International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Development and Ai-Based Prediction of Various Properties of Starch Based Edible Films

Shubhangi Nigam[1], Riya[2]

[1]Assistant Professor, Department of Food Technology Bundelkhand University Jhansi
[2]Student, Department of Food Technology Bundelkhand University Jhansi,India

ABSTRACT
The environmental burden of synthetic plastic waste has increased, which has intensified the search of biodegradable and sustainable alternatives. The paper is devoted to the work on the edible bioplastic films production based on the agro-waste materials, mainly the banana peel extract strengthened with cornstarch. In three sample formulations, the glycerol, vinegar, distilled water and citric acid were kept constant and a certain variation introduced in banana peel and cornstarch. This is not aimed at competing with high-performance petroleum-based plastics, such as polyethylene, but is expected to drive the usage of environmentally-friendly and biodegradable materials in the localized and low-impact usage, i.e., in food packaging. The films were described based on mechanical and physicochemical characteristics such as tensile strength, thickness, solubility, and water vapor permeability in addition to biodegradability of the films in terms of soil burial and FTIR Spectroscopy. Findings have shown that a balance ratio of banana peel extract to cornstarch yielded the most functional film. The study contributes to the heroic of agro-waste to become useful bioplastics, as well as the necessity of sustainable material development as a part of the principles of the circular economy.

Keywords: Bioplastics, Banana Peel, Agro-Waste, Starch-Based Films, Biodegradable Packaging, Sustainability, Circular Economy, Environmental Alternatives

INTRODUCTION
The main issue with food packaging technology is that it seeks to preserve the food quality within a significant time span whilst dealing with the other issues of cost of materials and energy, higher environmental consciousness and hard waste disposal regulations. The use of edible films is one of the most recent ways of improving the quality of food. Edible films have received a lot of attention due to their advantages over the synthetic films. Among the key advantages of edible packaging over synthetic packaging, it can be stated that they are an inseparable part of the food item and can be eaten without the need to unpack and dispose the packaging container.
The needs of consumers to have safe, convenient, stable, biodegradable packaging, have contributed to the attention towards edible films (Chetana Shanbhag et al., 2023). Edible films are a type of biopolymers based thin packaging material that is used to wrap the food components layer separation. Such movies enhance recyclability of the material in which the packaging is made as opposed to synthetic plastic material. The edible film is made of the natural polymers (polysaccharides, proteins, and lipids) mixed with plasticizers (glycerol, glycol, polyol) and surfactants (Ayat F. Hashim et al., 2022).

Starch is a biodegradable polysaccharide which is produced in allot at low consumption where it exhibits a thermo plasticity in nature. Starch a non-exhaustible resource, leaves a reputation of being the finest crude substance of biodegradable polymer which is cheap. Various sources of starch have been examined as a possible film forming agent such as corn, potato, barley, wheat, tapioca and rice. It is therefore the most promising alternative material, which can be used to substitute conventional plastics at the individual market segments (Flores et al., 2007). Starch based edible films are a promising type of sustainable packaging material, which builds on the peculiarities of starch and develops thin and flexible edible films, which can be used to envelop and preserve food products. Solvent casting, extrusion, or compression molding are the two most common ways of producing these films, whereby a mixture of starch and plasticizers, cross linking agents and other additives are blended to improve the mechanical properties and. The majority of the plastic wastes are discarded in landfills, land, oceans and water bodies thereby posing risk to plants, land and aquatic species and people.

Alternatively, bioplastics have a number of beneficial effects on the environment and economy of polymer manufacturing on the global level. The recycling process of conventional plastics results in a lot of CO_2 and other toxic emissions. Besides the compostable bioplastic polymers, bioplastics are low carbon emission process in their recycling. Thus, bioplastics might reduce the number of greenhouse gas emissions due to the partial or complete elimination of the use of fossil fuel derivatives using plant-based fibers and polymers (Sonil Nanda et al., 2021). The aims of the present research are the following: • To prepare biodegradable and edible bioplastic films formulations based on starch extracted as agro-waste resources (banana peels and cornstarch), using natural additives and plasticizers. • To measure the mechanical, functional and barrier characteristics of the prepared bioplastic films, moisture content, solubility, swelling index, tensile strength and biodegradability of the bioplastic films under controlled laboratory conditions. Aim: To perform Fourier Transform Infrared (FTIR) spectroscopy in the identification of key functional groups and confirmation of the chemical structure of the bioplastic matrix. unless the researchers are willing to apply the new bioplastics in creating sustainable food packaging as an alternative to synthetic plastics, which deserve a chance to contribute to environmental sustainability and waste valorization.

