Mango Pectic Oligosaccharides: A Novel Prebiotic for Functional Food

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Prebiotics are functional food ingredients that assist probiotic growth and render many other health benefits. Mango peel is the biomass of the processing industry and has recently been value-added as a dietary fiber pectin. Besides its general use as a food additive, mango peel pectin (MPP) is partially hydrolyzed by pectinase to obtain pectic oligosaccharides (POSs) that have recently gained attention as novel prebiotic products and in medical research. This review describes probiotic candidates responsible for the digestion of pectin derivatives and the advantages of POSs as functional additives and their current best retrieval options. Mango pectic oligosaccharide (MPOS) recovery from low methoxyl MPP from mango with prebiotic performance both *in vivo* and *in vitro* environments is discussed. Current research gaps and potential developments in the field are also explored. The overall worthiness of this article is the potential use of the cheap-green food processing bioresource for high-value components.

Keywords: fruit biomass, intestinal microflora, lactic acid bacteria, short-chain fatty acids, probiotic

INTRODUCTION

Functional food is a type of food that is supplemented with bioactive ingredients (e.g., dietary fiber, probiotics, and antioxidants) and derived food ingredients. It can be consumed as part of a normal daily diet that provides health benefits and reduced the risk of chronic diseases beyond those provided by adequate nutrition. The newborns' gastrointestinal (GI) tracts were inoculated with organisms at an early stage of life due to the influence of maternal intestinal flora and diets (1). These include aerobic Gram-positive cocci, enterobacteria, and *Lactobacilli*, which are the primary colonizers. These bacteria rapidly consume O_2, which enhances the growth of obligate anaerobic species, collectively known as gut microflora (2, 3). In particular, the microflora of breast-fed infants is dominated by a bifidobacterial population that purports to be in a better health condition than formula-fed babies (4). Human milk oligosaccharides (HMOs) are enriched with complex glycan compounds that are partially mediated by the modulation of the intestinal microbial ecology and immunological homeostasis associated with the prevention of intestinal diseases, improved general wellbeing, and reduced incidence of allergic symptoms (5, 6). Consequently,

galacto-oligosaccharides (GOSs) are often the predominant prebiotic oligosaccharides used in infant diets. It is believed that including GOSs in infant formula boosts the population of bifidobacterial, reduces pathogenic inoculums, and boosts metabolic activity in immune system regulation (7). GOSs are typically synthesized from lactose through the enzymatic activity of β-galactosidase (as well as β-glucosidases and β-glycosidases) *via* transgalactosylation (8). Besides GOSs, other prebiotic oligosaccharides such as fructo-oligosaccharide (FOS) and/or polydextrose (PDX) are also prevalent components in breast milk, but they are fundamentally absent in cow's milk (9–11). In addition to the ability to enhance the growth of *Bifidobacteria* and *Lactobacilli*, short-chain fatty acids (SCFAs) are produced as the by-products of oligosaccharide fermentation. In adult humans, the SCFA has a stronger link in the prevention of colon cancer (12). Recently, POS has been proposed as a new class of prebiotics capable of *in vivo* synergistic empowerment of immunomodulation caused by GOS and FOS (13, 14). Mango peel is a potential biomass for dietary fiber recovery with 5–11% pectin depending on the extraction methods, varieties, and, also, fruit morphological characteristics (15, 16). As a food additive, mango peel pectin (MPP) has been utilized as a food additive to alter the texture and firmness of food products, and a carrier material for drugs and medicine (17, 18). The extracted MPP could be partially hydrolyzed by a pectinase enzyme to obtain MPOS as a prebiotic in human food (19).

PROBIOTICS

Probiotics are defined by the World Health Organization as live microorganisms that enhance health benefits on the host when consumed in adequate amounts (20). They are non-pathogenic, beneficial, and active bacteria and yeast. The highly potent and commonly used probiotics are *Lactobacillus* spp., *Bifidobacterium* spp., *Saccharomyces boulardii*, *Propionibacterium* spp., *Streptococcus* spp., *Bacillus* spp., *Enterococcus* spp., and some specific strains of *Escherichia coli* (**Table 1**). Especially, the genus of *Lactobacillus* and *Bifidobacterium* of the Gram-positive, non-spore-forming, non-mobile, obligated are those of the facultative anaerobic bacteria. They are classified as lactic acid bacteria (LAB), which are catalase-negative bacterial species that can produce lactic acid as the main end-product of carbohydrate fermentation (23). LAB are generally used as food additives (**Table 2**) for health-promoting purposes.

