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Article

Sugar Composition of Apricot Fruit Oligosaccharides

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Abstract: Apricot pomace, a byproduct of fruit processing, is a rich source of pectin-derived oligosaccharides (POS) with potential applications in functional foods and nutraceuticals. This study aimed to characterize the sugar composition of POS fractions from apricot pomace using hydrolysis-extraction by high-performance liquid chromatography with refractive index detection (HPLC-RI). The analysis revealed that glucose (31–39%) and arabinose (24–37%) were the dominant sugars in all fractions, followed by maltose (16–20%) and sucrose (6–15%), with trace amounts of galactose and rhamnose detected in specific fractions. The highest yield of POS (12.7%) was obtained in the fraction isolated through membrane filtration. Compared to other fruit-derived POS, apricot POS exhibited a unique sugar profile dominated by arabinose, suggesting significant prebiotic potential. These findings highlight the value of apricot pomace as a sustainable source of bioactive compounds and provide a basis for further research into its structural and functional properties.

Keywords: Apricot pomace, Pectin-derived oligosaccharides (POS). Prebiotic potential

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1. Introduction

Fruit pomace, a byproduct of juice and pectin production, represents a valuable resource due to its high content of bioactive compounds such as prebiotics, antioxidants, and dietary fibers. Among these, oligosaccharides (OS) have garnered significant attention for their health-promoting effects and potential applications in functional foods and nutraceuticals. Oligosaccharides are short-chain carbohydrates consisting of monosaccharide units linked by glycosidic bonds [1], [2]. They exhibit resistance to digestion in the upper gastrointestinal tract, allowing them to reach the colon intact, promoting the growth of beneficial gut microbiota, promoting the production of volatile fatty acids, releasing constipation, reduce serum blood glucose, improve mineral absorption and lipid metabolism, prevent colonic cancer, inhibit pathogen adhesion, and modulate immune activity [3], [4], [5].

Functional oligosaccharides, including pectin oligosaccharides (POS), fructooligosaccharides (FOS), and xylooligosaccharides (XOS), are produced during the hydrolysis of plant cell walls. POS, in particular, has emerged as a promising class of prebiotics with demonstrated benefits such as improving gut health, reducing serum

cholesterol levels, modulating immune responses, and exerting anticancer effects. Despite these promising attributes, the potential of POS as value-added byproducts from pectin extraction processes remains underexplored [6], [7].

Previously, we reported isolating fat, waxes, and pectin oligosaccharides (POS) from different fruits. In another study, we investigated the effects of pectin and POS from various sources on bile acid biosynthesis and cholesterol

levels in rats [8], [9]. Notably, significant differences were observed in bile flow and the biliary secretion of lipids between animals receiving a crude pectin-supplemented diet—containing pectin oligosaccharides and polyphenols— and those receiving a control diet. Rats fed with pectin exhibited lower levels of biliary cholesterol and bilirubin, alongside increased phospholipids and bile acid pool size, compared to the control group. Interestingly, these effects were more pronounced in rats fed peach and apricot pectin, while the response was less significant with quince pectin. These findings highlight the functional potential of POS in modulating lipid metabolism and promoting gut health [10], [11].

Apricot pomace, an abundant byproduct in Central Asia, is a rich source of POS. The apricot is widely cultivated and consumed in various forms, including fresh, dried, and processed products. In addition to its nutritional value, apricot fruit contains multiple phytochemicals, including vitamins, carotenoids, and polyphenols, contributing to its antioxidant properties. Apricot pomace, often discarded as waste, could be a cost-effective raw material for extracting functional oligosaccharides [12], [13].

This study aims to characterize the sugar composition of oligosaccharides extracted from apricot pomace obtained during pectin production. Using hydrolysis and diaultrafiltration processes, three fractions of oligosaccharides were isolated and analyzed via high-performance liquid chromatography with refractive index detection (HPLC-RI). The findings provide insights into the potential utilization of apricot-derived oligosaccharides in food and pharmaceutical applications, contributing to sustainable waste valorization and functional ingredient development [14], [15].

2. Materials and Methods

Fresh apricot (*Prunus armeniaca L.*) fruits were purchased from a local market in Tajikistan in May. A total of 4,450 g of fresh fruit was used, from which the juice (1,800 mL) was extracted, and the kernel (630 g) was separated. The remaining pomace, accounting for 1,750 g (250 g dry weight), was used as the raw material for pectin and oligosaccharide extraction. Analytical-grade reagents, including concentrated hydrochloric acid and ethanol, were used for hydrolysis and precipitation. Standard sugars (sucrose, D-glucose, D-galactose, L-arabinose, and L- rhamnose) were purchased from Sigma-Aldrich (USA).