REVIEW LITERATURE

Bioplastics: A Green Alternative. The bioplastics are environmentally friendly substitutes to the traditional plastics, which are of renewable material, and which are meant to have a lesser environmental impact. They are different as compared to other plastics because of their origin, composition, and goals in sustainability. Bio plastics can be degraded by microbes (fungi, bacteria, and yeasts) resulting in CO_2, water, and biomass under aerobic or anaerobic environments (Ru et al., 2020). These biopolymers are used in the production of paints, disposable packaging products, and engineered use of chemicals and fertilizers in the agricultural system due to their strong physicochemical and biological properties (Liu et al., 2020). The necessity to utilize renewable resources cannot be disregarded since it is a cost-efficient solution to a large-scale manufacturing of biopolymers (Verdini et al., 2022). These are agro industrial wastes like food waste, dairy waste, grain waste, etc.

Fig 1. **Biode*gradable food packaging film***

Bioplastic is prepared using natural materials.

Banana Peel Banana peel bioplastics have been viewed as an effective way of making the plastics industry more efficient, at a cheaper rate than traditional plastics, reduced carbon footprint, and environmental safety (Hanan Arief Hasan el at., 2024). A banana peel bio-polymer plastic is the most alternative equivalent that is made purely of renewable organic materials, grounded on the food waste of agriculture, and agriculture by-products (Taodharos, 2018). The banana peels have also been used in production of biodegradable plastic films using pectin extracted in banana peels. A study conducted by Chodijah et al. (2019) used pectin peel extracted banana peels to create biodegradable films using citric acid, banana peel starch, and glycerol.

Fig 2. Banana peel as a source of starch

Corn Starch Starch is taken to be one of the most appropriate sources of bioplastic productions since it is renewable, sustainable as well as it is cheap and accessible. Starch is a desirable choice to be used in the making of bioplastic because it is thermoplastic and has a high level of degradability (Imre and Pukánszky 2013; Jiménez et al. 2012; Zhang et al. 2014). There are primarily two macromolecules of glycose in starch that are amylose and amylopectin (Pérez and Bertoft 2010); these are also different in their functions and structures (Carpenter, et al. 2017). The bioplastic efficiency is determined by the composition and the structure of the starch utilized (Pfister, et al. 2016). The corn starch is an amorphous polysaccharide that is mainly composed of 25 percent amylase and 75 percent introspection molecules. Amylase possesses molecules that are loosely arranged in water and this enhances its biodegradation and also, the introspection of the molecules augments the properties of plasticize. It is affordable, as well as readily available. Cornstarch can be put in the compost and reintroduced in the soil to restore its nutrients since it is biodegradable (Kowser et al., 2023).

Fig 3. Corn and extracted starch

Material and methods

.**Raw Materials** The raw materials of this study were sourced locally, to make them easy to access and to make them cost-effective. Fresh banana peels were obtained locally, boiled then blended and filtered to extract a starch-containing extract. Food-grade cornstarch (commercially available), glycerol (which was purchased as plasticizer), white vinegar (acetic acid), and citric acid (which was purchased as a crosslinking agent) were purchased in the local grocery and chemical supply stores. The distilled water was used to prepare all the formulations to ensure consistency and prevent impurities.

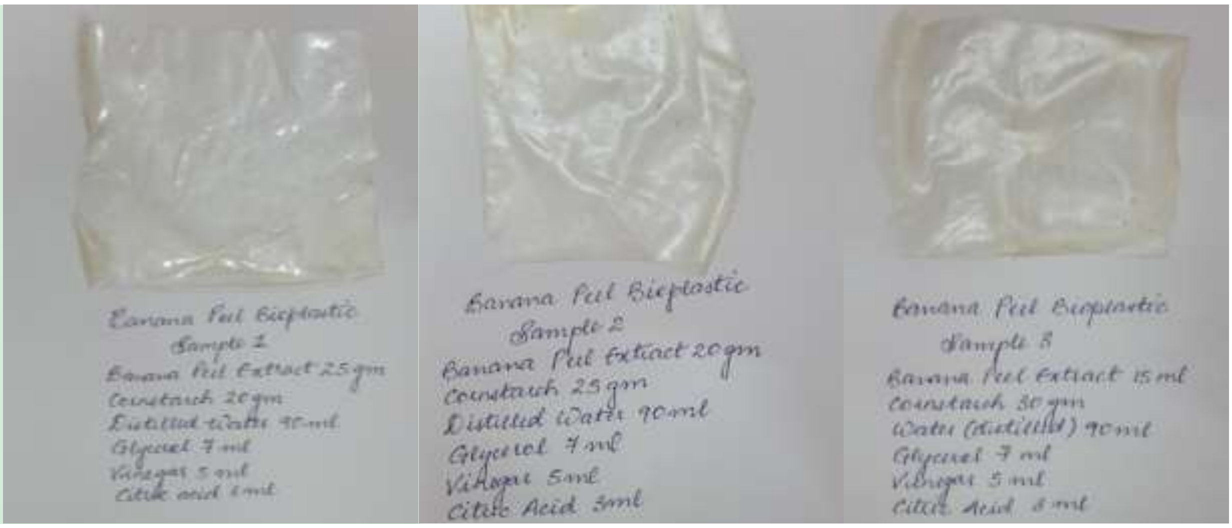
Banana peel extract was prepared by slicing banana peels into small round slices and placing them in a 40 ml beaker, then adding 5 ml of ethanol. The mixture was swirled until all the banana peel particles were covered by ethanol and the extract was concentrated to a single drop (see Fig. 2). The peels of fruit were Banana peels, which were produced as a waste product, which were initially vigorously washed with running water to eliminate contaminations. The peels that were washed were cut into small sizes and boiled in distilled water to obtain bioactive and starch compounds, about 20 minutes. The mixture was mixed thoroughly after it cooled down to get a homogenous slurry, and filtered on muslin cloth to get the liquid extract. The extract was subsequently neutralized by the addition of a small amount of citric acid in order to increase crosslinking. This was extracted by not purifying the product further and using it directly in the preparation of bioplastic films to preserve naturally occurring edible compounds.

