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Thermal and functional properties of a biofilms composed of fruits and vegetables waste

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Abstract

This study includes the development of biofilms from orange peel (OP), apple pomace (AP), tomato pomace (TP), and potato peel (PP). Thermogravimetric analysis (TGA), fourier transform infrared spectroscopy (FTIR), transparency, and water solubility were performed on the synthesized films. The biofilms were prepared using the casting method. The OP, AP, and TP, along with pectin and glycerol, form a flexible film at a concentration of 6%, whereas the PP forms a film at 4%. The TGA results showed that the OP film has the highest decomposition temperature, ranging from 194.5°C to 246.92°C. The FTIR spectra of the biofilms revealed the interaction between the plasticizer and polysaccharide compounds. The pectin film (PF) had a transparency of 2.19%, while the TP film had a transparency of 7.45%, the highest among the fruit & vegetable waste (FVW) films. The lower the transparency score, the more transparent the film. The water solubility of PF film was 89%, while that of FVW-based films was lower. The usage of FVW-based biofilms and their use in food packaging would minimize plastic products, resulting in reduced pollution.

Keywords biofilms, biomaterials, food packaging, FTIR, TGA

Introduction

A large amount of waste has been produced by the fruit and vegetable (F&V) processing industry. The waste generated by it has resulted in significant nutritional and economic losses, as well as environmental issues [1]. The processing of F&V alone generates enormous waste, amounting to 25–30% of the entire product [2]. Pomace, peels, rind, and seeds are the most common wastes and are high in useful bioactive substances such as carotenoids, enzymes, polyphenols, oils, and vitamins [3]. FVW is disposed of in landfills or incinerators after being mixed into municipal waste streams. However, because of its high water content, which causes microbiological instability, off-odor formation, and leachate, it is not the right option for FVW disposal [4]. FVW has high reuse, recycling, and energy recovery potential [4]. In recent decades, the application of biomaterials in the food sector has grown in importance as a means of reducing pollution [5]. The FVW used in this research were orange peel (OP), apple pomace (AP), and potato peel (PP), and tomato pomace (TP). Researchers have been active in the conflict resolution of pollution caused by the food manufacturing and the prospect of re-using it not just for livestock feed or organic fertilizer, but also as raw resources for unique products over last two decades [6]. The biomass generated by the F&V manufacturing industry is high in polysaccharides such as starch, cellulose, dietary fibres, pectin and bioactive substances [7]. Cellulose, hemicelluloses and pectin are abundant in dry citrus peels, whereas apple pomace comprises 7.2- 43.6% cellulose, 4.26- 24.40% hemicelluloses, 15.2- 23.5% lignin, 3.5- 14.32% pectin, and 4.7- 51.10% fibre [8]. These natural polymers have the potential to form bioplastics and their use as food packaging materials. This research work aims to analyze the prepared biofilms by TGA, FTIR, transparency, and water solubility.

Methodology

The raw materials OP, AP, and TP were collected from Juice-Stuff, Mahewa, Prayagraj. The PP was obtained from SHUATS, Canteen Prayagraj. The glycerol (M.W. 92.10) was procured from Rankem (Thane, India). Qualigens (Thermo Fisher Scientific India Pvt. Ltd Powai, Mumbai) supplied citric acid monohydrate, and pectin was acquired from Central Drug House Pvt. Ltd. The current experiment was carried out in the Food Process Engineering Department, SHUATS, Prayagraj.

Biofilm preparation

To remove the soluble sugars, the FVW was washed under running tap water. The washed FVW was immersed in water for 12hr before being washed twice more. The ratio of water to FVW was 1.5:1. After washing, the waste was trimmed using a knife and dried in a tray dryer at 50°C for 12 hr. A grinder was used to grind the dried material into a fine powder. The composition of the biofilms is shown in Table 1. The biofilms were prepared by using FVW powder; pectin and glycerol. A mixture of citric acid monohydrate solution (1%) with FVW powder and pectin was prepared and it allows for dissolving at 40°C for 30 minutes with steady magnetic stirring. The FFS (film-forming solution) was formed and 30 ml of the FFS was cast onto the glass petri-plate having a diameter of 9cm. The plates were dried at 50°C for 14hr. The drying was done in a hot air oven, and the cast films were removed. The biofilms were formed according to the method described by [9].

