota bacteria or probiotics, and being able to constitute synbiotic products as seen on Figure 2A. Detailed reports have shown the development of alimentary biotechnological products for alimentary purposes [122–124]. Several success stories can be highlighted here, where the use of one or more traditional food matrices is applied and can solve a necessity. This is the case in the development and innovation of maize products. We considered the specific case of blue maize, whose high anthocyanin content confers it valuable antioxidant effects, along with anti-inflammatory, anti-diabetogenic, and anti-carcinogenic properties [16,125]. As a result of modern alimentary necessities, the development of purple maize mayonnaise with better antioxidant activity in comparison with typical chemical antioxidants such as butylhydroxytoluene and ethylenediaminetetraacetic acid [126] can be mentioned. In addition, in the microbiological field, the co-culture with endogenous single starter cultures as *Lactoccocus lactis* and *Pediococcus pentosaceus* compared to spontaneously fermented beverages such as atole agrio lead to a controlled and safer fermentation process (antimicrobial activity) and enhanced sensory properties, offering a safe product with steady attributes [36]. On the other hand, blue corn is a cereal rich in phenolic compounds, used to make blue tortillas [16]. In this line, the development of new products of fermented blue corn displaying both prebiotic and probiotic effects could be an interesting opportunity, since previous studies have demonstrated that the prebiotic antioxidant compounds can effectively modulate the microbiota. As has already been shown, antioxidants increased the population of *Akkermansia* spp. in the intestinal microbiota in mice [127]. Another important combination could be maize with agavins, due to the potent immunomodulation power of inulin-type fructans and its potential health benefits [128].

The incorporation of nopal mucilage to maize-based soups improves the utilization of both food matrices properties to create a superior product. In this case, the thickening mucilage property also implied a reduction in chemical origin thickeners [129]. This same combination between different traditional food, has yet been tried for the formulation of maize and nopal tortillas, a central food for several countries; this formulation benefits from an increase in fibers and polyphenols. After its intake, an important decrease in glucose, cholesterol, and triglycerides levels has been already assessed on control human groups [130].

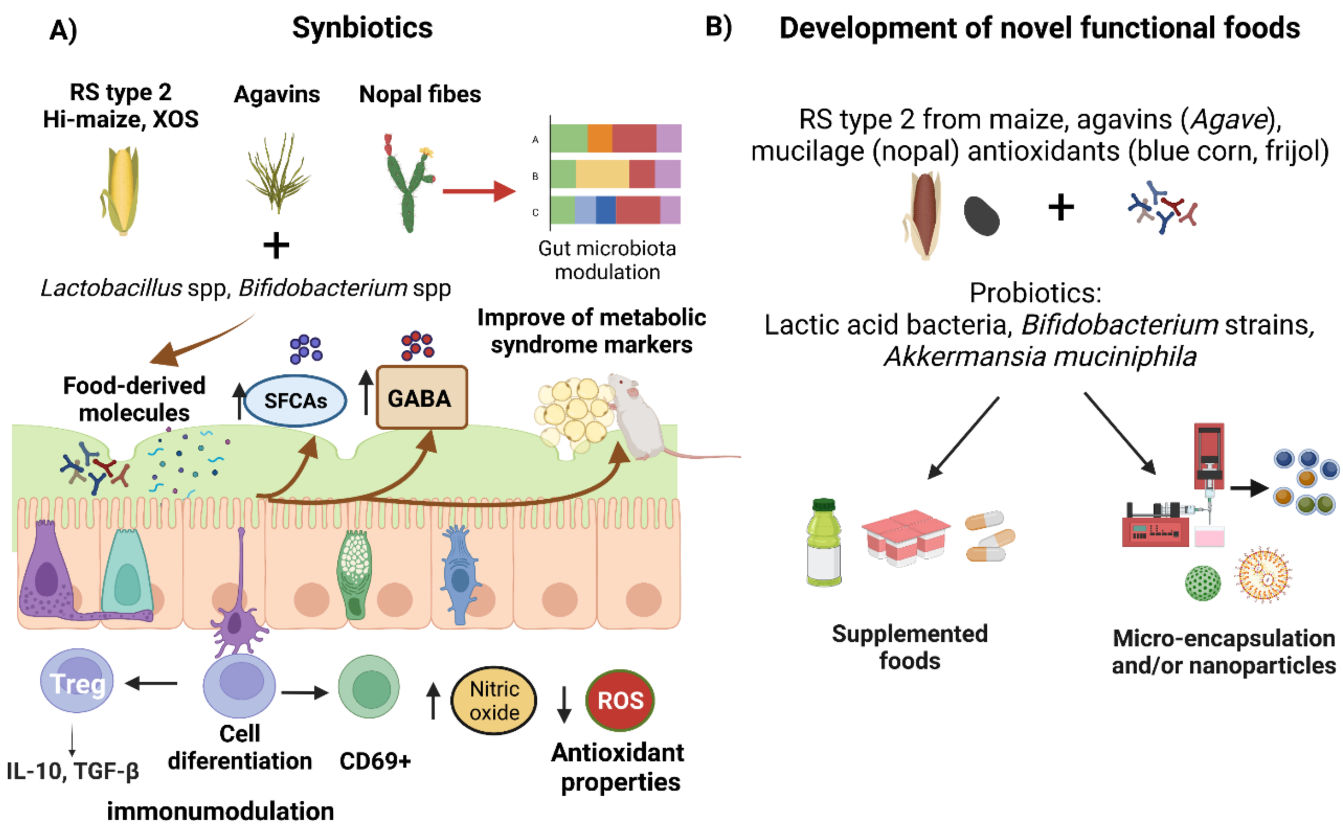

Figure 2. Mexican traditional food as a source of synbiotics for developing novel functional food products: (**A**) Prebiotic fibers in combination with probiotic strains could improve the release of food-derived compounds (as short chain fatty acids (SCFAs), or γ-aminobutyric acid (GABA)) and exert positive effects on intestinal and systemic health (i.e., immunomodulatory and antioxidant properties). (**B**) The selection of appropriate prebiotic and probiotic pairs for developing novel functional products. Traditional food supplements and the use of encapsulation and/or nanotechnology for the preservation and performance of synbiotics. Created by BioRender.com (2022) (accessed on 6 March 2022).

