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Development of Biofilms from Fruit and Vegetable Waste and Evaluation of its Mechanical and Physical Properties

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ABSTRACT

This research entails the synthesis of bioplastics films out of fruit and vegetable waste (FVW) and testing their mechanical and physical properties. Orange peel (OP), apple pomace (AP), potato peels (PP), and tomato pomace (TP) were the FVWs used in this study. The films were developed using the casting method. The FVW powder content in the film-forming solution (FFS) ranged between 2%, 4%, and 6%. Whereas glycerol was 2%, 1.5%, 1%, and 0.5% while pectin remains constant at 4%.The treatments T_0 to T_{12} were applied to each FVW with varying glycerol percentages. A high glycerol percentage resulted in a fragile film. From an experimental study, it was revealed that glycerol reduces tensile strength and young's modulus while increasing elongation at break, moisture content, and thickness. The potato peel powder (PPP) film containing 0.5% glycerol was identified as the most promising film, characterized by a tensile strength of 8.16 MPa, young's modulus of 9.96 MPa, and moisture content of 9.73%. Orange peel powder (OPP) film has the maximum elongation at break; measuring 16.35%. The thickness of 108.15µ was the maximum for the PPP film containing 2% glycerol. Based on the experimental study the prepared biofilms open up the possibilities for replacing the synthetic food packaging.

Keywords: *Biobased plastic, Food Packaging, Mechanical properties, Plasticizer*

Introduction

The fruit and vegetable (F&V) processing industries attract both research scientists and to industry because it has valuable compounds which can be recovered and converted into biologically active compounds (Schieber, 2017). The food industry is concerned about the waste generated by the F&V processing industry. The F&V industry generates massive amounts of waste, in the form of pomace, peel, pods, stones, and seeds, which accounts for 10-35% of the raw, mass (Dilucia *et al.*, 2020). Waste refers to inedible parts of F&V that are discarded at various stages of collection, handling, shipping, and processing (Kumar *et al.*, 2020). Waste generation has an impact on the environment, economy, and social sectors, contributing to greenhouse gas emissions. It is difficult to manage large amounts of biodegradable materials (Torres-leon *et al.*, 2018). Fruit and Vegetable Waste (FVW) can be converted into a variety of novel industrial products, including biosorbents, microbiological media, fortified probiotics, and bioplastics films (Kumar *et al.*, 2020). Food packaging is primarily dependent on synthetic packaging materials due to their good mechanical and barrier properties, but it is a significant cause of ecosystem

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disruption. The entire world is dealing with issues caused by plastics and their waste disposal. In such cases, using bioplastics for food packaging can be a viable alternative to reducing the use of synthetic plastics. This research deals with the utilization of FVW generated from the orange, apple, potato, and tomato processing industries. The biomass produced from the F&V processing industry is a rich source of polysaccharides such as cellulose, pectin, starch, dietary fibers, and bioactive compounds (Otoni *et al.,* 2017). The potato peel is the rich source of cellulose among all the vegetables and tomato pomace contains 60% fibers, 25% total sugars, 20% proteins, 8% pectin, 6% total fat, 4% minerals (Schieber, 2017). Dry citrus peels are rich in pectin, cellulose, and hemicelluloses whereas apple pomace is the major waste of apple cider and juice processing industries and which contains 7.2- 43.6% cellulose, 4.26- 24.40% hemicelluloses, 15.2-23.5% lignin, 3.5-14.32% pectin, 4.7- 51.10% fiber (Sharma *et al.,* 2016). Biopolymers and plasticizers combine to form a film with good properties. Plasticizers can be defined as low molecular weight, non-volatile substances use to increase the flexibility of the bioplastics film (Dianursanti *et al.,* 2018). The addition of a suitable plasticizer produces a microstructure change in the polymer matrix which leads to a reduction in intermolecular forces between polymer chains (Pasini Cabello *et al.,* 2015). This work aims to valorize the FVW into bioplastics and check its mechanical and physical properties.

