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Development and characterization of tomato puree-based biodegradable films for sustainable packaging applications

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Abstract

The goal of this research is to synthesize tomato puree based biodegradable films (BF) for packaging application. The films were prepared via a solution casting method incorporating the tomato puree (TP) to produce 3 types of films (T₁, T₂ and T₃). The aim was to evaluate the mechanical, transparency and moisture barrier properties of the developed films to determine their appropriateness as eco-friendly packaging materials. The maximum tensile strength of the film was observed to be about 4 MPa. The tensile strength (TS) of the films was measured which differed among all formulation. The films were also tested on their transparency and moisture retention ability to check their potential in food stabilization. Also an analysis of the moisture content (MC) of the films showed that the films performed well in the stability of the product. The result and the data taken from the experiment show that the films which are made up of tomato puree are suitable for short-term packaging. Also, the film being eco-friendly will have a maximum product shelf life of not more than 4 days. The above studies that show the impact of such films can help address the ever-increasing plastic wastes and develop biodegradable packaging solutions.

Keywords: Biobased packaging, food packaging, tomato puree, mechanical characteristics

1. Introduction

Food packaging is a critical component of the food industry, ensuring the safety, integrity, and quality of food products during storage and transportation. Petrochemical-based polymers are widely used in food packaging for their excellent mechanical, barrier, and optical properties. However, their non-biodegradability poses a significant global environmental challenge (Mayuri T. *et al.*, 2022) ^[7]. It encompasses a variety of materials and technologies, evolving to address environmental concerns and consumer demands. Biopolymers are primarily composed of polysaccharides and proteins that can be found in a variety of plant-based foods, including tomatoes, and contribute to their nutritional and functional qualities. Tomato puree contains various biopolymers, primarily non-starch polysaccharides (NSP) such as pectins, hemicelluloses, and cellulose. These biopolymers play significant roles in the texture and stability of the puree (Reinders & Thier, 1999) ^[12]. According to NABARD data, India is the second-largest tomato-producing nation, with an anticipated 20.62 million tonnes of tomatoes produced in 2022-2023. This research article discusses the biodegradable film made from tomato puree with the addition of pectin and gelatin as biopolymer and glycerol as plasticizer for the packaging of biscuits. Pectin, a polysaccharide derived from plant cell walls, is recognized for its capacity to create films with excellent mechanical strength and effective barrier characteristics (Thakur *et al.*, 2019) ^[19]. Gelatin, obtained through the hydrolysis of collagen, is appreciated for its flexibility, clarity, and ability to retain water. Films made from gelatin offer excellent oxygen barrier properties, making them essential for maintaining the quality of foods sensitive to oxygen (Sogut & Cakmak, 2020) ^[16]. The combination of pectin and gelatin produces synergistic effects, enhancing the mechanical strength, thermal stability, and moisture resistance of packaging films. These composite films are highly effective for food packaging, as they improve food preservation while remaining environmentally friendly (Pereda *et al.*, 2021) ^[10].

Glycerol is commonly used as a plasticizer in packaging films because it improves flexibility, reduces brittleness, and enhances the mechanical properties of biopolymer-based films (Sanyang *et al.*, 2016) ^[15].

2. Materials and methods

The experiments were performed at MIT-ADT University, Pune under the department of Food Technology from the period August to December 2024.

2.1 Materials

Materials required for preparing the film are tomato puree, pectin, gelatin, glycerol and distilled water. The materials were procured from food technology departmental laboratory MIT-ADT University, Pune.

2.2 Film preparation

2.2.1 Procedure

Ripe tomatoes were selected, washed, cleaned properly, cut into small pieces, and processed into tomato puree. Gelatin and glycerol were prepared. Distilled water was poured into a beaker, which was placed on a magnetic stirrer. Pectin and glycerol were added in small amounts, ensuring no lumps formed. The tomato puree was added simultaneously. After stirring for 45-50 minutes, a thick slurry formed.