Extraction and Fractionation of Oligosaccharides

The apricot pomace residue (1,700 g) was subjected to hydrolysis by mixing it with 2,500 mL of concentrated hydrochloric acid to adjust the pH to 2.0. The mixture was autoclaved using a flash method at elevated temperatures for 5 minutes (13). The resulting hydrolysate solution (5,150 mL) was separated from the cell wall residues via filtration. The hydrolysate was cooled with ice containers, neutralized to pH 3.4, and centrifuged to yield a purified solution (F1) and a residual precipitate (microgel, F2).

Diaultrafiltration and Oligosaccharide Isolation

The purified hydrolysate solution (F1) was subjected to diaultrafiltration (DUF) using a 100 kDa molecular weight cut-off (MWCO) polysulfone membrane on a KrosFlo DUF system (KrosFlo, USA). The resulting fractions were further processed:

1. POS-UFR. The retentate solution was concentrated and precipitated by adding twice the alcohol volume.

2. POS-UFP. The permeate solution was subjected to sequential filtration using 5 kDa and 1 kDa MWCO membranes. The resulting fractions were named F1C1 (5 kDa retentate) and F1C2 (1 kDa permeate).

The microgel (F2) was washed with hot alcohol for 40 minutes, followed by concentration and drying to yield 9.49 g of extract. The insoluble portion was treated with 10% ethanol to extract oligosaccharides and polyphenols, producing the POS-MG fraction.

HPLC-RI Analysis of Oligosaccharides

The monosaccharide composition of isolated water-soluble POS fractions was analyzed using high-performance liquid chromatography with refractive index detection (HPLC-RI). The extracted POS powders were dissolved in deionized water, filtered through a 0.45 μm membrane, and degassed before analysis.

Equipment and Conditions.

Standard carbohydrates, including sucrose, D-glucose, D-galactose, L-arabinose, L-rhamnose, and sorbitol, were purchased from Sigma-Aldrich. The chromatographic separation of monosaccharides was accomplished using a Waters HPLC system (Waters Company, Milford, MA, USA) equipped with a 1515 Isocratic Pump, 717 Autoinjector, and 2414 Refractive Index detector. Peak detection and integration were carried out using Breeze Chromatographic System software (Waters).

The separation was performed using a Varian MetaCarb 67C carbohydrate column (0.65 x 30-cm bed packed with a Varian cation-exchange resin in the Ca^{2+} ionic form, connected to an in-line filter and a guard). The column was equilibrated with distilled deionized water as the mobile phase, with a flow rate maintained at 0.5 mL/min. The column temperature was set to 90 °C. A 20 μL standard or sample solution volume was injected into the column.

Calibration and Sample Analysis.

The standard sample concentration range was 10–100 mg/L, and calibration curves were generated by injecting standard sugars at known concentrations. The calibration data were saved and analyzed using Breeze software to quantify the sugar composition of the extracted samples. The chromatograms were used to determine retention times and peak areas for sucrose, glucose, galactose, arabinose, rhamnose, and sorbitol, providing a detailed sugar profile of the fractions.

Statistical Analysis.

All experiments were performed in triplicate. The data were expressed as means ± standard deviation (SD). Statistical analysis evaluated the variability of sugar yields and compositions across the fractions. Correlation coefficients for calibration curves were calculated using linear regression, with an acceptance threshold of R^2>0.99.

3. Results

Chromatographic Profiles

The HPLC-RI chromatograms revealed distinct glucose, arabinose, maltose, and sucrose peaks in all fractions. Peaks corresponding to galactose and rhamnose were observed only in the POS-MG chromatogram. The chromatographic retention times (Rf) and peak areas indicated excellent separation and quantification of sugars. The calibration curves for all standard sugars in Figure 1 exhibited high linearity (R^2>0.99).