Materials and Methods

Materials

The raw materials such as apple pomace (AP), orange peel (OP), and tomato pomace (TP) were collected from Juice-Stuff, Mahewa, Prayagraj. The potato peel (PP) was obtained from SHUATS, Canteen Prayagraj. Glycerol (Rankem, M.W 92.10), Citric acid monohydrate, and Pectin (methoxyl content 6-10%) were procured from Loba Chemie Pvt. Ltd. India. The present experiment was carried out at the Department of Food Process Engineering, SHUATS, Prayagraj.

Pretreatment of Fruit and Vegetable Waste for Biofilms Preparation

The FVW was washed with potable water to extract soluble sugars. The FVW were soaked in potable water for 12h; then two further washing steps followed. The ratio of water to FVW was 1.5: 1. After washing the size of the waste material was reduced with a knife and they were dried at 50°C for 12h using a tray dryer. The dried material was milled to a fine powder using a grinder. The process was followed as per the study done by Bátori *et al.* (2017).

Formation of Biofilms

The biofilms were made by using FVW pretreated powder in the proportion of 2%, 4%, 6%. While the pectin content has remained constant, i.e., 4%, glycerol was varying from 0.5 to 2%. This formulation was made by taking into account previous work done by Bátori *et al.* (2017). The different treatments for biofilms formation are shown in Table 1. A mixture of citric acid monohydrate solution (1%) with FVW powder and pectin was prepared and it allowed dissolving under constant magnetic stirring at a temperature of 40°C for 30 min. When pectin was dissolved in the mixture glycerol was added and allowed for constant magnetic stirring. The FFS was formed and 30 ml of FFS was casted onto the glass petri- plates having a diameter of 9cm. The casted plates were dried in a hot air oven at 50 °C for 14h. After completion of uniform drying the casted films were detached from petri-plates.

Table 1. Treatments for Biofilms based on Fruit and Vegetable Waste Powder with varying Glycerol concentrations

Treatments	F&V waste Powder (%)	Pectin (%)	Glycerol (%)	Citric acid solution (%)
T_0	-	4	2	94
T_1	2	4	2	92
T_2	2	4	1.5	92.5
T_3	2	4	1.0	93
T_4	2	4	0.5	93.5
T_5	4	4	2	90
T_6	4	4	1.5	90.5
T_7	4	4	1.0	91
T_8	4	4	0.5	91.5
T_9	6	4	2	88
T_{10}	6	4	1.5	88.5
T_{11}	6	4	1.0	89
T_{12}	6	4	0.5	89.5

[a] T_0 - Pectin film without the addition of Fruit and Vegetable Waste Powder

[b] T_1, T_2, T_3.... T_{12} – Biofilms with varying amounts of Fruit and Vegetable Waste Powder, Glycerol, and Citric acid solution.

Characterization of Biofilms

Film Thickness

The thickness measurement of each film was performed through a digital vernier caliper (Mitutoyo 500- 196- 20). The thickness was measured at three random locations on each film and the average value and the standard deviation were recorded (Miller *et al.,* 2021).

Moisture Content

The moisture content of the prepared films was calculated by measuring the weight loss of the films upon drying in a hot air oven at 110 °C until the constant dry weight was achieved. The biofilms were cut into square pieces of 2×2 cm. The samples were weighed accurately before and after drying (Marichelvam *et al.,* 2019). Each film treatment was used with three replications, and the moisture content was measured as given in equation (1)

$$\text{Moisture content (\%)} = \frac{wi-wf}{wi} \times 100 \quad \text{.. (1)}$$

Where, wi= Initial weight of the film, wf= Film weight after drying

Mechanical Testing

The tensile strength, elongation at break, and elasticity modulus were measured using the universal testing machine (Make- International equipment, Mumbai) by the method ASTM D 882 (Bayer *et al.,* 2014). The specimens were tested at load 55.0 kg under 0. 405 cm.sq area. The specimen length and width were 100mm, 15mm respectively. All measurements were tested for three replications.