The slurry was poured into a Petri plate and kept in a hot air oven at 55 °C for 24 hours. After 24 hours, the film was cooled to room temperature and carefully removed from the petri plate. Table 1 & 2 contain the formulation of the pectin and gelatin film respectively

2.3 Characterization of packaging film

2.3.1 Sealing characteristics of the Film

Heat sealing of the film was done using an impulse sealer machine (Frede model No. 300 FH, Power: 240 V, 270 W, 50 Hz), equipped with a sealing bar of 12 mm width and 300 mm length. Sealing time and cooling time were set, and the sealing was controlled using a foot pedal. Rectangular strips of film (150 x 50 mm) were cut, and sealing was performed in the temperature range of 65 to 155 °C (Wang *et al.*, 2015) ^[20].

2.3.2 Water Solubility of the Film

Three samples of each film (2.3 g) were weighed (initial weight) after being kept at 55 °C for 24 hours in a lab oven. Water solubility (%) was calculated using the formula no.1 (Han *et al.*, 2014) ^[5].

$$WS (\%) = \frac{W_0 - W_f}{W_0} \times 100 \quad (1)$$

Where, W_0 is the original dry film weight and W_f is the weight of the insoluble dried film. All the tests were repeated three times.

2.3.3 Transparency of the Film

The transparency of the film was evaluated using a UV-visible spectrophotometer. The transparency was determined using the absorbance measured at 600 nm and film thickness (in mm) by applying formula 2. (Mayuri *et al.*, 2022) ^[7].

$$Opacity = \frac{Abs_{600}}{x} \quad (2)$$

Where x is the film thickness in mm and Abs 600 is the absorbance measured at 600 nm.

2.3.4 Tensile strength testing of tomato puree based film

The tensile strength was measured using the universal testing machine (Make- International equipments, Mumbai) by the method ASTM D 882 (Bayer *et al.*, 2014) ^[2]. The specimens were tested at load 55.0 kg under 0.405 cm. sq area. All measurements were tested for three replications.

2.3.5 Thickness of the film

An automated vernier calliper was used to measure the film's thickness. (Miller *et al.*, 2021) ^[8].

2.3.6 Biodegradation of tomato puree based film

The soil burial test was utilised to evaluate the biodegradability of the film, similar to Emadian *et al.* (2017) ^[4]. The film strip has been cut into 5 × 5 cm lengths. Soil was collected. Pectin and gelatin film samples were buried in a pot of soil for one month. Soil samples were weighed prior to burial. The degradation rate of film was calculated using formula 3.

$$\text{Weight loss } (\%) = \frac{W_0 - W}{W_0} \times 100 \quad (3)$$

Where samples' weights prior to and following the test are denoted by W_0 and W , respectively.

2.4 Film as packaging material

Developed films were used as packaging material for biscuit. The biscuits were packed in film and kept for 15 days. After 15 days moisture content of biscuits were analysed.

2.4.1 Moisture content of biscuits

The moisture content of the tomato puree based film packed biscuits were determined by the method described in AACC (2000). The % moisture was measured by using formula 4.

$$\% \text{ Moisture} = \frac{W_1 - W_2}{W_1 - W} \times 100 \quad (4)$$

Where,

W =weight in gram of the empty moisture dish.

W_1 =weight in gram of the moisture dish with the material before drying.

W_2 =weight in gram of the moisture dish with the material after drying.

3. Result and discussion

3.1 Sealing of the tomato puree based film

Tomato puree based pectin and gelatin films have a sealing property. Treatment T_0 & T_1 of the pectin and gelatin films sealed at a temperature of 85 °C. When temperature of sealing increased above 85 °C films were stick to the sealing machine. Treatment T_2 & T_3 of the pectin and gelatin films sealed at 70 °C. The dwell time required to seal the films ranged from 1 to 4 seconds. Similar findings about the film sealing ability were reported by Kim and Ustunol (2001) ^[6].

3.2 Water solubility of the tomato puree based film

Table 3 shows the water solubility of the tomato puree based pectin and gelatin films. Treatment T_1 to T_3 of pectin films

had the water solubility 83.21, 83.03, 83.01 respectively while gelatin films had water solubility 97.71, 97.48, 97.07 respectively. It was observed that the high tomato puree shows the higher water solubility. Water solubility is decreased by the addition of vegetable powder (Alves *et al.*, 2016) ^[1].

