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# Mechanical and Functional Properties of Biodegradable Films Compounding from Low-density Poly Ethylene (LDPE), Modified Corn Starch (MCS)

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## ABSTRACT

**Background:** Plastics are well suited as a food packaging material due to their availability, processability, flexibility and seal strength. However, it has the inherent flaw of not being biodegradable. This research focuses on the synthesis and characterization of mechanical and functional properties of a biodegradable films made from a fusion of LDPE and modified corn starch (MCS).

**Methods:** MCS was plasticized with glycerol and, urea and talc powder was added for film hardness. By employing a twin-screw extruder, the mix was allowed to compound before being blown into a thin film by a blown film extruder. Virgin LDPE ($T_0$) and LDPE with MCS blends were made in the ratios of 95:5 ($T_1$), 90:10 ($T_2$), 85:15 ($T_3$) and 80:20 ($T_4$) for comparison.

**Result:** As an outcome, as the starch content was increased the tensile strength decreased to 7.23 MPa from 14.55 MPa ($T_0$). Similarly, the elongation at break also reduced to 264.35% from 370.9% ($T_0$) while the elasticity modulus increased to 229.06 MPa from 172.15 MPa ($T_0$). With the addition of MCS concentration, the thickness and water solubility increased significantly. In the temperature range of 85-155°C, the films demonstrated good sealing performance. The prepared films can be used for food packaging due to the aforementioned characteristics of the manufactured films.


**Key words:** Biodegradable, Functional properties, LDPE, Mechanical properties, Modified corn starch.

## INTRODUCTION

Plastic is used in a variety of sectors as well as household items. Because of its ease of availability, processability, flexibility and seal strength, LDPE is one of the most widely used packaging materials; yet, it has the inherent flaw of non-degradability Gupta *et al*, (2010). Statista estimates that global plastics output reached 367 million metric tons in 2020 (Ian, 2011). India creates 15,342 tons of plastic garbage every year, according to the Central Pollution Control Board, the year 2018 data with Delhi responsible for 689.5 tons per day. As a consequence of the limitations of plastics, biodegradable plastics need the hour.

Biodegradable plastics are generated from renewable biomass starch, cellulose, chitosan and protein Azahari *et al.* (2011). Because of starch abundant availability, biodegradability, low cost and renewability, starch is one of the most extensively utilized polymers in this category (Heydari and Vossoughi, 2013); Pushpadass *et al.* (2010). Amylose predominates in starches, resulting in stronger films Tabasum *et al*. (2019)., Nordin *et al.* (2020). In general, adding more amylose enhances mechanical, barrier and film-forming qualities, as well as processing conditions Azevedo *et al.* (2017). The amylose content of corn is about 27% (Khader, 2019). Therefore, corn starch is one of the main materials used for producing polysaccharides- based packaging film (Ke *et al*., 2019). In the current study, carboxymethylated corn starch, also known as modified corn starch, was employed.

Plasticizers are added to polymers to minimize brittleness by increasing the free space between polymer chains, decreasing intermolecular tensions and enhancing polymer flexibility and extensibility (Arik Kibar and Us, 2013). In addition to glycerol, urea and talc powder were utilized in this research as additives. Urea helps in plasticizing starch. Whereas, talc powder increases the hardness of the material (Jia *et al*., 2014).

The purpose of this study was to synthesize LDPE/MCS films using plastic processing technologies such as twin-screw and blown film extrusion methods. The mechanical and functional qualities of the films were investigated to establish their suitability for packaging various food products.

## MATERIALS AND METHODS

The experiments were performed at the Central Institute of Petrochemicals Engineering and Technology (CIPET) in Ahmedabad and the Department of Food Process

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## Materials

Low-density polyethylene (film grade) was purchased from Tejash Industries, Ahmedabad; MCS was obtained from Industrial polymers, Ahmedabad; Glycerol, talc powder and urea were purchased from Loba Chemie Pvt. Ltd.