Flowchart.1: Procedure of banana peel extraction

Fig. 5: Banana Peel Extraction

Sample Preparation It is also a research in which an edible bioplastic film was developed based on starch-rich agro-waste banana peel extracts, in conjunction with cornstarch and natural additives. Three different formulations were made with each one having constant amounts of vinegar, glycerol, citric acid and distilled water banana peel extract and cornstarch and changing the concentration of banana peel extract and cornstarch. The choice of these components was informed by their biodegradability, filmation properties and compatibility with the sustainable packaging objectives.

Bioplastic film fabrication was done using the solution casting technique. It entailed the dissolution of cornstarch in distilled water and its mix with banana peel extracts after which it was heated to facilitate the process of gelatinizing. They were supplemented with food grade glycerol as a plasticizer to enhance the elasticity, and vinegar and citric acid were also added to help in interaction of the polymers and pH equilibrium. The homogeneous mixtures were poured on level greased trays and allowed to dry under ambient conditions (25 2 C) over a period of 24-48 hours, creating hard uniform bioplastic films.



BP1	BP2	BP3

Table 1: Composition of Bioplastic Samples

Samples	Banana Peel Extract (mL)	Cornstarch (mL)	Water (mL)	Glycerol (mL)	Vinegar (mL)	Citric Acid (mL)
BP1	25	20	90	7	5	3
BP2	20	25	90	7	5	3
BP3	15	30	90	7	5	3

CHARACTERIZATIONS OF BIOPLASTIC FILM

Proximate Analysis

Moisture content

Moisture content was evaluated by weighing the film before and after drying it in a hot air oven at 105° for 24 hours. The difference in weight was used to determine moisture content using the formula:

$$\textbf{Moisture Content}\ (\%) = \frac{W1-W2}{W1} \times 100$$

Where W_1 = Initial weight
W_2 = Final dry weight

Ash content

Ash content was determined by incinerating dried samples in a muffle furnace at 550 °C for 4 hours. The remaining mineral residue was weighed, and ash percentage was calculated as:

$$\textbf{Ash Content (\%)} = \frac{Weight\ of\ Ash}{Initial\ Dry\ Weight} \times 100$$

According to the AOAC (1990) standard

Functional Properties

Water absorption capacity

To assess the water affinity of films, dry film samples were immersed in distilled water for 24 hours. Water absorption was calculated by the increase in weight using:

$$\textbf{Water Absorption}\ (\%) = \frac{W_2 - W_1}{W_1} \times 100$$

Where W_1 = Initial dry weight
W_2 = Wet weight after immersion (ASTM D570-98)

Swelling index

Swelling capacity was determined by immersing the film in distilled water for 24 hours and noting the thickness before and after. The swelling index was calculated as:

$$\textbf{Swelling Index}\ (\%) = \frac{T_2 - T_1}{T_1} \times 100$$

Where T_1 and T_2 are the thickness before and after swelling, respectively

Solubility in water

Solubility was determined by immersing dry films in distilled water for 24 hours. The residue was dried and weighed. Solubility percentage was calculated using:

$$Solubility\ (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

Mechanical Properties

Tensile strength

Tensile strength was measured using a Universal Testing Machine (UTM) based on ASTM D882. Films were cut into standard strips, and the maximum load before break was recorded:

$$\boldsymbol{Tensile\ Strength\ (MPa)} = \frac{F}{A}$$

Where F is the force at break and A is the cross-sectional area

Biodegradability

Soil Burial Test

Bioplastic samples were buried 10 cm deep in natural soil for 7 days. Samples were cleaned, dried, and reweighed. Weight loss was used to determine degradation:

$$\boldsymbol{Biodegradability}\ (\%) = \frac{\boldsymbol{W_1 - W_2}}{\boldsymbol{W_1}} \times 100$$