Characterization of biofilms

The prepared biofilms were analyzed for thermal property (TGA), FTIR, water solubility and transparency of film.

Thermogravimetric analysis

A thermogravimetric analyzer was used to test the thermal stability of bioplastics films (Make: shimadzu, Model: TGA 50). Under a nitrogen environment, a selected sample was heated from room temperature to 700°C at a rate of 10°C/min.

Fourier Transform Infrared Spectroscopy

An FTIR spectrophotometer (Shimadzu, IR affinity-1S) was used to obtain FTIR spectra ranging from 4000 to 400 cm^{-1}. The number of scans taken for each sample was 45.

Transparency of the biofilms

A UV-visible spectrophotometer (Make: Microtech, Model: Jasper, UV007) was used to evaluate the film's transparency in terms of opacity at a wavelength of 600nm [10]. Equation (1) was used to compute the opacity:

$$\text{Opacity} = \frac{\text{Abs600}}{x} \quad \text{.......(1)}$$

The film thickness in mm is x, and Abs600 is the absorbance measured at 600nm.

Water solubility

The film's water solubility was tested in triplicate using the previously reported procedure by [11]. The film samples (2x2 cm) were dried for 24hr at 100°C in a drying oven before being weighed to determine the initial film composition. The samples were incubated for 24hr at 25°C in glass beakers containing 100 ml of distilled water. After that, samples were dehydrated for 24hr at 100°C in a drying oven, and the resulting solid was weighed to determine the weight of the water-soluble solid. The dried film's water-dissolved fraction was determined using equation 2.

$$WS\ (\%) = \frac{W_0 - W_f}{W_0} \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where, W_0 = Original dry film weight, W_f = Weight of the insoluble dried film.
All the tests were repeated three times.

Statistical analysis

All treatments were performed three times. An analysis of variance (ANOVA) was performed on the experimental data using SAS 9.1. (SAS Institute Inc., Cary, NC, USA). Tukey's method was used to evaluate if there was a significant difference between treatments at a level of significance ($p<0.05$). All of the data was presented using the mean standard deviation.

Results and Discussion

Thermogravimetric analysis (TGA)

TGA was used to investigate weight variations as a result of temperature and time, and a difference between films was observed in this experiment. The PF demonstrated the two major decomposition stages depicted in Figure 1A. The pectin decomposition starts at 189.21°C and the second major thermal decomposition occurred at 246.51°C. The thermal behavior of pectin is affected by its chemical composition as well as state transitions that occur during processing [12]. The temperature at the end of pectin decomposition was 315.66°C. The total weight lost during the procedure was 94.60%. The amount of weight loss was greater than previously reported by [9]. Figure 1B shows the TGA analysis for OPF. It includes the decomposition stages, with the initiation of decomposition beginning at 194.5°C and ending at 246.92°C. Weight reduction was 64.96% in the first stage and 22.78% in the second stage. In the second stage, the decomposition began at 559.6°C and ended at 610.5°C. The thermal degradation of the APF, TPF and PPF film is shown in Figures 1 C-E. The degradation took place at a lower temperature than that of PF. The addition of glycerol alters the structure and creates a gap between the polymers, resulting in thermal degradation at lower temperatures than PF [13]. The decomposition temperature observed for FVW films was much lower than the cellulose film made from vegetable waste by Bayer et al., [14].