## Film preparation

### Compounding

The MCS was dried for 12 h at 70°C in a hot air oven to a moisture content of 3%. The additives (1% glycerol, 0.5% urea and 0.5% talc powder), MCS and LDPE mixture were then mixed at 1800 RPM in a high-speed mixer (Model No. HSM-5) until homogeneous. The obtained mixture was compounded with 100:0, 95:5, 90:10, 85:15 and 20:80 of LDPE/MCS in a twin-screw extruder (Model No. ZV 20). $T_0$, $T_1$, $T_2$, $T_3$ and $T_4$ were the names of the prepared formulations. The extruder was of the Co rotating type and had a screw speed of 600 RPM. The following was the extrusion condition: The extruder includes five heating zones for barrels and one for the die head, with a temperature profile of 91-106-117-125-130-140°C from feed zone to die and a screw speed of 234 RPM. Zones 4 and 5 of the vessels have an open vacuum vent for eliminating moisture and volatiles. The prepared strings were palletized using a palletizer with a capacity of 26 kg/h and several strips to be cut into dicers. For the formulation and characterization of biodegradable packaging film, (Gupta *et al*., 2010) used twin-screw extrusion and the film blown method.

### Film blowing

Extrusion film blowing machine (Model KBF/32) was used to blow the compounded pallets into 55-120 μ size film. The barrel temperature profile was maintained at 150-160-170-180-190-180°C in different zones and the screw speed and nip roller speed were kept at 42 RPM and 5 RPM, respectively. The air pressure was kept constant at around 5-6 bar.

## Characterization of LDPE/MCS based film

### Mechanical testing

As per the ASTM D882:2014 the tensile strength, elongation at break and elasticity modulus were measured using the universal tensile machine. The specimens were measured after being stored in a controlled chamber at RH 50±5%, at a temperature of 23±2°C for about two weeks. The crosshead space was 10mm/min. All measurements were performed for five specimens.

### The water solubility of the film

Three samples of each film (1 × 3 $mm^2$) were weighed ($w_i$) dry matter after being kept for 24 h at 105°C in a lab oven. The dry weighed samples were soaked for 24 h at room temperature in a sealed beaker containing 50 ml distilled water. After that, the film residues were taken from the beaker and dried for 24 h at 105°C before being reweighed ($w_f$) dry matter. The water solubility of each film was calculated as given in equation (1) (Ibrahim *et al*., 2019).

$$\text{Water solubility (\%)} = \frac{\text{W initial-W final}}{\text{W initial}} \times 100 \quad .....(1)$$

### Film thickness

A digital vernier caliper was used to measure the thickness of the film (Mitutoyo 500-196-20). Fifteen readings were randomly taken and the mean value was calculated.

### Transparency of film

The transparency of the film was evaluated using a UV-Visible spectrophotometer (Microtech Jasper, UV007) at a wavelength of 600 nm.

Equation (2) was used to compute the transparency (Yan *et al*., 2012).

$$\text{Transperency} = \frac{A600}{x} \quad .....(2)$$

Where

x is the film thickness (in mm) and A600 is the absorbance measured at 600 nm.

### Sealing properties of the film

Heat sealing of film was done by an impulse sealer machine (Model No. 300 FH Power- 240V/270W/50Hz.) provided with seal bar of 300 mm length and 12 mm width, sealing time setting knob, cooling time setting knob and foot pedal. Rectangular strips of film (150 × 50 mm) were cut. Sealing was done in the temperature range of 85 to 155°C.

### Biodegradability test

The soil burial test was used for evaluating the biodegradability of the film in the present study as followed by other researchers like Emadian *et al.* (2017). The film strip was cut into 8 × 8 cm lengths. The soil was collected from the roots of nitrogenous bacteria-rich plants. The five samples $T_0$, $T_1$, $T_2$, $T_3$ and $T_4$ were buried in soil in a pot for six months. Before burying the samples, the weight of the soil was measured. Before and after testing, the weight of the samples was checked. The rate of biodegradation was measured by equation (3) Marichelvam *et al.* (2019).

$$\text{Weight loss (\%)} = \frac{w_0 - w}{w_0} \times 100 \quad .....(3)$$

Where

$W_0$ and w are the weights of samples before and after the test respectively.

