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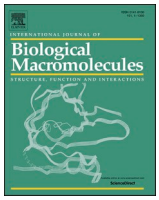

Comparative study on thermo-mechanical, structural and functional properties of pectin extracted from immature wasted apples and commercial pectin

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ABSTRACT

Pectin yield of 22.22 ± 0.98 % (dry basis) was achieved from prematurely dropped Golden Delicious apples, having a light orange hue (hue value: 78.08 ± 0.04) and an overall color difference (ΔE) of 9.92 ± 0.01 compared to commercial pectin (CP). Extracted AP exhibited a lower equivalent weight (725.24 ± 29.73) and higher methoxy content (8.36 ± 0.28 %) in contrast to CP. However, a similar degree of esterification of 71.57 ± 0.79 and 70.55 ± 0.59 %, was observed in AP and CP respectively. Apple pectin demonstrated slight lower galacturonic acid (GalA) content of 68.10 ± 3.94 % in comparison to 72.31 ± 4.62 % of CP, which was further corroborated by reduced intensity in FTIR fingerprint region (912–1025 cm^{-1}). Morphology revealed a sheet-like cloudy appearance indicating a significant presence of associated sugars whereas X-ray diffraction highlighted the highly amorphous nature of AP. AP and CP solutions (3–9 %) displayed a shear-thinning flow and viscoelastic behavior where the loss (G') moduli dominated over the storage moduli (G"). Owing to high degree of esterification, galacturonic acid content (>65 %) that aligns with commercial standards and viscoelastic behavior, the extracted AP holds promise for potential utilization in commercial applications. This study underscores the potential for sustainable utilization of prematurely dropped apples through pectin extraction, contributing to valorization of the wasted bioresource.

1. Introduction

Biopolymers viz. polysaccharides and polypeptides are of immense importance due to renewability, sustainability and applicability in diverse fields of food processing, packaging, biomedicine, drug delivery, water purification, etc. [1–3]. Agro-waste is rich in natural biopolymers, often containing multiple types within a single source [4]. Pectin, a hydro-colloidal hetero-polysaccharide of α-D-polygalacturonic acid, is found in the cell wall and middle lamella of dicotyledonous plants as proto-pectin, and formed through artificial or natural hydrolysis, which converts it into soluble pectin, pectic acid, and finally, pectinic acid [5]. Pectin is characterized by the esterification of carboxylic acid groups in the polymer chain, with high and low methoxy pectin corresponding to greater than and lower than 50 % DE, respectively [6]. It has health-promoting effects, especially in diabetics and cholesterol maintenance, and its global market is expected to reach 1.8 billion USD (2026, CAGR = 6.5 %) [7]. Also, it has numerous food and non-food functional applications, with a growing demand for its use in various industries. Commercial pectin extraction is currently done from apple and citrus fruits using mineral acids, but new technological interventions are being explored for commercial viability [8]. It holds a remarkable potential in the food, pharmaceutical, and biotechnological sectors due to its gelling, stabilizing, and emulsifying properties. The valorization of pectin from underutilized sources presents an opportunity to mitigate food waste, reduce environmental impact, and bolster the supply of this versatile biopolymer.

Circular economy, often referred to as the "zero waste" approach, is a holistic strategy that encompasses material reduction, recycling, and reuse. Projections indicate a substantial increase in global waste generation, rising from 2010 million MT (as of 2016) to an estimated 3400

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