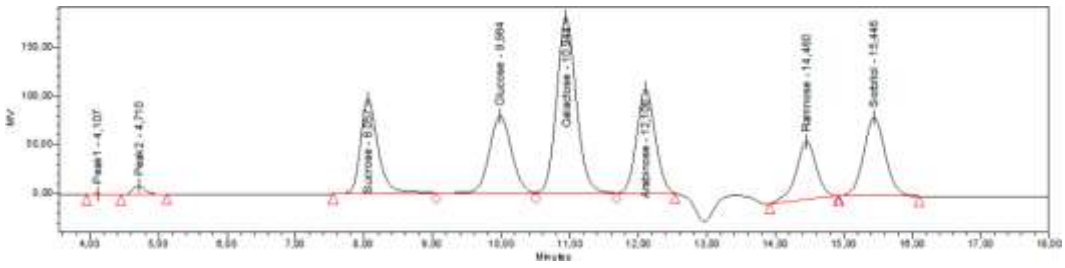

Figure 1. The chromatograms of sugar mixtures (sucrose, D-glucose, D-galactose, L-arabinose, L-rhamnose, and sorbitol). The column Varian MetaCarb 67C, the column temperature is 90 oC, the mobile phase is DI-ionized water, flow rate 0.5ml/min, sample injection volume 20ul, and RI sensitivity 64. The sample concentration is 1000 mg/L.

Figures 2, 3, and 4 present the HPLC-RI chromatograms of the POS-MG, POS-UFR, and POS-UFP fractions, respectively. Each chromatogram displayed well-defined peaks corresponding to the dominant sugars (glucose, arabinose, maltose, and sucrose), with retention times aligning with those of the standard sugars. Peaks for galactose and rhamnose were observed only in the POS-MG chromatogram.

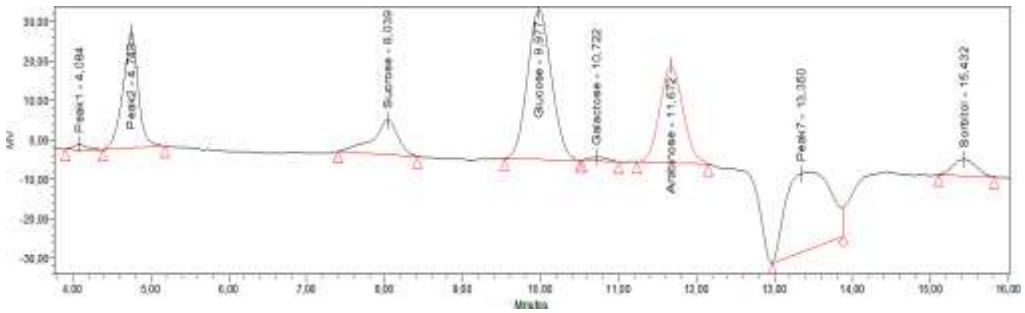

Figure 2. HPLC-RI chromatogram of the POS-MG fraction, showing peaks for glucose, arabinose, maltose, sucrose, galactose, and rhamnose.