Analytical Properties

FTIR Spectroscopy

Fourier Transform Infrared (FTIR) spectroscopy was conducted on bioplastic samples BP1, BP2, and BP3 to identify the presence of characteristic functional groups. The samples were scanned in the range 4000–450 cm^{-1}. The spectra obtained confirmed the presence of hydroxyl (–OH), aliphatic (C–H), carbonyl (C=O), and polysaccharide (C–O, C–O–C) groups consistent with starch and glycerol-based bioplastics.

Sensory Evaluation

Sensory evaluation of the bioplastic films was carried out with the help of 5 semi-trained panelists. The films were cut into small uniform pieces and assessed for the following attributes: color, texture, aroma, and overall acceptability.

Each panelist evaluated the samples using a 9-point hedonic scale, where:

- **9** = Like extremely
- **8** = Like very much
- **7** = Like moderately
- **6** = Like slightly
- **5** = Neither like nor dislike
- **4** = Dislike slightly
- **3** = Dislike moderately
- **2** = Dislike very much
- **1** = Dislike extremely

RESULT AND DISCUSSION

Moisture and Ash Content

Table 2 gives the moisture and ash content of the bioplastic films. The moisture level in all films was moderate in the range between 9.8 and 13.5, and the level of ash was low (0.9 to 1.3). The banana peel to cornstarch ratio has an effect on the trend in moisture with banana peel having higher intrinsic moisture content. Therefore, BP1 (maximum banana peel) had a greater amount of moisture whereas BP3 (minimum banana peel, maximum starch) was drier. Mineral residue after burning is reported as ash. Ash content in all samples was below 1.5 percent and this is consistent with agro-waste starch-rich films.

Table 2 Moisture and ash content of Bioplastic Films

Sample	Moisture Content (%)	Ash Content (%)
BP 1	13.5	1.3
BP 2	11.2	1.1
BP 3	9.8	0.9

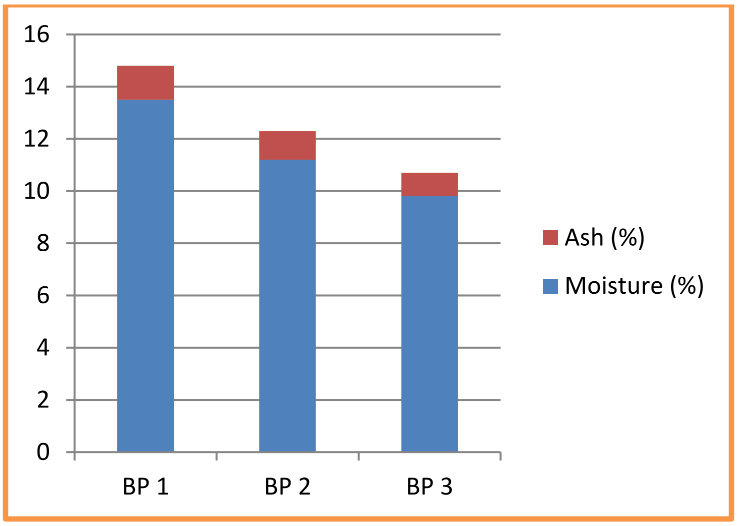


Fig. 6: Moisture and Ash Content (%) of BP Samples

FUNCTIONAL PROPERTIES

Water Absorption, Swelling and Solubility.

The hydrophilic quality of the bioplastics is tested using functional tests. BP1 (containing more banana peel) demonstrated the greatest amount of water absorption (33%), as well as swelling index (14.2%), as indicated in Table 3. Pectin and cellulose in banana peel help to keep the water and starch helps to maintain the gel-like films. The bp3 (starch-dominant) had the lowest water interaction and enhanced structural stability. The same was followed by solubility, with BP1 (~65%) and BP3 (~51) having the highest and lowest respectively. That means films made of starch are more waterproof and stable in longer periods, which is good when it comes to packaging.