Statistical analysis

All treatments were carried out in triplicate. SAS 9.1 was used to do an analysis of variance (ANOVA) on the experimental data (SAS Institute Inc., Cary, NC, USA). A significant difference between treatments was determined using Tukey's method at a level of significance ($p < 0.05$). The mean ± standard deviation was used to present all of the data.

Results and Discussion

Film Thickness

Table 2 shows that the plasticizer concentration affected the thickness of the film. From the experimental study, it was revealed that at a higher concentration of the glycerol the thickness value was also high. The thickness of the PF was 62.15µ and it increases with increasing the amount of FVW powder and glycerol. The thickness of the OPP and APP films for the T_1 to T_{12} ranged from 83-105µ and 84-

Table 2. Thickness of the Biofilms with varying Glycerol concentration

	Thickness (µ)			
Treatments	OPP	APP	PPP	TPP
T_0	$62.15^{j} \pm 0.03$	$62.15^{m} \pm 0.03$	$62.15^{m} \pm 0.03$	$62.15^{m} \pm 0.03$
T_1	$84.46^{g} \pm 0.005$	$85.14^{i} \pm 0.02$	$86.55^{i} \pm 0.03$	$86.15^{i} \pm 0.01$
T_2	$84.11^{h} \pm 0.01$	$85.07^{j} \pm 0.05$	$86.39^{j} \pm 0.02$	$86.08^{j} \pm 0.05$
T_3	$83.87^{h} \pm 0.01$	$85.03^{k} \pm 0.05$	$86.24^{k} \pm 0.03$	$85.75^{k} \pm 0.005$
T_4	$83.43^{i} \pm 0.02$	$84.94^{l} \pm 0.01$	$86.02^{l} \pm 0.01$	$85.37^{l} \pm 0.01$
T_5	$86.14^{e} \pm 0.02$	$89.14^{e} \pm 0.02$	$89.58^{e} \pm 0.01$	$87.98^{e} \pm 0.01$
T_6	$86.07^{e} \pm 0.02$	$89.04^{f} \pm 0.015$	$89.13^{f} \pm 0.02$	$87.76^{f} \pm 0.01$
T_7	$85.88^{e} \pm 0.05$	$88.96^{g} \pm 0.02$	$89.07^{g} \pm 0.05$	$87.41^{g} \pm 0.02$
T_8	$85.44^{f} \pm 0.02$	$88.61^{h} \pm 0.01$	$88.96^{h} \pm 0.01$	$86.97^{h} \pm 0.01$
T_9	$105.69^{a} \pm 0.41$	$106.36^{a} \pm 0.01$	$108.15^{a} \pm 0.01$	$107.86^{a} \pm 0.01$
T_{10}	$103.96^{b} \pm 0.02$	$105.97^{b} \pm 0.01$	$108.05^{b} \pm 0.01$	$107.21^{b} \pm 0.01$
T_{11}	$98.14^{c} \pm 0.02$	$105.25^{c} \pm 0.01$	$107.86^{c} \pm 0.02$	$106.87^{c} \pm 0.01$
T_{12}	$92.15^{d} \pm 0.01$	$104.87^{d} \pm 0.01$	$107.16^{d} \pm 0.01$	$106.09^{d} \pm 0.01$

This value is an average of three repetitions ± standard deviation.

[a]OPP - Orange Peel Powder, APP- Apple Pomace Powder, PPP- Potato Peel Powder, TPP- Tomato Pomace Powder.

[b]T_0 - Pectin film without the addition of Fruit and Vegetable Waste Powder

[c]T_1, T_2, T_3…. T_{12} – Biofilms with varying amounts of Fruit and Vegetable Waste Powder, Glycerol, and Citric acid solution.

[d]Different letters in the columns indicate that there are statistical differences ($p < 0.05$) between samples.

106μ, respectively. Whereas the thickness of the PPP and TPP films for T_1 to T_{12} was in the range of 86-108μ, 85-107μ, respectively. Junianto (2012) reported glycerol behavior for biofilms that were comparable to these findings. The highest thickness value was observed for treatment T_9 of the PPP film and it is 108.15μ. The plasticizer holds the polymers molecules which help to increase the thickness of the films (Otoni *et al.,* 2017).