3.3 Tensile strength

The tensile strength of both gelatin and pectin films was evaluated across three treatment levels (T₁ to T₃), and the results are presented in Table 4 both gelatin and pectin films demonstrated a progressive decrease in tensile strength as the treatment severity increased, though pectin films consistently showed higher tensile strength than gelatin films at all treatment levels.

Pectin films showed a similar trend of decreasing tensile strength with increasing treatment severity. The tensile strength at T₁ was 5.1 MPa, which was higher than the tensile strength of the gelatin film at the same treatment level. At T₂, the tensile strength of the pectin film decreased to 4.8 MPa, and further decreased to 4.1 MPa at T₃. Although the reduction in tensile strength was observed, pectin films consistently maintained higher mechanical strength compared to gelatin films throughout the treatments. This could be attributed to the inherent structural differences between the two biopolymers. At T₁, the tensile strength of the gelatin film was 4.8 MPa. However, as the treatment intensity increased, the tensile strength of the gelatin film decreased. At T₂, the tensile strength reduced to 3.5 MPa, and further decreased to 3.1 MPa at T₃. This decline indicates that the treatment negatively affected the mechanical properties of the gelatin film, which may be due to changes in the molecular structure of the gelatin matrix, such as the breakdown of polymer chains or excessive hydration, making the film weaker. Gelatin, being a protein-based polymer, is more susceptible to thermal and chemical degradation under certain treatment conditions, whereas pectin, a polysaccharide, may maintain greater structural integrity under similar conditions. Both gelatin and pectin are sensitive to changes in temperature, moisture, and chemical treatments, which can lead to the depolymerization or disruption of the polymer network, reducing the film's ability to resist tension (Sadeghi *et al.*, 2021) ^[13].

For gelatin, which is derived from collagen, heat or excessive hydration could cause the protein structure to break down, weakening the bonds between the polymer chains and leading to a reduction in tensile strength (Zhao *et al.*, 2016) ^[22]. Similarly, pectin, being a polysaccharide, may undergo depolymerization when exposed to high temperatures or excessive water, reducing its molecular weight and weakening the film (Tao *et al.*, 2020) ^[18]. Additionally, the increased water content from treatment could further plasticize both films, making them more flexible but less able to withstand tensile stress and causing it to become more prone to deformation and breaking under stress (Bourtoom, 2008) ^[3].

3.4 Film thickness

The data presented in Table 5 illustrates the thickness measurements of gelatin and pectin films under three different treatments. The gelatin film thickness ranged from 82 μ to 88 μ . Similarly, the pectin films showed a range of thickness from 87 μ to 96 μ . The results demonstrate that both gelatin and pectin films were thickest in T₁ and thinned

progressively in T₂ and T₃. These variations in film thickness are likely attributed to differences in formulation and processing conditions, such as the concentration of biopolymer components or the drying time and temperature used in each treatment (Rahman *et al.*, 2020) ^[11]. It is possible that higher concentrations or longer drying times in Treatment 1 could lead to thicker films, while adjustments in the preparation or drying methods for T₂ and T₃ resulted in reduced thickness.

3.5 Biodegradation rate

The biodegradation rates of both gelatin and pectin films under three different treatments are presented in Table 6. The gelatin films exhibited biodegradation rates ranging from 92.71% in Treatment T₁ to 94.48% in Treatment T₃. Specifically, T₁ showed a biodegradation rate of $92.71 \pm 0.02\%$, T₂ increased to $94.07 \pm 0.05\%$, and T₃ had the highest biodegradation rate of $94.48 \pm 0.01\%$. Similarly, the pectin films demonstrated a trend of increasing biodegradation rates, with T₁ showing $91.03 \pm 0.01\%$, T₂ reaching $93.01 \pm 0.02\%$, and T₃ achieving $95.10 \pm 0.01\%$. The progressive increase in biodegradation rates across the treatments for both gelatin and pectin films suggests that the formulation or processing conditions in T₂ and T₃ were more conducive to biodegradation. The higher degradation rates in T₃ could be attributed to factors such as the increased availability of biodegradable components in the films, which might enhance microbial breakdown. The films' molecular structure or the presence of additives that accelerate biodegradation could have varied across treatments, contributing to the observed differences (Yuan *et al.*, 2021) ^[21].