Table 3Functional properties of bioplastic films

Sample	Water Absorption (%)	Swelling Index (%)	Solubility (%)
BP1	33.0	14.2	65.0
BP2	28.5	11.8	58.5
BP3	24.0	9.5	51.0

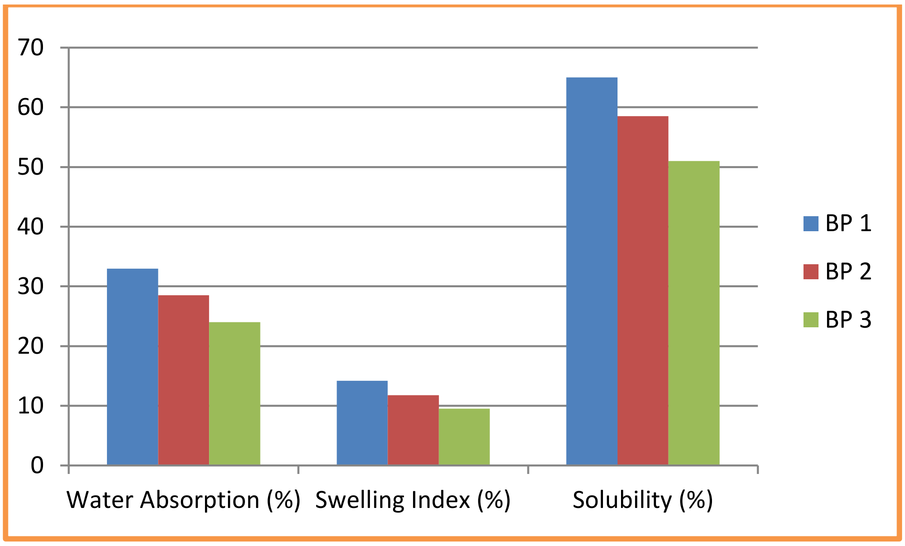


Fig. 7: Comparison of Water Absorption, Swelling Index, and Solubility in BP Samples

MECHANICAL PROPERTIES

Tensile Strength

Table 4 demonstrates the tensile strength of the films. There was a noticeable enhancement as the quantity of cornstarch content increased. BP3 had the greatest tensile strength (about 8.2Mpa), and BP1 had the least tensile strength (about 5.1Mpa). This is not surprising because starch improves rigidity and structural strength whereas banana peel, owing to the presence of fibrous and pectin, improves flexibility but lowers tensile stability. These values coincide with those found in other blends of starch-biopolymers.

Table 4Tensile strength of bioplastic films

Sample	Tensile Strength (MPa)
BP1	5.1
BP2	6.8
BP3	8.2

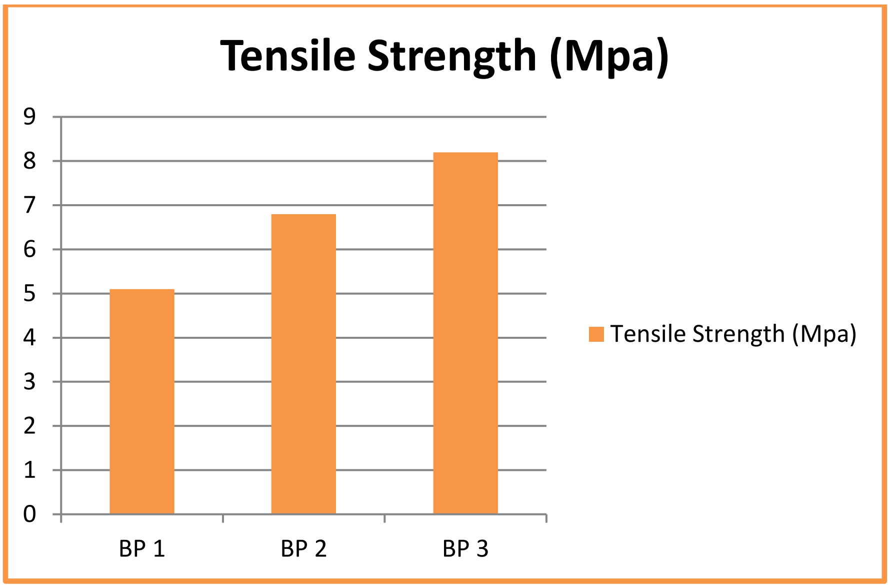


Fig. 8: Tensile Strength (MPa) of BP1, BP2, and BP3

BIODEGRADABILITY

Soil Burial Test It is the percentage of weight loss during soil burial which shows that the film is biodegradable. Table 5 demonstrates that BP1 deteriorated the quickest because it contains more banana peel as it gives the colony of microbes more colonies to proliferate and rupture. The high starch and lower fiber content of BP3 resulted in slower weight loss (approximately half of the weight was lost in 28 days), in spite of the biodegradable nature.

Table 5Biodegradability of films as percent weight loss in soil over 4 weeks.