Fourier Transform Infrared Spectroscopy

FTIR spectroscopy was used to investigate the nature and interaction of the compounds. The FTIR spectrum of the PF is shown in Figure 2 A. The peaks observed between 3500 to 2800 cm^{-1} correlate to free hydroxyl stretching vibration and asymmetric and symmetric stretching of N-H bonds in the amino group. Sharp peaks observed between 1406.1 to 1016.49 show the presence of alkanes and alkyl amine [15]. Figures 2 B–E show the FTIR spectrum of the OPF, APF, TPF, and PPF, respectively. The OPF spectra in Figure 2 B represent, a peak between 3695-3332 corresponding to the stretching vibration of bonded amines & amide (N-H/ C-H/ O-H), 1099 (C-H), 530-420 corresponding to the asymmetric bending of So_4 group. The APF showed the O-H stretching surface hydroxyl groups & H_2O at 3338-2933 whereas at 1014-1224 (C-O stretching vibration) an increase in the absorbance band at 1438 to 1014. In the case of PPF peak values observed were 3695 (O-H stretching vibration), and the frequency of C-O in the alcohol hydroxyl group is 1014.5. The TPF hit a peak of

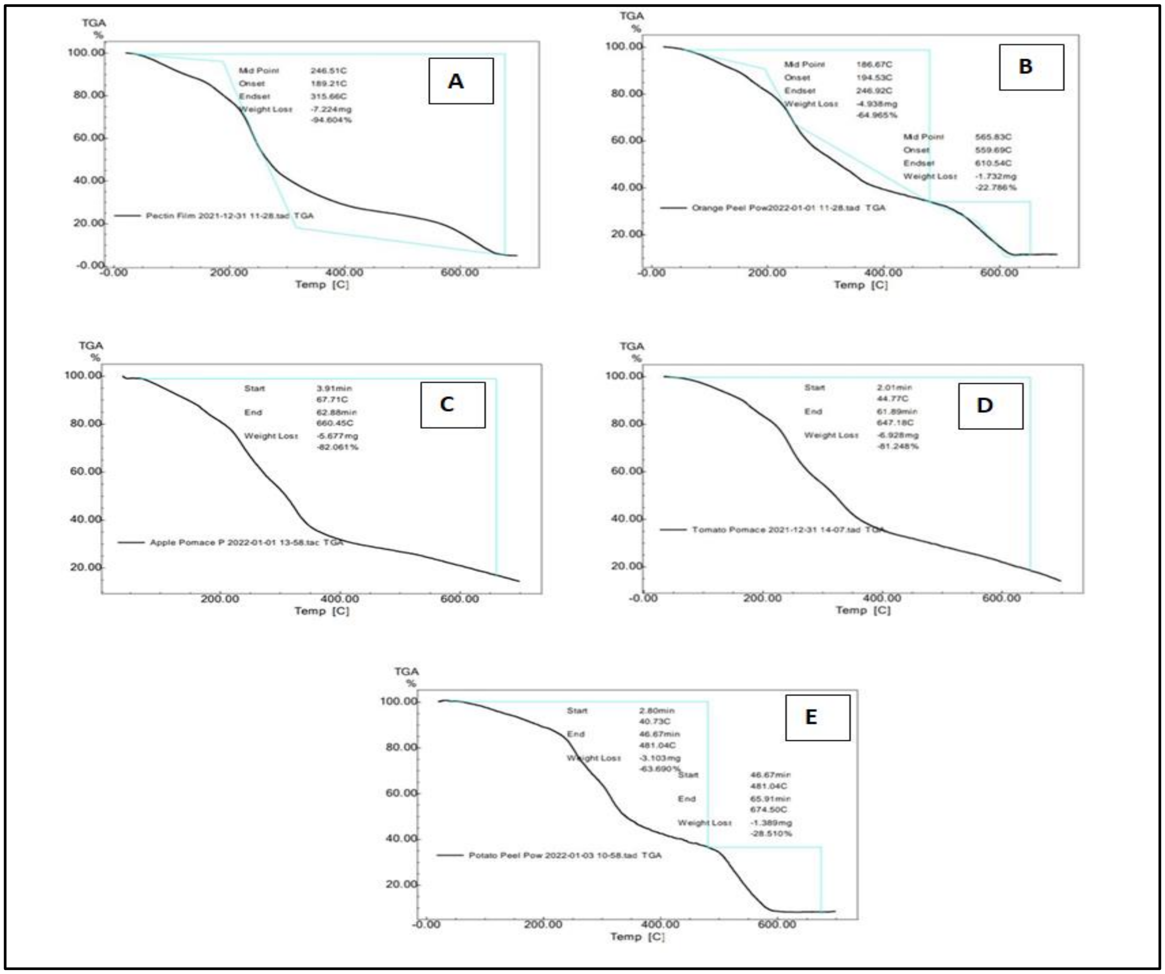

Figure 1. (A) TGA curve of Pectin Film (B) TGA curve of Orange Peel Film (C) TGA curve of Apple Pomace Film (D) TGA curve of Tomato Pomace Film (D) TGA curve of Potato Peel Film