Moisture content

The results of the moisture content of the biofilms were shown in Table 3. As per Table 3, the PF had a higher moisture content of 16.03 %, which decreased with the addition of FVW powder. For treatments T_1 to T_{12} the moisture content of the OPP and APP films was in the range of 13 to 14% and 10 to14%, respectively. The moisture content of the PPP and TPP, on the other hand, was in the range of 9 to12% and 10 to14%, respectively. While the higher the glycerol content, the greater the moisture in the films. These findings are in complete agreement with the Miller *et al.* (2021). The moisture content of the film is one of the important parameters by considering the use of the film as a packaging material. Glycerol is easily dissolved in water and increases the viscosity of the solution and binds the water and molecules of the solution, which helps to increase the moisture in the films (Khairunnisa *et al.,* 2018).

Mechanical testing

Tensile strength

The tensile strength of the bioplastics films made from FVW is shown in Table 4. The OPP and APP films both had tensile strength in the range of 6-7 MPa, while the PPP and TPP films had a tensile strength of 6 to 8 MPa, 6 to 7 MPa, respectively for T_1 to T_{12}. In OPP and APP films the T_{12} shows the highest tensile strength i.e., 7.35 MPa, and 7.40 MPa respectively. The tensile strength of the T_8 PPP film was 8.1 MPa, the highest of the four raw materials. The addition of potato skin residue improves the tensile strength of the bioplastics (Schieber, 2017). The TPP films at T_{12} showed the tensile strength of 7.57 MPa, which was the highest. Plasticizers reduce the polymer chain to chain interaction and positioning between polymer molecules and it leads to reduced brittleness, stiffness, and increases flexibility, stretchability, and toughness (Otoni *et al.,* 2017). Glycerol affects the mechanical properties of biofilms. Table 4 shows that lowering the glycerol concentration increased tensile strength. Santana *et al.,* (2018) obtained results with biofilms that are relevant to glycerol behavior.

Table 3. The Moisture content of the Biofilms with varying Glycerol concentration

	Moisture content (%)			
Treatments	OPP	APP	PPP	TPP
T_0	$16.03^{a} \pm 0.01$	$16.03^{a} \pm 0.01$	$16.03^{a} \pm 0.011$	$16.03^{a} \pm 0.01$
T_1	$14.47^{d} \pm 0.01$	$14.34^{b} \pm 0.05$	$12.89^{b} \pm 0.01$	$14.13^{c} \pm 0.011$
T_2	$14.26^{e} \pm 0.015$	$13.76^{c} \pm 0.026$	$12.67^{c} \pm 0.02$	$13.75^{d} \pm 0.01$
T_3	$14.05^{f} \pm 0.01$	$13.35^{d} \pm 0.01$	$12.31^{d} \pm 0.01$	$13.35^{e} \pm 0.01$
T_4	$13.67^{h} \pm 0.01$	$13.15^{e} \pm 0.01$	$11.71^{f} \pm 0.01$	$14.35^{b} \pm 0.015$
T_5	$14.83^{b} \pm 0.02$	$13.76^{c} \pm 0.02$	$11.87^{e} \pm 0.02$	$13.35^{e} \pm 0.01$
T_6	$14.48^{d} \pm 0.05$	$13.15^{e} \pm 0.01$	$11.52^{g} \pm 0.02$	$13.13^{f} \pm 0.01$
T_7	$14.07^{f} \pm 0.01$	$12.54^{f} \pm 0.01$	$11.31^{h} \pm 0.01$	$12.35^{g} \pm 0.01$
T_8	$13.88^{g} \pm 0.01$	$11.95^{h} \pm 0.01$	$10.92^{i} \pm 0.01$	$11.93^{h} \pm 0.02$
T_9	$14.66^{c} \pm 0.01$	$12.36^{g} \pm 0.02$	$11.87^{e} \pm 0.005$	$11.73^{i} \pm 0.015$
T_{10}	$14.27^{e} \pm 0.015$	$11.95^{h} \pm 0.01$	$10.52^{j} \pm 0.02$	$11.53^{j} \pm 0.01$
T_{11}	$13.68^{h} \pm 0.01$	$11.53^{i} \pm 0.02$	$10.12^{k} \pm 0.01$	$11.34^{k} \pm 0.005$
T_{12}	$13.32^{i} \pm 0.02$	$10.96^{j} \pm 0.01$	$9.73^{l} \pm 0.01$	$10.54^{l} \pm 0.005$