The health mechanisms of these probiotic genera are described in **Figure 1**, which includes (1) increased adhesion to the intestinal mucosa, (2) enhancement of the epithelial barrier, (3) inhibition of pathogen adhesion, (4) production of antimicroorganism substance, (5) competitive exclusion of pathogenic microorganisms (i.e., acid and SCFA), and (6) modulation of the immune system (25, 26). *Lactobacillus reuteri* is a well-studied probiotic bacterium that colonizes a large number of mammals. It has been clarified as a heterofermentative species that can grow in oxygen-limited atmospheres and colonize the GI tract of humans and animals (27). It can

also survive in a variety of pH conditions, employ multiple mechanisms for pathogenic microorganism inhibition, and secrete many antimicrobial intermediates (28–30). *B. animalis* is considered a natural inhibitor of human and other mammalian GI tracts, as well as widely supplemented in numerous fermented dairy products (31). The major subspecies of *B. animalis* include *animalis* and *lactis,* of which the latter subspecies is regarded as technologically suitable to use as a probiotic adjunct due to its resistance against acid, bile, and oxygen than other members of the genus (32, 33). Clinical properties for health advancement and/or disease defense of the probiotics are to provide symptom relief to individuals with common GI symptoms, irritable bowel syndrome, and constipation and to boost the immune response (34). The survival rate of probiotics in gastric conditions depends on the types of prebiotics and their resources. Larsen et al. (35) claimed that *Lactobacillus fermentum* PCC and *L. reuteri* RC-14 were more resistant to gastric tract in the presence of different pectin types. The variable amount of polygalacturonic acids in the backbone was also crucial for bacterial protection (35). The protective function of pectin is linked primarily to the complex fluctuation in surface charges and, as a result, influences the pectin-bacteria electrostatic interactions. Additionally, Corcoran et al. (36) and Hernandez-Hernandez et al. (37) suggested that the survival improvement of *Lactobacilli* in the gastric juice by prebiotic oligosaccharides was in association with the presence of metabolizable sugars, which could maintain pH homeostasis by increasing ATP generation.

TYPES OF PREBIOTICS AS FUNCTIONAL FOOD INGREDIENTS

Prebiotics are short-chain carbohydrates (SCCs) that are non-digestible by digestive enzymes in humans and sometimes known as resistant SCCs because they are only fermented in the intestinal tract (38). It encourages the growth and/or activity of one or a limited number of intestinal bacteria that reside in the gut rather than introducing the exogenous species (39). Non-digested carbohydrate (CHO) molecules, saccharides (di-, oligo-, and poly-), resistant starches, and sugar polyols have been claimed to have the potentiality of prebiotic (40). The carbohydrate sources are identified as prebiotic properties that achieve the following criteria; (a) resistance to gastric acidity and mammalian enzymes, (b) susceptibility to fermentation by gut bacteria, and (c) ability to enhance the viability and/or activity of beneficial microorganisms (41). For these, GOS, FOS, and inulin are commercially accepted for food-grade prebiotics. GOSs and FOSs are non-digestible carbohydrates derived from lactose that can be found naturally in human milk. Inulin and fructan are known as prebiotics derived from soluble dietary fibers, which are vastly obtained from plants such as asparagus, chicory, tomatoes, mango, onion, and garlic (40, 42). Prebiotic compounds are classified based on chemical structures, chain length or degree of polymerization, and applications (43). Most of the functional food prebiotics are saccharide derivatives, which are mostly of plant origin. Besides, protein or peptide and lipid prebiotics can be naturally found (44). The different types of prebiotics

TABLE 1 | Most important representatives of probiotic microorganisms.