Table 1. The Composition of FVW based Biofilms

Biofilms	FVW Powder (%)	Pectin (%)	Glycerol (%)	Citric acid solution (%)
PF	-	4	0.5	95.5
OPF	6	4	0.5	89.5
APF	6	4	0.5	89.5
TPF	6	4	0.5	89.5
PPF	4	4	0.5	91.5

[a]PF- Pectin Film, OPF- Orange Peel Film, APF- Apple Pomace Film,
TPF- Tomato Pomace Film, PPF- Potato Peel Film. [b]FVW- Fruit and Vegetable Waste

3311(carboxylic acid). The film samples showed peaks between 400-600 cm^{-1} which represents the dye came from the FVW [16]. The FVW films also showed peaks at a wavelength which gave an idea about the presence of polyphenolic compounds [17].

Transparency in terms of opacity

Table 2 shows the transparency of the film in terms of opacity. The PF showed the less transparency while the PPF showed the highest transparency value i.e., 2.19%, and 23.19% respectively. The lower the transparency value, the more transparent the film [18].

Table 2. Transparency of the Biofilms

Films	Transparency (%)
PF	$2.19^{e} \pm 0.02$
OPF	$21.22^{b} \pm 0.16$
APF	$18.39^{c} \pm 0.1$
TPF	$7.45^{d} \pm 0.015$
PPF	$23.19^{a} \pm 0.28$

[a]PF- Pectin Film, OPF- Orange Peel Film, APF- Apple Pomace Film, TPF- Tomato Pomace Film, PPF- Potato Peel Film. [b]Different letters in the columns indicate that there are statistically significant variations between samples (p <0.05).