Time (days)	BP1 Weight Loss (%)	BP2 Weight Loss (%)	BP3 Weight Loss (%)
7	18	13	10
14	35	28	21
21	50	43	35
28	70	60	50

ANALYTICAL PROPERTIES

Sensory Evaluation Five semi-trained panelists did a sensory assessment of the bioplastic films with regards to appearance, odor, feel, and overall acceptability by using a 9-point hedonict scale. All the samples were cut in small squares and put under the same conditions. The score of BP3 was highest in terms of texture and overall acceptability because it has a smoother surface and is more flexible. All attributes were balanced in BP2 and slightly firmer and darker in BP1 with higher banana peel content resulting in a lower rating of appearance and texture. These data show that increased starch level enhances the physical attractiveness and handling properties of the film

Table 6Sensory ratings (mean, 1–9) of bioplastic films

Attribute	BP1	BP2	BP3
Appearance	6.5	7.0	7.8
Odor	7.0	7.0	6.8
Texture	6.5	7.0	8.0
Overall Acceptability	6.6	7.0	8.0

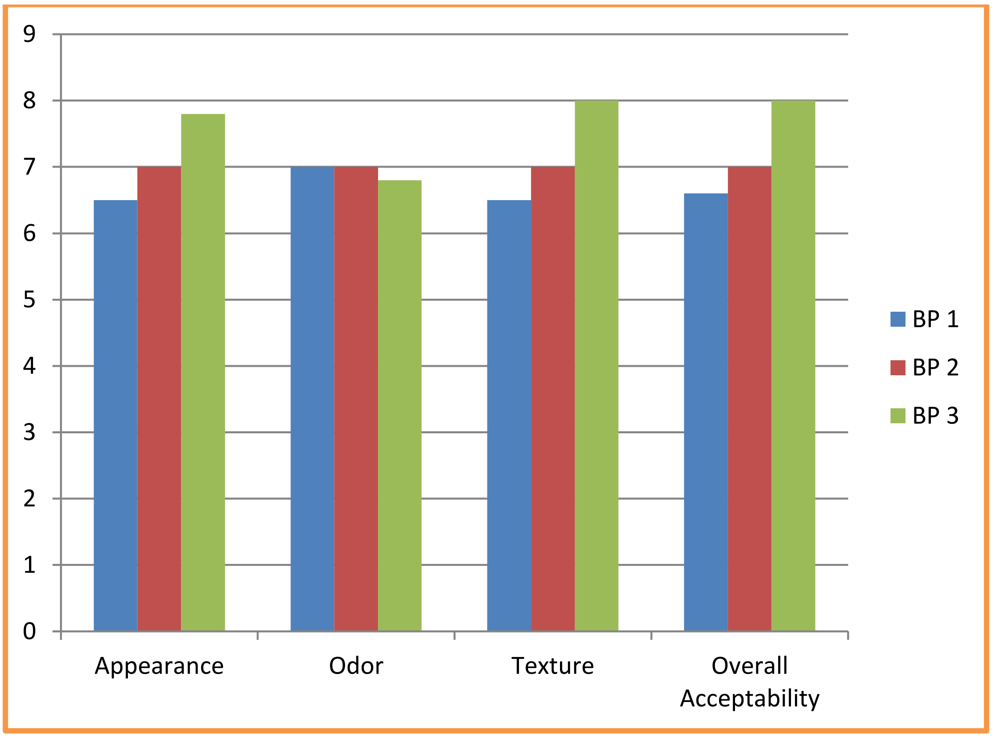


Fig. 10: Sensory Evaluation Scores of BP Samples

FTIR Spectroscopy

The Fourier Transform Infrared (FTIR) spectroscopy was done in order to determine the key functional groups of the bioplastic samples (BP1, BP2 and BP3). The sample was analysed at the Innovation Centre, Bundelkhand University, on a PerkinElmer Spectrum Two spectrometer that had a diamond Attenuated Total Reflectance (ATR) accessory attached to it. Scans were done at 32 scans per sample at a 4 cm -1 resolution range of 4000-450 cm -1. Figure 11 to 13 show the FTIR spectra of the three samples.