Lactobacillus species	*Bifidobacterium* species	Other LABs	Non-LABs
L. acidophilus	*B. adolescentis*	*Enterococcus faecalis*[a]	*Bacillus cereus var. to yoi*[a]
L. casei	*B. animalis*	*E. faecium*	*Escherichia coli strain nissle*
L. crispatus	*B. bifidum*	*Lactococcus lactis*	*Propionibacterium freudenreichii*
L. galinarum[a]	*B. breve*	*Leuconostoc mesenteroides*	*Saccharomyces cerevisiae*
L. gasseri	*B. infantis*	*Pediococcus acidilactici*	*S. boulardii*
L. johnsonii	*B. lactis*[b]	*Sporolactobacillus inulinus*	
L. paracasei	*B. longum*	*Streptococcus thermophilus*	
L. plantarum			
L. reuteri			
L. rhamnosus			

[a] *Mainly used for animals.*
[b] *Recently reclassified as Bifidobacterium animalis sub sp. lactis (21).*
Adapted from Holzapfel et al. (22) and Kechagia et al. (23).

TABLE 2 | Probiotic products and their compositions.

Products	Probiotic compositions
Align	*B. infantis* 35,624; 4 mg/capsule = 1 billion CFU
Activia yogurt	*B. lactis*; 100 million bacteria per g
Culturelle	*L. rhamnosus*: 10 billion bacteria plus insulin 200 mg per capsule
Culturelle for kids	1.5 billion bacteria per packet
Howaru	*L. acidophillus/B. lactis*: 10 billion bacteria per capsule
Kefir	*L. lactis, L. rhamnosus, L. plantarum, L. casei, L. acidophilus, L. reuteri, Leuconostoc cremosis, Streptococcus diacetylactis, S. florentinus, B. longum, B. breve, B. lactis*: 7–10 billion CFU per cup
Lactinex	*L. acidophilus, L. bulgaricus*: 10^6 CFU/tablet and 10^9 CFU/packet
Protectis	*L. reuteri*: 100 million bacteria per dose
RepHresh Pro-B	*L. rhamnosus, L. reuteri*: 5 billion CFU per capsule; vaginal use
VSL#3	*L. plantarum, L. paracasei, L. bulgaricus, B. breve, B. infantis, B. longum, S. thermophiles*: 225 billion bacteria per 2 capsules
Yakult	*L. casei*: 8 billion bacteria per 80 mL bottle

CFU, colony forming unit.
Pharmacist's Letter 2012; 28(7):280707. Islam (24).

and their plant sources are summarized in **Table 3**. Inulin is a polysaccharide fructan that produces SCFAs that are extracted from fruits and vegetables. The fatty acids such as propionate, butyrate, and acetate endure the reduction effect of lipids and cholesterol and possibly attain a reduction in hypertension risk (58). Similarly, pectic oligosaccharides (POSs), which are the products of partial hydrolysis of pectin, are currently classified as emerging prebiotics, but only limited studies are there to support their use at the commercial level (59).

PECTIC OLIGOSACCHARIDES

Pectic oligosaccharide is a non-digestible oligosaccharide that possesses prebiotic activity. POS beneficially affects the host by selectively enhancing the growth and/or activity of one or a limited number of *Bifidobacteria* and *Lactobacilli* in the colon (56, 60). The colonic fermentation of POS generates SCFA, which provides a great variety of health effects, including inhibition of pathogenic bacteria, constipation relief, reduction in blood glucose levels, improvement in mineral absorption, reduction of colonic cancer, and modulation of the immune system (13). POS also has a potential inhibitory on the growth of entero-putrefactive and pathogenic organisms (61, 62). Pectic polysaccharide (i.e., pectin) extracted from various sources is cut into smaller chains of POS using different preparations, *viz.* enzymatic, chemical, and physical techniques (63, 64). The techniques for POS preparation from several raw materials and biomasses are comprehensively collected as shown in **Table 4**. Enzymatic treatment has been extensively applied for POS production due to the specificity and selectivity as well as minimum adverse chemical modifications of products (74, 75).