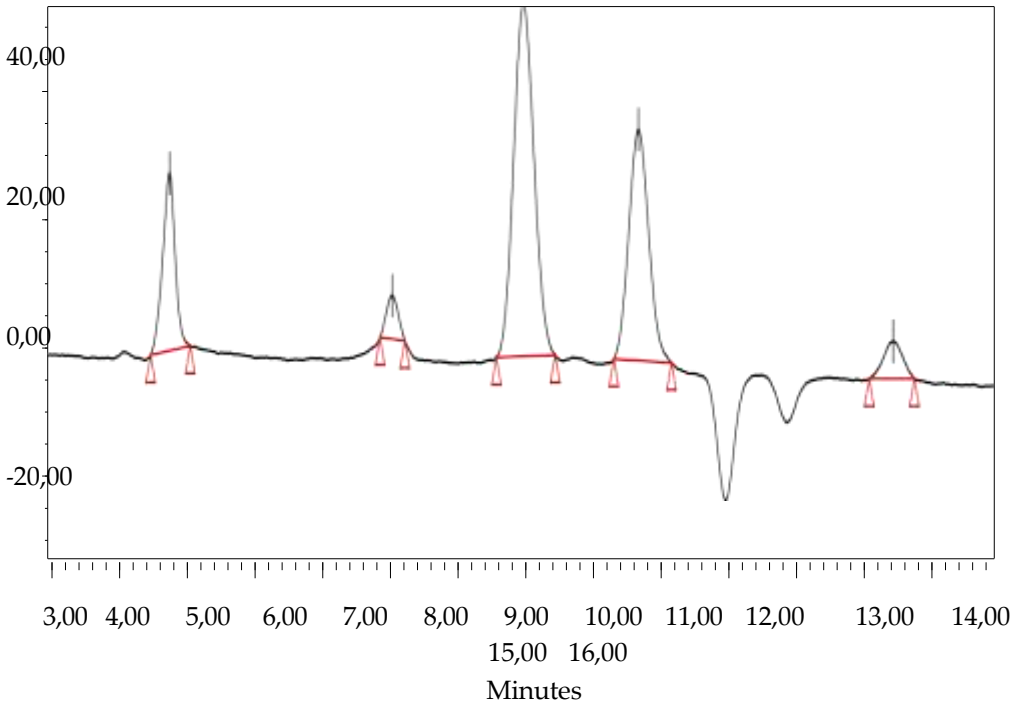

Figure 3. HPLC-RI chromatogram of the POS-UFR fraction, displaying dominant peaks for glucose, arabinose, maltose, and sucrose.

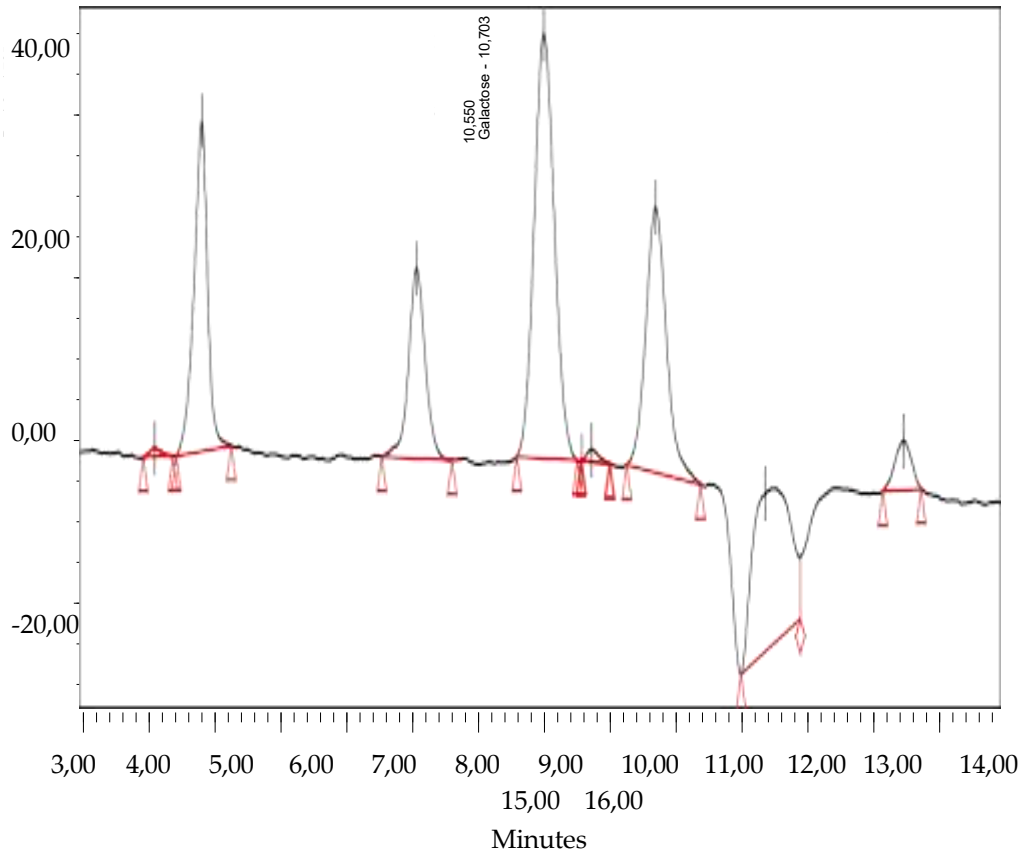

Figure 4. HPLC-RI chromatogram of the POS-UFP fraction, illustrating the distribution of glucose, arabinose, maltose, and sucrose.

Yield and Composition of Oligosaccharide Fractions

Three oligosaccharide fractions were obtained during the processing of apricot pomace: POS-MG (from microgel extract), POS-UFR (retentate from diaultrafiltration), and POS-UFP (permeate from diaultrafiltration). The yields of these fractions were 3.52%, 12.7%, and 2.14%, respectively, relative to the dry weight of the pomace. Among these, the highest yield was observed in the POS-UFR fraction, indicating a significant concentration of oligosaccharides in the retentate during diaultrafiltration, see Table 1 [14]. Table 1 shows retention time (Rf), area and height of peaks, quantity of loaded sugars, recovery in mg/L, and percentage of sugars generated from the calibration curve of Figure 1.