This value is an average of three repetitions ± standard deviation.

[a]T_0 - Pectin film without the addition of Fruit and Vegetable Waste Powder

[b]T_1, T_2, T_3…. T_{12} – Biofilms with varying amounts of Fruit and Vegetable Waste Powder, Glycerol, and Citric acid solution.

[c]OPP - Orange Peel Powder, APP- Apple Pomace Powder, PPP- Potato Peel Powder, TPP- Tomato Pomace Powder.

[d]Different letters in the columns indicate that there are statistical differences ($p < 0.05$) between the samples.

Young's modulus

The results of the analysis of variance for the young's modulus were shown in Table 5. The young's modulus of the OPP and APP was 6 to 9 MPa and 7 to 9 MPa, respectively, for treatments T_1 to T_{12}. The PPP and TPP films had young's modulus of 7 to 9 and 6 to 9, respectively. The use of additives in bioplastics film affects the mechanical properties of the film (Azieyanti *et al.,* 2020). At a higher concentration of the glycerol, the young's modulus was

Table 4. Tensile strength of the Biofilms with varying Glycerol concentration

Treatments	Tensile strength (MPa)			
	OPP	APP	PPP	TPP
T_0	$6.02^{l} \pm 0.01$	$6.02^{j} \pm 0.011$	$6.02^{l} \pm 0.01$	$6.02^{f} \pm 0.01$
T_1	$6.13^{k} \pm 0.017$	$6.26^{h} \pm 0.01$	$6.083^{k} \pm 0.01$	$6.32^{def} \pm 0.26$
T_2	$6.22^{j} \pm 0.011$	$6.35^{g} \pm 0.011$	$6.56^{j} \pm 0.001$	$6.12^{f} \pm 0.02$
T_3	$6.57^{i} \pm 0.01$	$6.86^{e} \pm 0.01$	$7.23^{f} \pm 0.02$	$6.24^{ef} \pm 0.02$
T_4	$7.31^{b} \pm 0.01$	$7.26^{b} \pm 0.015$	$7.66^{c} \pm 0.015$	$6.66^{cde} \pm 0.015$
T_5	$6.58^{i} \pm 0.01$	$6.13^{i} \pm 0.020$	$7.04^{g} \pm 0.01$	$6.47^{def} \pm 0.02$
T_6	$6.78^{h} \pm 0.005$	$6.36^{g} \pm 0.015$	$7.34^{e} \pm 0.430$	$6.86^{bcd} \pm 0.025$
T_7	$7.03^{e} \pm 0.01$	$6.86^{e} \pm 0.011$	$7.88^{b} \pm 0.01$	$7.07^{abc} \pm 0.01$
T_8	$7.14^{d} \pm 0.01$	$7.04^{d} \pm 0.02$	$8.16^{a} \pm 0.011$	$7.16^{abc} \pm 0.02$
T_9	$6.87^{g} \pm 0.017$	$6.74^{f} \pm 0.015$	$6.72^{i} \pm 0.01$	$6.72^{cde} \pm 0.025$
T_{10}	$6.97^{f} \pm 0.01$	$6.86^{e} \pm 0.02$	$6.97^{h} \pm 0.01$	$7.38^{ab} \pm 0.69$
T_{11}	$7.22^{c} \pm 0.011$	$7.13^{c} \pm 0.015$	$7.25^{f} \pm 0.01$	$7.14^{abc} \pm 0.02$
T_{12}	$7.35^{a} \pm 0.01$	$7.4^{a} \pm 0.02$	$7.57^{d} \pm 0.02$	$7.57^{a} \pm 0.017$

This value is an average of three repetitions ± standard deviation.