The hydrolysis enzyme of pectin has been used, which acts synergistically to produce POS (64, 76, 77). The methyl esters of galacturonic acid residues are cleaved by pectin methyl esterase (PME) (78). This enzyme acts before polygalacturonase (PG). PG degrades the glycosidic bond of the α-(1,4)-polygalacturonan in a random position (79). Nevertheless, the less esterified the structure of the pectin substrate, the greater the activity of PG (80). Meanwhile, pectin lyase (PL) highly catalyzes the esterified pectin, producing unsaturated methyloligogalacturonates through transelimination of glycosidic linkages (81). Physical pretreatments, including hydrothermal, dynamic high-pressure microfluidization (DHPM), and irradiation, have been adapted to partially degrade the raw materials for oligosaccharide release (71, 82, 83). Using the hydrothermal method, arabino and galacto-oligosaccharides (GOSs) were effectively obtained from various bioresources. While the chemical hydrolysis of pectin for the production of POS has been limitedly explored. This is because there are some disadvantages to the chemical process, including toxicity and limitation of the desired degree of polymerization (75).

Furthermore, probiotics in the gut system respond differently to alternate types of prebiotics. Olano-Martin et al. (84) reported that different types of pectins and POSs had significant selective effects on the growth of gut bacteria as shown **Figure 2**. The data were regenerated using the principal component analysis (PCA). From the figure, the first two dimensions of the PCA accounted for 91.66% across the PCA score plot (PC1; 64.57% and PC2; 27.09% of the variance). Overall, it was found that the *Lactobacillus* spp. gave mostly positive responses to the
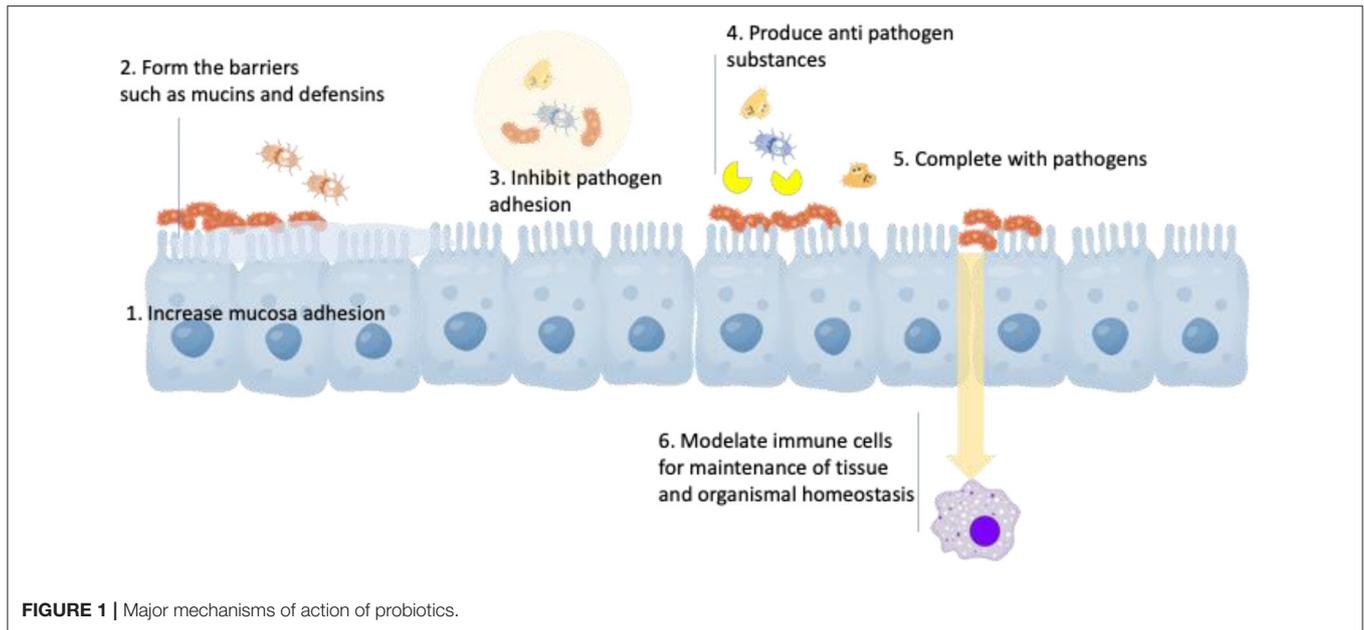
FIGURE 1 | Major mechanisms of action of probiotics.