### Statistical analysis

All treatments were carried out in triplets. 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

### Mechanical properties of the film

Mechanical property testing of the film is crucial for its use in food packaging since it determines the strength of the film and its influence on the product to be packed. The fluctuation of tensile strength and elongation at the break of LDPE/MCS-based films is shown in Fig 1.

Tensile strength and elongation at break both reduced as starch content increased, whereas the elasticity modulus, as seen in Fig 2 increased. A starch concentration of up to 10% is desired, as it produces a film that is comparable to virgin LDPE. Tensile strength and elongation at break values dropped dramatically as starch content increased to 15% and 20%, respectively, in treatments $T_3$ and $T_4$. The reason for this is that the LDPE matrix prevents a higher percentage of starch from being assimilated. It results in films that are less flexible, stiff and non-homogenous. As the starch content increases from $T_0$ to $T_4$ in prepared film the tensile strength and elongation at break has been dropped from 20.96%, 28.52%, 41.58% and 50.37% and 13.62%, 17.94%, 23.98% and 28.72% respectively while the elasticity modulus increased in order of 6.47%, 14.85%, 22.76% and 24.84% respectively as shown in Table 1.

A comparable drop in mechanical characteristics of corn starch/LDPE blend was documented in previous work at high corn starch concentration by Matzinos *et al.* (2001); Datta and Halder, (2018); Mazerolles *et al.* (2020).

### The water solubility of the film

The water insolubility is desired quality as far concerned with food packing. Because starch molecules are hydrophilic, the rate of water solubility increases as the starch content increases as shown in Table 2. Since LDPE is hydrophobic, it behaves oppositely as starch. The additives have an impact on the film's water solubility. The plasticizers glycerol and urea aid in the creation of free space between polymer

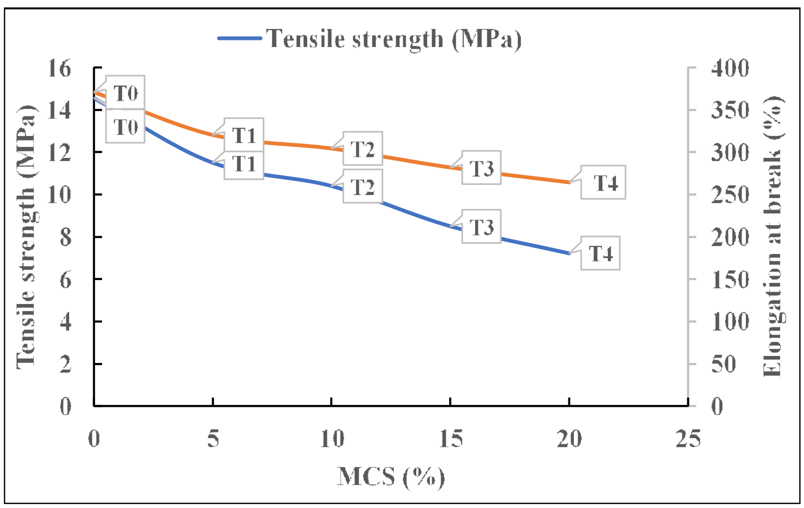


**Fig 1:** Variation between tensile strength and elongation at break of LDPE/MCS blown film

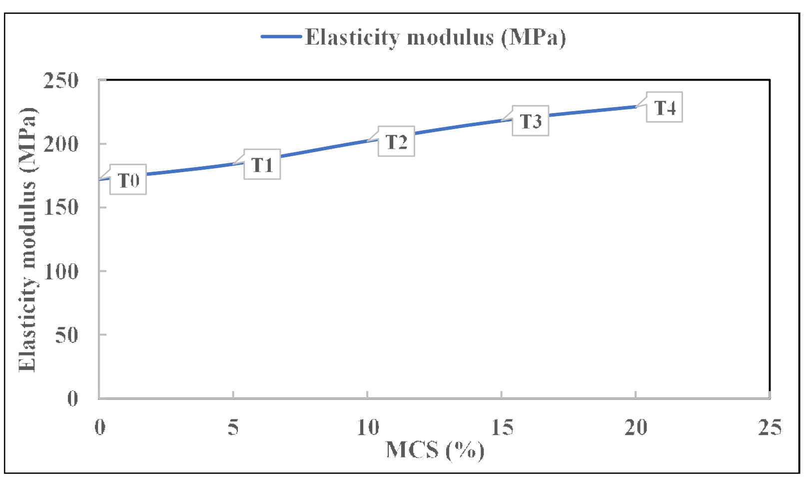


**Fig 2:** Variation of the elasticity modulus of LDPE/MCS blown film

**Table 1:** Tensile strength, elasticity modulus and elongation at the break to the different formulations of LDPE/ MCS blend.