[a]T_0 - Pectin film without the addition of Fruit and Vegetable Waste Powder

[b]T_1, T_2, T_3…. T_{12} – Biofilms with varying amounts of Fruit and Vegetable Waste Powder, Glycerol, and Citric acid solution.

[c]OPP - Orange Peel Powder, APP- Apple Pomace Powder, PPP- Potato Peel Powder, TPP- Tomato Pomace Powder.

[d]Different letters in the columns indicate that there are statistical differences ($p < 0.05$) between samples.

Table 5. Young's modulus of the Biofilms with varying Glycerol concentration

Treatments	Young's modulus (MPa)			
	OPP	APP	PPP	TPP
T_0	$6.36^{k} \pm 0.02$	$6.36^{j} \pm 0.02$	$6.36^{k} \pm 0.02$	$6.36^{m} \pm 0.02$
T_1	$8.86^{d} \pm 0.02$	$8.14^{f} \pm 0.025$	$7.96^{e} \pm 0.02$	$7.75^{i} \pm 0.005$
T_2	$9.13^{c} \pm 0.01$	$8.89^{c} \pm 0.005$	$8.57^{d} \pm 0.015$	$8.41^{e} \pm 0.01$
T_3	$9.38^{b} \pm 0.01$	$9.27^{b} \pm 0.02$	$9.33^{b} \pm 0.01$	$9.13^{b} \pm 0.01$
T_4	$9.86^{a} \pm 0.011$	$9.51^{a} \pm 0.015$	$9.96^{a} \pm 0.015$	$9.62^{a} \pm 0.02$
T_5	$6.13^{l} \pm 0.015$	$7.11^{i} \pm 0.02$	$7.23^{i} \pm 0.01$	$6.96^{l} \pm 0.01$
T_6	$6.56^{j} \pm 0.01$	$7.87^{h} \pm 0.01$	$7.58^{g} \pm 0.01$	$7.66^{j} \pm 0.015$
T_7	$6.96^{i} \pm 0.01$	$7.91^{h} \pm 0.015$	$7.97^{e} \pm 0.005$	$8.13^{g} \pm 0.01$
T_8	$8.12^{f} \pm 0.005$	$8.24^{e} \pm 0.02$	$8.62^{c} \pm 0.015$	$8.92^{c} \pm 0.02$
T_9	$7.08^{h} \pm 0.015$	$7.88^{h} \pm 0.005$	$7.04^{j} \pm 0.01$	$7.14^{k} \pm 0.02$
T_{10}	$7.9^{g} \pm 0.0152$	$8.02^{g} \pm 0.01$	$7.35^{h} \pm 0.01$	$7.86^{h} \pm 0.02$
T_{11}	$8.11^{f} \pm 0.015$	$8.25^{e} \pm 0.015$	$7.86^{f} \pm 0.02$	$8.26^{f} \pm 0.026$
T_{12}	$8.18^{e} \pm 0.017$	$8.82^{d} \pm 0.015$	$8.55^{d} \pm 0.01$	$8.74^{d} \pm 0.02$

This value is an average of three repetitions ± standard deviation.

[a]T_0 - Pectin film without the addition of Fruit and Vegetable Waste Powder

[b]T_1, T_2, T_3…. T_{12} – Biofilms with varying amounts of Fruit and Vegetable Waste Powder, Glycerol, and Citric acid solution.

[c]OPP - Orange Peel Powder, APP- Apple Pomace Powder, PPP- Potato Peel Powder, TPP- Tomato Pomace Powder.

[d]Different letters in the columns indicate that there are statistical differences ($p < 0.05$) between samples.