TABLE 3 | Types and sources of natural prebiotics.

Prebiotic types	Prebiotic sources	References
Arabinoxylooligosaccharides	Wheat bran	(45)
Cyclodextrins	Water-soluble glucans	(46)
Enzyme-resistant dextrin	Potato starch	(47)
Fructooligosaccharides	Asparagus, sugar beet, garlic, chicory, onion, Jerusalem artichoke, wheat, honey, banana, barley tomato, rye	(48)
Galactooligosaccharides	Human's milk and cow's milk	(49)
Isomaltulose	Honey, sugarcane juice	(50)
Isomaltooligosaccharides	Starch	(51)
Lactulose	Lactose (milk)	(52)
Maltooligosaccharides	Starch	(51)
Pectic oligosaccharide	Mango, sugar beet, citrus	(19, 53, 54)
Raffinose oligosaccharides	Seeds of legumes, lentils, peas, beans, chickpeas, mallow composite, mustard	(55)
Soybean oligosaccharide	Soybean	(56)
Xylooligosaccharides	Bamboo shoots, fruits, vegetables, milk, honey, wheat bran	(57)

prebiotic pectins, while *Bifidobacteria* appeared opposingly. It was also apparent that the low methoxyl pectin (LMP) and its pectic oligosaccharide hydrolysate (POS II) were specifically responsive to *Lactobacillus plantarum* 0207. Meanwhile, high methoxyl type (HMP) and its hydrolysate (POS I) had a slight influence on the growth of the two strains of *Lactobacillus casei* and *Lactobacillus acidophilus*.

MANGO PECTIC OLIGOSACCHARIDES

Purification

Mango peel accounts for 20% of fruit biomass and is known as a potential source of dietary fiber consisting of a high pectin (5–10%) composition depending on fruit characteristics, the extractions, and varieties (16, 37–41). Previous studies have illustrated that peel from the Thai mango variety, Chok Anan, provided a substantially high amount of pectin (13%), mainly of low methoxyl content, illustrating gelation properties at low sugar content; thus, it has been widely used as a food additive (18). The MPP was used as a potential source for POS II with pectinases and the longer the hydrolysis time and pectinase concentrations, the lower the molecular weight (M_w) obtained (85). The MPOS was evaluated for prebiotic activity with *L. reuteri* and *B. animalis*, whose highest proliferation was 4% (w/v) of the MPOS supplemented condition at 72 h of the fermentation time (19). Pectinase and long hydrolysis cleaved pectin to be active molecules with high prebiotic efficiency (13). It is encouraged that purification processes are highly recommended to obtain food-grade final products. Generally, the purification of POS can be operated either by membrane-based technology, including those of ultrafiltration with the regenerated cellulose membrane of different pore sizes (83, 86), or chromatographic separation (87, 88) with a specific resin/matrix (74). The purification steps are chosen based on the selection of the components from the mixture. In the case of POS produced from orange peel wastes (OPWs), the POS was purified by a two-step membrane process (i.e., discontinuous diafiltration and concentration) to yield a refined product comprising up to 90% oligosaccharides (89). Likewise, Holck et al. (90) implemented a regenerated cellulose membrane for purification of sugar beet POS, while Iwasaki and Matsubara (91) purified the oligomers acquired from citrus pulp pectin from the membrane using two

TABLE 4 | Preparation of POS from various sources by different techniques.