| Treatment | Tensile strength (MPa) | Elasticity modulus (MPa) | Elongation at break (%) |
|---|---|---|---|
| $T_0$ | $14.55^a \pm 0.33$ | $172.15^e \pm 0.03$ | $370.9^a \pm 0.09$ |
| $T_1$ | $11.5^b \pm 0.26$ | $184.07^d \pm 0.06$ | $320.35^b \pm 0.39$ |
| $T_2$ | $10.4^c \pm 0.10$ | $202.18^c \pm 0.10$ | $304.34^c \pm 0.40$ |
| $T_3$ | $8.51^d \pm 0.39$ | $218.17^b \pm 0.05$ | $281.94^d \pm 0.10$ |
| $T_4$ | $7.23^e \pm 0.03$ | $229.06^a \pm 0.09$ | $264.35^e \pm 0.04$ |

[a]$T_0$ Virgin LDPE film without modified corn starch (MCS); $T_1$, $T_2$, $T_3$, $T_4$,-Biodegradable films with 95:5, 90:10, 85:15 and 80:20 LDPE/MCS.
[b]Different letters in the columns indicate that there are statistically significant differences ($p<0.05$) between samples.

**Table 2:** Thickness, water solubility, transparency and biodegradation rate to the different formulations of LDPE/ MCS blend.

| Treatment | Thickness (μ) | Water solubility (%) | Transparency | Biodegradation rate (%) |
|---|---|---|---|---|
| $T_0$ | $59.73^e \pm 0.64$ | $0^e \pm 0.00$ | $2.95^a \pm 0.02$ | $0^e \pm 0.00$ |
| $T_1$ | $71.68^d \pm 0.59$ | $3.02^d \pm 0.01$ | $2.14^b \pm 0.04$ | $6.21^d \pm 0.02$ |
| $T_2$ | $86.91^c \pm 0.37$ | $5.9^c \pm 0.36$ | $1.38^c \pm 0.03$ | $9.56^c \pm 0.03$ |
| $T_3$ | $105.68^b \pm 0.23$ | $7.74^b \pm 0.32$ | $1.09^d \pm 0.01$ | $14.02^b \pm 0.03$ |
| $T_4$ | $117.21^a \pm 0.21$ | $8.67^a \pm 0.20$ | $0.9^e \pm 0.04$ | $20.32^a \pm 0.02$ |

[a]$T_0$ Virgin LDPE film without modified corn starch (MCS); $T_1$, $T_2$, $T_3$, $T_4$,-Biodegradable films with 95:5, 90:10, 85:15 and 80:20 LDPE/MCS.
[b]Different letters in the columns indicate that there are statistically significant differences ($p<0.05$) between samples.

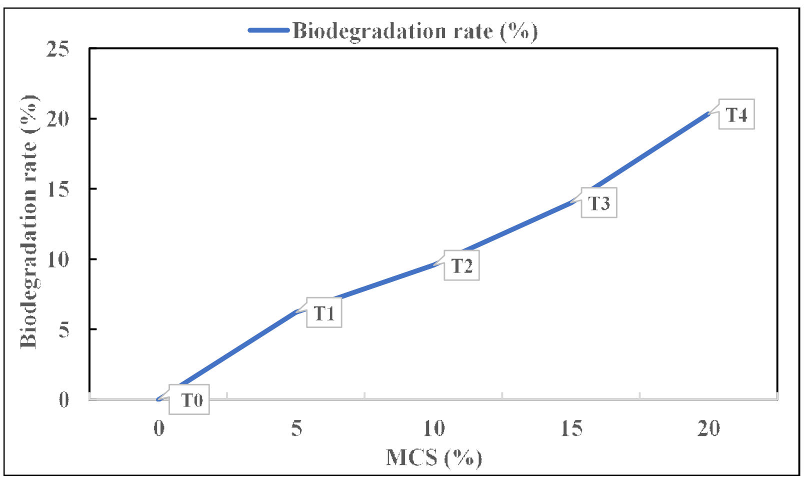


**Fig 3:** The film biodegradation rate according to MCS percentage

chains, allowing water molecules to enter the film matrix. Similar or lower results were found by Datta and Halder, (2018).