Moisture content of packed biscuit in Pectin & Gelatin Film

The biscuits were stored for 15 days in pectin and gelatin films made from tomato puree. It was observed that the biscuits' moisture content had increased during storage.

Table 7 shows the moisture content of biscuits packed in the tomato puree based pectin and gelatin. In film T₁ to T₃ of pectin and gelatin films moisture content increased. T₃ film of pectin and gelatin shows the highest moisture content. T₁ film of pectin content 3.32% moisture while T₃ content 4.67%. Moisture content of gelatin films are 7.3, 10.13, 11.51% from T₁ to T₃. An equilibrium moisture level of 4.7% was found in a study on biscuits made with different types of flour (Sampaio *et al.*, 2009) ^[14]. The Bureau of Indian Standards (BIS) sets regulations for the moisture content in biscuits. As per IS 1011:2002, the moisture level in biscuits must not exceed 5% by weight. Experimental data show that the films are not suitable as a packaging material for biscuit.

Table 1: Formulation of pectin film

Treatment	Pectin (ml)	Tomato puree (ml)	Glycerol (ml)	Distilled water (ml)
T1	6	10	2	82
T2	4	8	2	86
T3	2	6	2	90

Table 2: Formulation of gelatin film

Treatment	Gelatin (ml)	Tomato puree (ml)	Glycerol (ml)	Distilled water (ml)
T1	6	10	2	82
T2	4	8	2	86
T3	2	6	2	90

Table 3: Water solubility of the tomato puree based pectin and gelatin films

Treatment	Pectin film water solubility (%)	Gelatin film water solubility (%)
T ₁	83.21 ± 0.02	97.71 ± 0.01
T ₂	83.03 ± 0.01	97.48 ± 0.01
T ₃	83.01 ± 0.01	97.07 ± 0.01

Table 4: Tensile strength of Pectin & Gelatin Film

Treatment	Tensile Strength (MPa) Pectin Film	Tensile Strength (MPa) Gelatin Film
T ₁	3.8 ± 0.152753	3.8 ± 0.115
T ₂	3.5 ± 0.11547	3.5 ± 0.0577
T ₃	3.1 ± 0.057735	3.1 ± 0.02

Table 5: Pectin & Gelatin Film Thickness

Treatment	Pectin film thickness (μ)	Gelatin film thickness (μ)
T ₁	96 ± 1.1	88 ± 1
T ₂	92 ± 0.5	83 ± 0.76
T ₃	87 ± 1	82 ± 0.57

Table 6: Biodegradation rate of the tomato puree based pectin & Gelatin Film

Treatment	Pectin film Biodegradation rate (%)	Gelatin film Biodegradation rate (%)
T ₁	91.03 ± 0.01	92.71 ± 0.02
T ₂	93.01 ± 0.02	94.07 ± 0.05
T ₃	95.10 ± 0.01	94.48 ± 0.01

Table 7: Moisture content of packed biscuit in pectin & gelatin Film

Treatment	Moisture content (%) in Pectin Film	Moisture content (%) in Gelatin Film
T ₁	3.32 ± 0.017321	7.33 ± 0.02
T ₂	3.91 ± 0.005774	10.13 ± 0.01
T ₃	4.67 ± 0.015275	11.51 ± 0.02

Conclusion

Biodegradable tomato puree-based film consisting of pectin and gelatin exhibits acceptable properties such as tensile strength, water solubility, sealing, and thickness. The film containing content high amount of tomato puree demonstrates the good effects. The developed film was used as a packaging material for biscuits, but it was not suitable for the purpose. This film can be use as packaging material for low shelf life products.

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