Sources/ types of POS	Preparation techniques	Molecular weight	*In vitro* probiotic test	Major SCFAs products	References
Apple pomace	Enzymatic technique (Pectinex Ultra SP-L, Viscozyme, Rohapect Ma Plus T, Rapidase Smart)	DP 7–10	*Lactobacillus plantarum, L. brevis, L. paracasei, Leuconostoc mesenteroides*	Acetic acid, propionic acid	(65)
Artichoke	Enzymatic technique (Peclyve CP)	0.3–100.0 kDa	n/a	n/a	(66)
Citrus peel	Enzymatic technique (Peclyve CP)	<1.0–1.8 kDa	*Bifidobacterium bifidum* and *L. acidophilus*	n/a	(67)
Lemon peel	Enzymatic technique (Crude gungal PL and yeast PG)	51.4 kDa	Bacterial groups; Bifidobacterium, *Lactobacillus*, Enterococcus	Acetic acid, butyric acid	(68)
Mango peel	Enzymatic technique (Pectinex® ultra tropical)	<1.0 kDa	*B. animalis* and *L. reuteri*	Acetic acid, propionic acid	(19)
Orange peel	Enzymatic technique (Fungal crude enzyme; pectinase, cellulase, CMCase, xylanase)	<1.0–>3.0 kDa	*B. infantis* and *L. acidophillus*	n/a	(69)
Sugar beet pulp	Enzymatic technique (Crude gungal PL and yeast PG)	63.9 kDa	Bacterial groups; *Bifidobacterium, Lactobacillus, Enterococcus*	Acetic acid, butyric acid	(68)
Sunflower	Enzymatic technique (Commercial cellulase *Aspergillus niger* with pectinase)	100–800 kDa	Bacterial groups from fecal	Acetic acid	(70)
Apple pectin	Physical technique (Dynamic high-pressure microfluidisation)	n/a	Bacterial groups from fecal	Acetic acid, propionic acid	(63)
Lemon peel waste	Physical technique (Hydrothermal treatment)	DP 2–18	n/a	n/a	(71)
A. argute fruit	Mixed technique (Ultrasound-assisted enzymatic treatment)	<0.7–>3.0 KDa	Bacterial groups from fecal	Acetic acid, propionic acid, butyric acid	(72)
Hawthorn fruit	Mixed technique (Ultrasound-assisted enzymatic treatment)	0.8–2.2 KDa	n/a	n/a	(73)
Citrus peel pectin	Chemical technique (Trifluoroacetic acid)	2.0–4.0 KDa	*Bifidobacterium bifidum* and *L. acidophilus*	n/a	(54)

DP, degree of esterification; PL, pectin lyase, PG, polygalacturonase.

steps to maintain the high MW constituents and eliminate a small molecule of monosaccharides and saccharose.

Structural Characterization

The POS structure is complicated because of the complex chemical composition of pectin and the chemical alteration during POS production. The complex mixtures of POS can be analyzed using high sensibility and ability methods such as matrix-assisted laser desorption ionization-mass spectrometry (MALDI-MS) (92), electrospray ionization (ESI)-MS (93), capillary electrophoresis-MS (94), capillary electrophoresis with UV detection (95), and NMR and ESI-MS identification (96–98) with fluorescent labeling (99). Arabino-oligosaccharides degraded from sugar beet pulp pectin were able to be classified by MALDI-time-of-flight-MS and high-performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) (100). The M_w of POS can be evaluated using the size exclusion chromatography (SEC) (19, 101), HPAEC-PAD (64), as well as hydrophilic interaction liquid chromatography (HILIC) with online ESI ion trap-MS-evaporative light scattering detection (ELSD) (102). The presence of Mw of MPOS affected the probiotic growth because the utilization of prebiotics by lactic acid requires the presence of specific enzyme hydrolysis and transport systems for the particular prebiotic (103). The β-galactosidase activity in the tested strains was correspondent with low-molecular-weight substrate (104). For the quantity analysis of sugars in POS liquefaction, high-performance liquid chromatography (HPLC) (19), HPAEC-PAD (53), and HPAEC-fluorescence detection (105) are widely used to specify the monosaccharide contents in the recovered POS. The major sugar compositions of the oligosaccharide from mango peel were fructose (24.41%) and glucose (19.52%) (19).