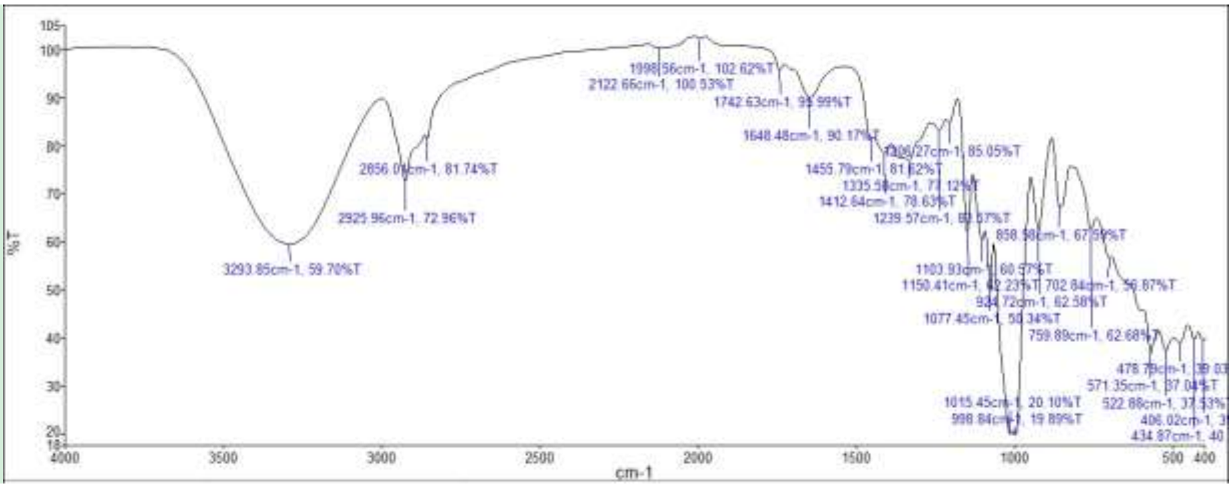


Fig. 11: FTIR spectrum of bioplastic sample BP 1

FTIR spectrum of BP1 showed the significant peak of starch and glycerol. At 3293 cm -1, a general peak was ascribed to hydroxyl group and hydrogen bonding O-H stretching. There was also the appearance of aliphatic C -H resonance bands at 2927 cm -1 and 2885 cm -1 which are consistent with saturated carbon chains. There was a sharp peak at 1646 cm -1 which was discussed as H -O -H bending vibrations which acted as an indication of the remaining moisture. Strong C-O and C-O-C vibrations associated with glycosidic connections in the starch structure appeared in the fingerprint region (between 11501000 cm -1). It is important to note that there was no carbonyl peak (approximately 1740 cm -1), indicating that there was no esterification in BP1.

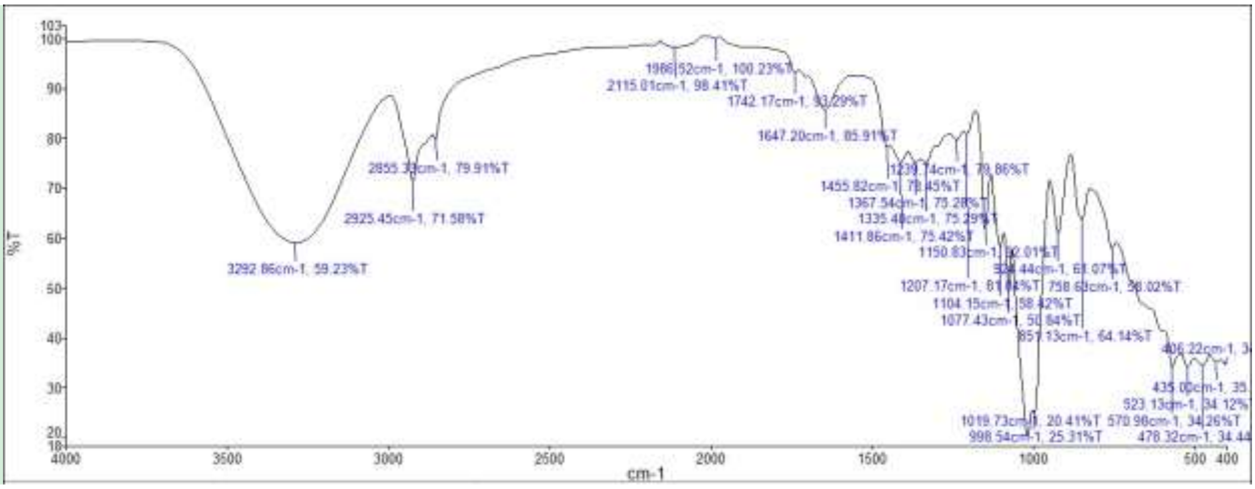


Fig. 12: FTIR spectrum of bioplastic sample BP2

The FTIR spectrum of BP2 exhibited broad O-H stretching vibration at around 3291 cm -1, which is an indicator of hydroxyl groups in starch and glycerol, which shows a lot of hydrogen bonding. Aliphatic C H stretching was attributed to peaks around 2925 cm -1 and 2854 cm -1. An evident peak of 1648 cm -1 is associated with H -O -H bending, which indicates the presence of moisture. Within the fingerprint area, the strong absorptions at 1000-1150 cm -1 verified that it contained C -O and C -O -C linkages, which are linked to starch glycosidic bonds.