### Film thickness

The thickness of the synthesized biodegradable film was measured and the average was 95 microns. According to the findings, increasing MCS content from 5% to 10%, 15% and 20% increases film thickness by 16.67%, 31.46 %, 43.53% and 49.08%, respectively, when compared to pure LDPE film. Table 2, shows the values of film thickness produced from the four different treatments. With different proportions of additives, Mazerolles *et al.* (2020) attained a film thickness of 75-100 μ for corn starch of 60 wt%.

### Transparency

The transparency of the prepared films is given in Table 2, indicating that the film's components were well accordant. In comparison to virgin LDPE film, as the starch concentration in the biodegradable film increased, the transparency values gradually declined. The results showed that LDPE/MCS-based films could be employed as a transparent internal food packaging material. The films tested by Mazerolles *et al.* (2020) demonstrated high transparency, with a percentage of transmitted light exceeding 87% for all corn starch/LDPE samples at 600 nm wavelengths.

### Sealing properties of the film

LDPE/MCS films were found to be sealed at temperatures ranging from 95°C to 155°C. The film could not be sealed at temperatures below 95°C; nevertheless, when the temperature was raised above the temperature range, the seal became burned. The dwell period for sealing varied

**Table 3:** A comparison of LDPE and biodegradable film with varying qualities.

| Property | LDPE film | Biodegradable film |
|---|---|---|
| Tensile strength (MPa) | 14 | 7-11 |
| Elasticity modulus (MPa) | 172 | 184-229 |
| Elongation at break (%) | 370 | 264-320 |
| Water solubility (%) | 0 | 3-8 |
| Thickness (μ) | 59 | 71-117 |
| Transparency | 2.95 | 0.90-2.14 |
| Biodegradation rate (%) | 0 | 6-20 |

between 1 and 3 seconds. The seals were manually examined and found to be in good condition.

### Biodegradability test

The MCS is blended with LDPE, the resulting film matrix contains chains of starch-containing hydroxyl groups, which serve as a site for microbial action. The results of the biodegradation rate of different blends of prepared films in the soil as a function of starch percentage are shown in Table 2. As shown Fig 3, the percent weight loss of the films increases continuously as the starch contect increase. The maximum percent weight loss was observed in the $T_4$ sample, indicating a result of 20%. After six months of soil burial, the films became brittle and torn. (Gautam and Kaur, 2013) found that if a two-year study of degradation under the soil is conducted, an enhanced degradation rate of about 54% can be achieved.

### Comparison of LDPE and biodegradable film

The mechanical, functional and biodegradable properties of the prepared biodegradable films were found to be satisfactory when compared to virgin LDPE film. As shown in Table 3, the analysis results show that the film qualities vary with an increasing percentage of MCS in film.

## CONCLUSION

In comparison to virgin LDPE, the results showed that a biodegradable film compounded from LDPE, MCS was effectively made and had acceptable mechanical and functional qualities. MCS inclusion up to 10% in the making of the biodegradable film appears to be the best fit film from the perspective of food packaging, as it recorded the maximum tensile strength and elasticity modulus. Snack food goods such as chips and biscuits can be packaged with the prepared film. The film has more than 10% MCS tends to cause processing issues in both extrusion and film blowing. However, more research should be conducted to improve the aforementioned features of the LDPE/MCS films to make them comparable to virgin LDPE-based films. As a result, biodegradable films derived from renewable resources can be used in place of non-renewable resource-based films, reducing the amount of plastic waste and its detrimental impacts on human and aquatic systems.

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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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