In vivo and *in vitro* Performance

Pectic oligosaccharides have been proposed as a new class of prebiotics capable of exerting a number of health-promoting effects, including bifidogenic flora promotion, antioxidant activity (106), lowering the serum levels of total cholesterol and triglyceride (107), antiadhesive properties for food pathogen toxins (*E. coli* O157:H7), and apoptosis stimulation of colon cancer cells (108). For the simulation of prebiotic fermentation, *B. animalis* TISTR 2195 showed higher proliferation in 4% (w/v) of MPOS supplemented (8.92 log CFU/ml) than that of *L. reuteri* (8.53 CFU/ml) at 72 h of the fermentation time. This may be as a result of the intracellular enzymes of *Bifidobacterium,* which could hydrolyze the oligosaccharides into monosaccharides (i.e., glucose and fructose phosphates) and utilize them as a nutrient source (67). The main SCFAs derived from MPOS were acetic acid and propionic acid. Both acids are known as the main SCFAs derived from POS fermentation (109). The highest value of total SCFA was achieved from the 4% (w/v) MPOS supplementation for both *B. animalis* (68.57 mM) and *L. reuteri* (69.15 mM).

Besides, POS defends colonic cells against Shiga toxins (Stx) secreted from *E. coli* O157:H7 by neutralization of Stx activity from POS interaction with the galabiose receptor (110). The higher the molecular mass of POS, the greater the inhibitory activity obtained. This may be due to the increased access to
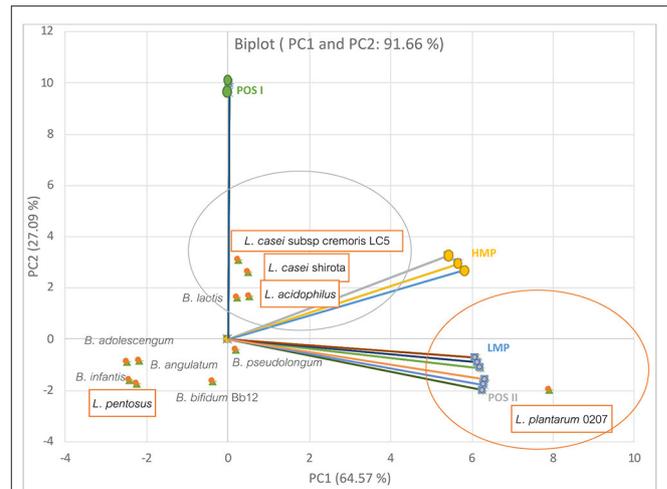

FIGURE 2 | The relationship between prebiotic types and the specific growth rate of selected gut bacteria. The plot was regenerated from the data presented in (84).

the receptor-binding sites on the toxin. POS also prevents the adhesion of P-fimbriated *E. coli* to uroepithelial cells *in vitro*. Oligogalacturonic acid, disaccharide, and trisaccharide were the most active POS (111). In the case of cancer preventative ability, POS can stimulate the apoptosis process in human colonic adenocarcinoma cells (112). The incident is due predominantly to the growth enhancement of *Bifidobacteria* and further promotes their immunomodulatory capacity (113). *In vivo* synergistic empowerment of immunomodulation caused by GOSs and FOSs mixed with pectin-derived acidic oligosaccharides showed systemic Th1-dependent immune responses in a murine vaccination model. It can therefore be assumed that the application of these oligosaccharides in infant formulas is beneficial for the development of the infant's immune system (114). The potential for *in vivo* cardiovascular protection of POS is also reported by Li et al. (107), and it was found that haw POS (HPOS) significantly reduced the serum levels of total cholesterol and triglycerides and inhibited the accumulation of body fat. Therefore, HPOS can be applied as a drug therapy to combat cardiovascular diseases. Additionally, *in vivo* and *in vitro* studies confirmed that acidic POS was not cytotoxic or mutagenic in the Ames test, making it suitable for use in food products for children and babies (60).