Table 1. The retention time, area and peak parameter of standard sugars.

#	Referred Peak	Retention Time	Area	Height	Amount, mg/L (By HPLC-RI)	Theoretical concentration, mg/L	Recovery, %
1	Maltohexose	4,107	16732	1305			
2	Maltopentose	4,710	123071	9572			
3	Sucrose	8,057	1763764	97757	64.45	60.6	99.4
4	Glucose	9,984	1823640	80052	53.12	53.4	99.5

5	Galactose	10,944	3621038	181212	54.31	55.2	98.4
6	Arabinose	12,106	2022201	107001	62.62	64.2	97.5
7	Rhamnose	14,460	1237949	59576	69.08	67.8	98.1
8	Sorbitol	15,446	1766661	80947	52.16	55.2	94.5

HPLC-RI Analysis of Monosaccharides and Disaccharides

The sugar compositions of the POS fractions were analyzed using HPLC-RI. The dominant sugars identified in all fractions were glucose, arabinose, maltose, and sucrose, with trace amounts of galactose and rhamnose observed primarily in the POS-MG fraction [15], [16], [17]. The monosaccharide and disaccharide compositions for each fraction are summarized in Table 2.

Table 2. The retention time, monosaccharide composition, yield of the POS fractions

Referred Peak	Rf, min	POS-MG		POS-UFR		POS-UFP	
		mg/L	%	mg/L	%	mg/L	%
Maltopentose	4.762	12.543	16.31	17.67	19.09	17.67	20.11
Sucrose	8.025	5.522	7.18	13.6	14.70	5.49	6.25
Glucose	9.913	23.939	31.14	33.69	36.40	34.21	38.94
Galactose	10.920	1.756	2.28	-	-	-	-
Fructose	11.664	-	-	-	-	-	-
Arabinose	12.133	26.548	34.53	22	23.77	24	27.32
Arabitol	13.333	3.757	4.89	3.385	3.66	4.207	4.79
Rhamnose	14.434	0.552	0.72	-	-	-	-
Sorbitol	15.416	2.265	2.95	2.2	2.38	2.28	2.60
POS fraction yield		-	3.52	-	12.7	-	2.14

The composition of sugars varied across the fractions. Glucose and arabinose were the most abundant sugars, accounting for 31–39% and 24–35%, respectively, in all fractions. Maltose was consistently present at 16–20%, and sucrose ranged from 6–15%. The POS-MG fraction retained small amounts of galactose and rhamnose, likely adsorbed onto the microgel components during the extraction process. These sugars were not detected in the POS-UFR and POS-UFP fractions, suggesting their removal during membrane filtration.

The results indicate that based on their sugar composition, the oligosaccharides derived from apricot pomace can be classified primarily as gluco-arabino and malto oligosaccharides. The predominance of glucose and arabinose in the fractions suggests a linkage pattern common to prebiotic oligosaccharides, although further structural analysis would be required to confirm this.

The study demonstrates that the diaultrafiltration process effectively concentrates oligosaccharides in the retentate (POS-UFR) while allowing smaller sugars and other byproducts to pass into the permeate (POS-UFP). This highlights the potential for process optimization to maximize oligosaccharide recovery from apricot pomace.

4. Discussion

The study successfully characterized the sugar composition of oligosaccharides (OS) derived from apricot pomace, a byproduct of pectin extraction, using HPLC-RI. The analysis revealed that glucose, arabinose, maltose, and sucrose were the dominant sugars in all fractions, with trace amounts of galactose and rhamnose observed in the POS-MG

fraction. The findings highlight the potential of apricot pomace as a valuable source of gluco-arabino and malto oligosaccharides, with implications for their use in functional foods and nutraceuticals.

The highest yield of oligosaccharides was obtained in the POS-UFR fraction (12.7%), which contained the concentrated retentate from the diaultrafiltration process. This suggests that the separation process effectively isolates larger oligosaccharides, retaining them in the 5 kDa membrane. The relatively low yields of the POS-MG (3.52%) and POS-UFP (2.14%) fractions indicate that these fractions may represent either less soluble oligosaccharides or smaller sugar components that pass through the membrane filtration system. These findings emphasize the importance of optimizing the extraction and filtration processes to maximize oligosaccharide recovery.