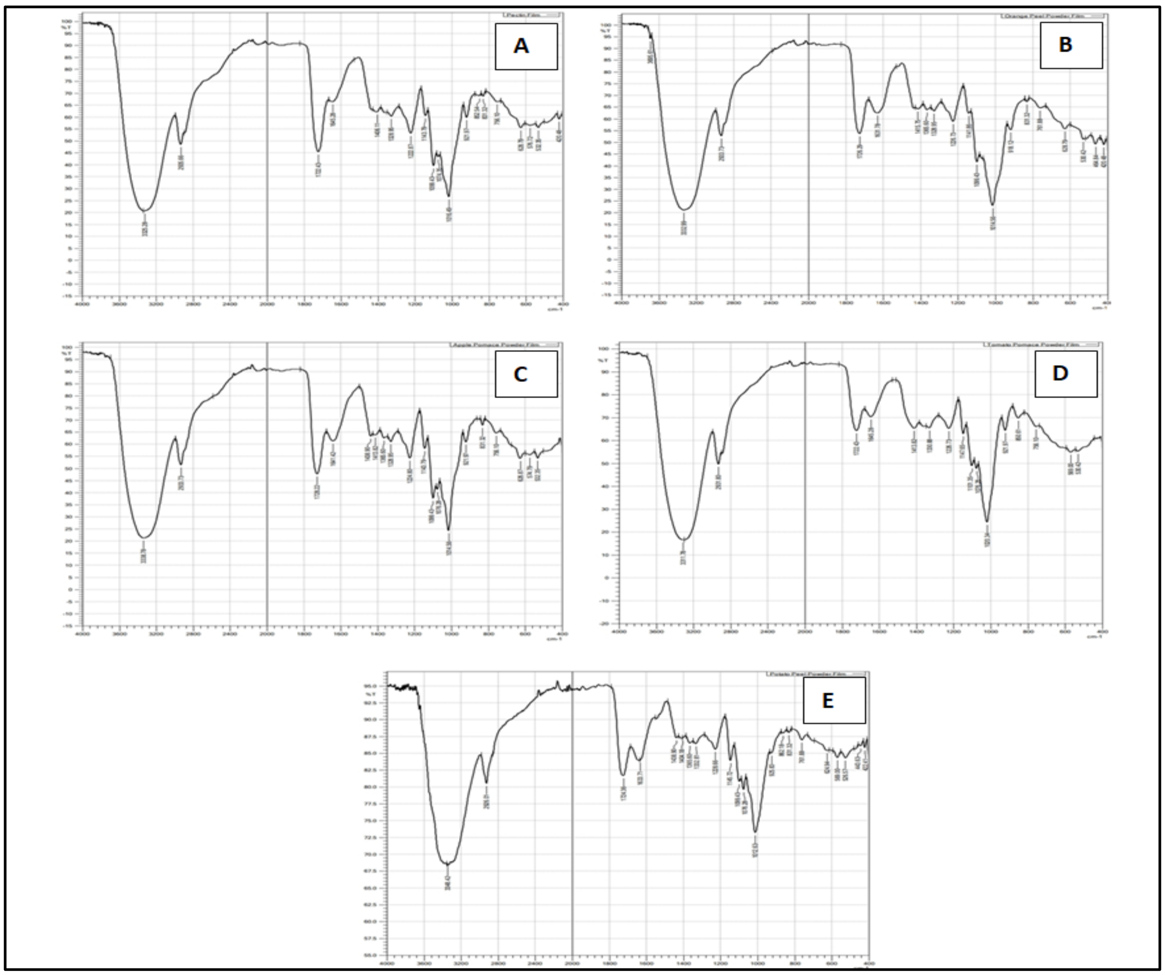

Figure 2. (A) Pectin Film's FT-IR Spectra (B) Orange Peel Film's FT-IR Spectra (C) Apple Pomace Film's FT-IR Spectra (D) Tomato Pomace Film's FT-IR Spectra (E) Potato Peel Film's FT-IR spectra

The TPF had the lowest transparency value of 7.45% when compared to other FVW films. The transparency of the OPF and APF was 21.22% and 18.39% respectively. The greater the thickness value, the more turbid and less transparent the film [19]. The wavelength affects the film's transmittance; at longer wavelengths, the film shows more transparency [20]. The transparency values were comparable to the previous study's findings [21].

Water solubility

Table 3 shows the water solubility of biofilms. Pectin film showed highest water solubility 89.8% as pectin is soluble in water and film loses its structure and dissolves in water within 15-20 min [22]. The water solubility of the FVW based films was in the range of 71-77% because cellulose is water insoluble but can be dissolved in extremely acidic and alkaline solutions. The addition of FVW powder reduces the water solubility [23]. PP contains the highest amount of cellulose among the vegetables [24] and its water solubility was lower than that of other films. The water solubility of films shows that free -OH or -COOH groups of starch and pectin polymers may have a high attraction for water [25].

Table 3. Biofilms water solubility

Films	Water solubility (%)
PF	89.80^{a} ±0.10
OPF	71.47^{c} ± 0.11
APF	71.34^{c} ± 0.24
TPF	77.51^{b} ± 0.12
PPF	71.007^{c} ± 0.29

[a]PF- Pectin Film, OPF- Orange Peel Film, APF- Apple Pomace Film, TPF- Tomato Pomace Film, PPF- Potato Peel Film. [b]Different letters in the columns reflect statistically significant ($p < 0.05$) differences between samples. Data in the same column with the same letter are not statistically different at the ($p < 0.05$) level.

Conclusion

The study demonstrated a novel method for incorporating the FVW into biofilms. The FVW of the OP, AP, and TP forms a film up to 6% concentration while the PP forms a film up to 4%. The TGA results revealed that, except for the OP film, the biofilms could not withstand high temperatures. The FTIR spectra indicated a significant overlap between the compositions of the biofilms. The transparency of biofilms is depending on the thickness of the film, the absorbance wavelength, and the concentration of FVW powder in the film. The water solubility of the biofilms is considerable, which should be reduced for the biofilms to be used in food packaging.

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Conflict of Interest

The author affirms that there is no conflict of interest in the current work.

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