CLINICAL PRACTICE GUIDELINES

Prebiotics are substances that exist naturally in food or are fortified during manufacturing to improve the functional efficacy of probiotics. Food containing both prebiotics and probiotics is usually recognized as "symbiotic" (43). The fructan inulin is the common prebiotic that has been categorized as "Generally Accepted as Safe" by the American Food and Drug Administration (58). POSs of plant origins have been proposed
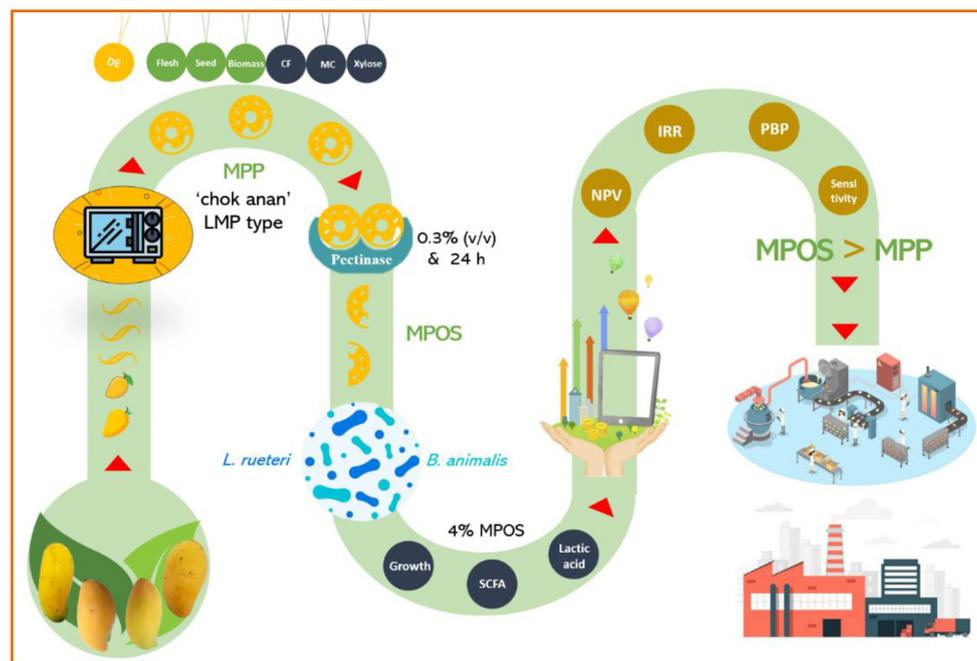
FIGURE 3 | Mango peel pectin and mango pectic oligosaccharide recovery from different varieties of mango fruits.

as excellent candidates for new-generation prebiotics (115–117). It is believed that microorganisms are able to utilize the carbon sources from POS better than they are with the polysaccharides, and in fact, pectinolytic enzymes are only characterized by *Bacteroides* sp. and *Clostridium butyricum-Clostridium beijerinckii* group in the human gut (84). The prebiotic effect of POS depends upon the M_w of the fractions. Low-molecular-weight POS has better prebiotic potential than high-molecular-weight POS (118), even though the clinical trials and toxicity studies are limited. POSs have also been shown to possess *in vitro* anti-inflammatory and antioxidant activity (66, 119). It also illustrates a vasoprotective effect that increased the serum SOD activity and lowered the content of MDA in these mice that are fed a high-fat diet, which can be used as a supplement for protection against cardiovascular diseases (107). Moreover, POS improves the gut mucosal structure, which is a barrier for rotavirus infection that induces diarrhea caused by damaging the intestinal organs in children and young animals (120). It is no doubt that MPOS is a novel prebiotic dietary fiber with antipathogenic potential against *Staphylococcus aureus*, *E. coli*, *Bacillus subtilis,* and *Salmonella typhimurium* (121). The research study regarding these novel prebiotic resources is in a very early stage. Optimization of the extraction and purification steps together with the characterization of POS derived from the

MPP still needs to be explored to a greater extent. Consequently, the clinical studies and safety evaluation of MPOS used in food should be performed. All in all, it is conclusively recommended from the information gathered herein that MPOS is a novel functional food ingredient that provides the opportunity for a sustainable development approach through biomass utilization (**Figure 3**).

AUTHOR CONTRIBUTIONS

SS and MW conceptualized the topic, researched and analyzed the literature, wrote the manuscript, and including interpretations. PT analyzed the background literature and drafted portions of the manuscript. NL, KJ, PR, PS, YP, TC, WR, and PJ provided substantial scholarly guidance on the conception of the topic, manuscript draft, and interpretation and revised the manuscript critically for intellectual content. All authors contributed to the article and approved the submitted version.

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