Table 6. Elongation at break of the Biofilms with varying Glycerol concentration

	Elongation at break (%)			
Treatments	OPP	APP	PPP	TPP
T_0	$15.72^f \pm 0.03$	$15.72^e \pm 0.03$	$15.72^c \pm 0.03$	$15.66^b \pm 0.03$
T_1	$16.19^b \pm 0.01$	$16.03^c \pm 0.015$	$16.08^a \pm 0.01$	$15.87^a \pm 0.02$
T_2	$16.03^c \pm 0.02$	$15.85^d \pm 0.02$	$15.37^f \pm 0.01$	$15.12^c \pm 0.02$
T_3	$15.84^e \pm 0.02$	$15.1^g \pm 0.02$	$14.81^i \pm 0.015$	$15.17^c \pm 0.005$
T_4	$14.9^j \pm 0.011$	$14.52^j \pm 0.02$	$14.4^j \pm 0.01$	$14.23^g \pm 0.025$
T_5	$16.35^a \pm 0.015$	$16.89^a \pm 0.02$	$16.09^a \pm 0.02$	$14.97^d \pm 0.015$
T_6	$15.96^d \pm 0.02$	$16.22^b \pm 0.015$	$15.87^b \pm 0.01$	$14.85^e \pm 0.011$
T_7	$15.56^g \pm 0.01$	$15.87^d \pm 0.015$	$15.44^e \pm 0.006$	$14.96^d \pm 0.005$
T_8	$15.18^h \pm 0.015$	$15.033^h \pm 0.032$	$15.12^g \pm 0.025$	$14.86^e \pm 0.01$
T_9	$15.74^f \pm 0.01$	$15.64^f \pm 0.02$	$15.65^d \pm 0.015$	$14.82^e \pm 0.02$
T_{10}	$15.12^i \pm 0.01$	$14.92^i \pm 0.02$	$15.05^h \pm 0.02$	$14.42^f \pm 0.02$
T_{11}	$14.54^k \pm 0.01$	$14.12^k \pm 0.02$	$14.39^k \pm 0.017$	$14.07^h \pm 0.01$
T_{12}	$13.86^l \pm 0.01$	$13.54^l \pm 0.034$	$13.22^l \pm 0.02$	$13.42^i \pm 0.02$

This value is an average of three repetitions ± standard deviation.

[a] T_0 - Pectin film without the addition of Fruit and Vegetable Waste Powder

[b] T_1, T_2, T_3…. T_{12} – Biofilms with varying amounts of Fruit and Vegetable Waste Powder, Glycerol, and Citric acid solution.

[c] OPP - Orange Peel Powder, APP- Apple Pomace Powder, PPP- Potato Peel Powder, TPP- Tomato Pomace Powder.

[d] Different letters in the columns indicate that there are statistical differences ($p < 0.05$) between the samples.

lowered. These results agree with those of Miller *et al.* (2021) that the young's modulus was decreased with increasing plasticizer concentration.

Elongation at break

The results of the elongation at break for different treatments of the bioplastics films are shown in Table 6. The PF had a percent elongation of 15.72%. The treatment T_5 of the FVW films demonstrated the highest elongation, indicating that 4 % FVW powder and 2 % glycerol offer the maximum elongation. The increase in the percent elongation occurs because the plasticizer reduces the fragility (Hidayati *et al.*, 2021). Galus *et al.* (2013) observed that at high glycerol concentration elongation at break was also higher. Experiment results showed that the plasticizer has a significant impact on elongation at break, similar trend was obtained by Sofiah *et al.* (2019) in accordance with glycerol.

Conclusion

The development of biofilms by FVW aids in the utilization of unused materials from the F&V processing industries. The plasticizer percentage used in bioplastics affects the mechanical and physical properties of the film. Bioplastics films made from FVW could be a good alternative to reducing plastic use. The prepared bioplastics films can be used as a food packaging material, but they have some limitations due to their lower mechanical properties and moisture content. The use of fillers and functional additives aid in the improvement of the biofilms' physical and mechanical properties.

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Conflict of Interest

Hereby, the author declares that in the current study there is no conflict of interest.

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