The sugar composition varied between the fractions:

1. **POS-MG:** Contained significant amounts of glucose (31.14%) and arabinose (34.53%), with smaller contributions from maltose (16.31%) and sucrose (7.18%). Trace amounts of galactose (2.28%) and rhamnose (0.72%) were observed, likely adsorbed onto the microgel matrix during extraction.
2. **POS-UFR:** Had the highest glucose content (36.40%) and relatively balanced amounts of arabinose (23.77%) and maltose (19.09%), along with a higher sucrose content (14.70%) compared to other fractions.
3. **POS-UFP:** Displayed the highest relative concentration of glucose (38.94%) and arabinose (27.32%), with maltose (20.11%) and sucrose (6.25%) present in smaller proportions.

The findings of this study on apricot-derived pectin oligosaccharides (POS) provide valuable insights into their composition and potential applications, particularly when compared with existing literature on pectin oligosaccharides from other fruit sources. The sugar profile of apricot POS, dominated by glucose, arabinose, maltose, and sucrose, reflects the unique characteristics of apricot pomace as a raw material. Trace amounts of galactose and rhamnose in specific fractions further highlight the distinct structural attributes of apricot-derived POS. This composition contrasts with citrus-derived POS, which are primarily characterized by high levels of galacturonic acid alongside notable quantities of glucose and galactose. The dominance of neutral sugars in apricot POS suggests differences in functional properties, such as solubility and bioactivity, compared to the acidic sugar-rich citrus POS.

The compositional differences observed between apricot and citrus POS underscore the influence of the source material on pectin-derived oligosaccharides. In citrus POS, galacturonic acid is associated with strong immunomodulatory and antioxidant properties and a higher degree of polymerization (DP3–DP8). In contrast, apricot POS's glucose- and arabinose-rich profile suggests their potential for prebiotic applications, promoting the growth of beneficial gut microbiota such as *Bifidobacteria* and *Lactobacillus*. These differences in sugar composition and structure highlight the diversity of pectin oligosaccharides across sources and suggest the possibility of tailored applications depending on the origin and processing of the pectin.

The methodologies employed in this study further differentiate the findings from existing literature. While this study relied on HPLC-RI for sugar composition analysis, other studies, such as those on citrus POS, have incorporated advanced techniques like LC/MS for molecular weight distribution and glycosidic linkage analysi. Another of our research on apricot pectin polysaccharides has utilized NMR spectroscopy and FTIR to explore structural diversity and branching. Incorporating such advanced analytical methods into future studies of apricot-derived POS could provide deeper insights into their molecular structure, glycosidic linkages, and functional properties.

The unique structural features of apricot-derived POS align with findings from broader pectin research. For example, previous studies on pectin-cellulose interactions in tomatoes and carrots have demonstrated how the cell wall matrix can influence the characteristics of extracted pectin and its derivatives. Given their source from pomace, such interactions likely play a role in the yield and properties of apricot POS. The use

of diaultrafiltration and other fractionation methods in this study successfully isolated distinct POS fractions, further highlighting the versatility of apricot pomace as a resource for bioactive compounds.

5. Conclusion

This study demonstrated that apricot pomace, a byproduct of the fruit processing industry, is a rich source of pectin-derived oligosaccharides with unique sugar compositions. The analysis revealed that glucose, arabinose, maltose, and sucrose were the dominant sugars across different POS fractions, with minor amounts of galactose and rhamnose in specific fractions. The compositional differences between the fractions highlight the effectiveness of diaultrafiltration in isolating oligosaccharides with distinct molecular profiles.

The apricot POS's glucose- and arabinose-rich profile suggests significant potential for prebiotic applications, particularly in promoting the growth of beneficial gut microbiota such as *Bifidobacteria* and *Lactobacillus*.

The valorization of apricot pomace supports sustainability efforts by utilizing agricultural byproducts as sources of valuable bioactive compounds. While this study successfully characterized the sugar composition of apricot POS, future research should focus on detailed structural analyses, including glycosidic linkages and degrees of polymerization, to better understand their functionality. Additionally, *in vivo* and *in vitro* studies are necessary to evaluate the biological efficacy of apricot POS, particularly their prebiotic and health-promoting properties.

In conclusion, apricot-derived POS represents a promising resource for developing functional ingredients with applications in health and nutrition. The findings of this study contribute to the growing body of knowledge on pectin oligosaccharides and their potential uses, paving the way for further research and industrial applications.

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