Recent studies have shown that the addition of liquid and powdered cactus mucilage in raw cow's milk, led to a decrease in the development of pathogenic microorganisms such as mesophilic aerobic bacteria and total coliforms that represent a sanitary risk in the production of fresh cheese in different regions of the country [131]. Likewise, the use of *Opuntia* spp. fruit has been proposed as an additive in the development of meat and even bakery products, where the fruit powder represents a viable and low-cost source of fiber, protein, and bioactive compounds that promote the development of beneficial microorganisms in the product formulation [132]. When analyzing agave-derived products, inulin and other fructans with prebiotic and anti-inflammatory function can be incorporated to food [133]. Martínez-Gutiérrez and collaborators, Martinez-Gutierrez, et al. [134], reported the incorporation of FOS powders derived from *Agave salmiana*, as a prebiotic agent promoting the development of probiotic bacteria, superior to the effect generated by commercial products with the same alimentary functions. In the same way, recent studies demonstrated that agave syrup obtained from *A. salmiana* and *A. mapisaga* mead by evaporation processes has high antioxidant activity, phenolic compounds and can be used as a possible substitute for honey as it also has a higher protein content than this food [135]. On the other hand, it has been previously indicated that beans contain high levels of phenols, RS, vitamins, and FOS, which are known to protect against conditions such as oxidative stress and various degenerative diseases, positioning this legume as an excellent functional food [136].

The characteristics of both beans and corn together have been tested since 2017, analyzing corn-bean chips made with non-digestible fraction of the beans. The anti-inflammatory effect of both food matrices was examined in RAW 264.7 macrophages, assessing a decrease in oxidative species at 24 h, where a significant increase in SCFAs levels and up-regulation of anti-inflammatory cytokines such as TIMP-1 and I-TAC were assessed [137]. Sparvoli, et al. [138] also evaluated the sensory characteristics, iron bioavailability, and glycemic index of bio-fortified snacks and cream using bean flour as a base, finding that flour with reduced phytic acid and active lectins represents an important source for the preparation of food products for children and adults. The above has been previously evaluated in rodent trials where an increase in protein and amino acid availability was observed when consuming previously extruded and baked bean flour [139]. The use of bean meal has not only been evaluated for the purpose of generating food for human consumption; some authors have evaluated taking advantage of its functional properties by incorporating it into the development of aquafeeds, where 15% bean meal extruded at 18% moisture and 120 °C has been recommended [140]. As is mentioned above, extremely oxygen-sensitive bacteria are increased by supplementation of maize type 2 RS, this could be an interesting strategy for novel development of functional foods, due to the special culture conditions of *Faecalibacterium* and *Akkermansia muciniphila*. Therefore, approaches using the prebiotic fiber to increase its growth are prudent, rather than a more direct probiotic approach [29]. Regarding the prebiotic effect, this could be increased in the maize-based foods. This will be improved during food process, in fact, during making-elaboration and storage of corn-tortilla, native starches suffer starch retrogradation, increasing RS levels [141], but this also can be increased with an extrusion process [142]. Several studies have pointed out the biotechnological uses of traditional food as a therapeutical advancement, and in health promotion fields [143], and as a logical consequence, we have seen the increase in food technology studies that may increase the functionality of several food bioactives and interesting components. Microencapsulation, which refers to the introduction of certain bioactive substances in a liquid or gaseous phase (enzymes, flavors, vitamins, or essential oils) to a homogeneous or heterogeneous matrix [143]. A big number of techniques (such as emulsification, spray-drying, extrusion, and freezing drying [144] and many substances are used to encapsulate. From these, alginate, chitosan, polyvinyl alcohol, and several polysaccharides are more frequently chosen [145]. For the importance of the method and the feasibility of reproducing it and offering higher quality food items that remain active in the digestive tract, in the next years, we hope to see several traditional foods being searched and adapted to this technique (Figure 2B). For the importance of the method and the feasibility of reproducing it and offering higher quality food items, in the next years, we hope to see several traditional foods being searched and adapted to this technique (Figure 2B). On the other side, nanotechnology is a brilliant area on the alimentary scene [146]. Several food matrices remain under study in order to determine whether they can be used for a specific purpose or not [147]. This same technology showed a few years ago how the preparation of a lycopene nano emulsion added to tomato extract, increased the in vitro bio-accessibility of the active, turning stable in an aqueous medium [147].

Other areas in the food technology, manufacture, and presentation of food items, even at the level of the ecological footprint, are urgently needed to make the most of these traditional food matrices and to exploit their properties to obtain better quality products to accomplish both economic and nutritious goals. Finally, this new plant-based meal era has just re-started but promises to grow and revolutionize the agro-industrial field. Modern societies do not need modern food, just the elements to discover how to adapt it so they can satisfy their necessities. The rapid global growth of the bioeconomy is expected to accelerate and increase the demand of biotechnological products [148]. Within this portfolio of novel products, functional foods can synergistically and/or additionally confer overwhelming protection against degenerative diseases through the modulation of several processes [149], or even facilitate the intake of some healthy molecules in order to increase their consumption by a specific population that may benefit from them. These novel food matrices must be considered as an alternative to help in health promotion, disease prevention, and individually designed nutrition therapies, giving a new approach to nutrition and health science [150].

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