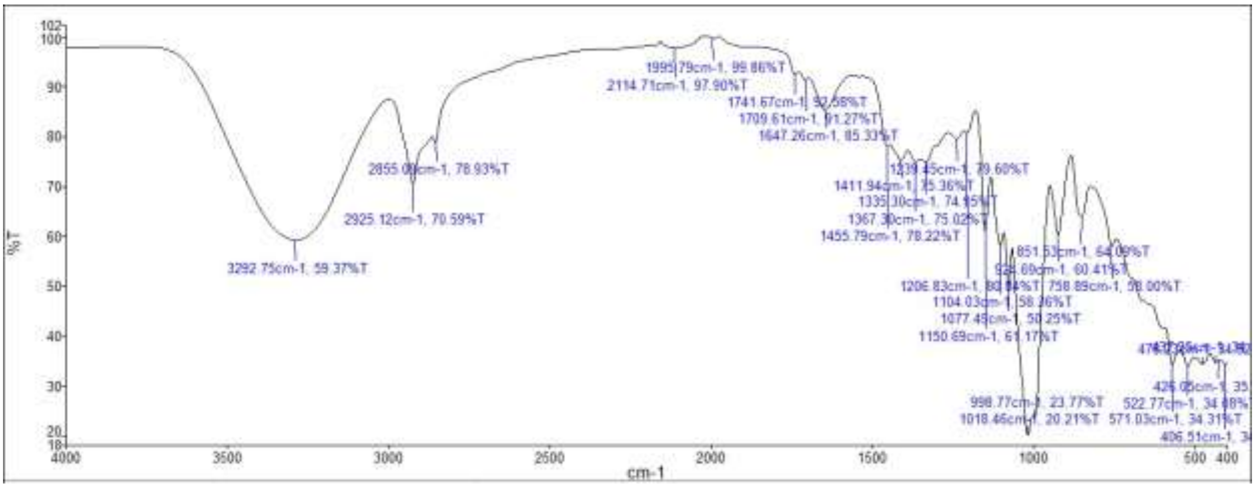


Fig. 13: FTIR spectrum of bioplastic sample BP3

BP3 had the same spectral characteristics as BP2 with distinct differences. OH not only was the band more intense at approximately 3289 cm -1, indicating more hydrogen bonding, but it was also stronger, probably because citric acid is higher. C-H stretch was seen at 2926 cm -1 and 2855 cm -1, and H-O-H bending vibration at around 1647 cm -1 indicated the presence of residual moisture. The greatest difference between BP3 and BP1 was the appearance of weak peak at 1742 cm -1, which is normally associated with C=O stretching in the ester groups. It means that citric acid could be partially esterified with the hydroxyl groups that are present in starch or glycerol. The presence of such an ester bond formation may lead to a little more flexible and hydrophilic film structure which is correlated with higher biodegradability and solubility during functional testing.

At the region of 11501000 cm -1 the fingerprint was also visible, which proved the polysaccharide structure of the film. The three samples of bioplastics (BP1, BP2, and BP3) had characteristic peaks of films based on polysaccharides which are broad OH stretches near 3290–3293 cm-1, strong C O and C O C stretch between 11501000 cm -1 and aliphatic C H stretch between 29252885 cm -1. These are characteristic of starch, glycerol and cornstarch frameworks.BP3 has been the only sample with a clear absorption at around 1742 minus 1 indicating the presence of ester carbonyl (C=O) stretching. This implies a response between citric acid and hydroxyl groups, which could result in the creation of ester bonds and increase plasticity. There was no or lower esterification in BP2 and BP1, as they did not have this ester peak. BP2 and BP3 had greater moisture retention, indicated by the position of the -16471648 cm -1 H -O -H bending peak, than the position of the BP1. This is in line with the functional test results in which BP3 was more soluble and absorbed more water.

CONCLUSION

The study was implemented with the aim of creating and describing the biodegradable and edible bioplastic films using agro-waste (banana peel extract and cornstarch). Three mixtures (BP1, BP2 and BP3) were developed by varying the ratio of banana peel and starch whilst holding the concentrations of glycerol, citric acid, vinegar, and water level constant. The objective was to assess their mechanical, functional and chemical properties with the view of making them viable in short term sustainable packaging. Every formula was effective in the formation of films of different natures.

The banana peel extract was added to the fiber content and biodegradability, whereas cornstarch was added to the structural strength and reinforcement. Glycerol and citric acid were used as plasticizers to enhance the appearance and flexibility of films. The moisture (13.5) and ash level (1.3) of BP1 were the highest since they contained more banana peel, whereas the figures shown by BP3 were the lowest ones, which implies that it was more stable. Water absorption, solubility, and index of swelling were also greatest in BP1 and least in BP3 which shows that starch-rich films resist the moisture less. The tensile strength of the mechanical testing showed that BP3 was the strongest (8.2 MPa), which confirms the fact that the higher the starch content, the stronger the film matrix. Using the biodegradability tests, BP1 was found to degrade the quickest (70% weight loss in 28 days) and BP3 (50% weight loss) was found to degrade slowly, but to exhibit eco-friendly behavior.

The FTIR spectroscopy revealed that polysaccharide components (OH, C O, C O C and C H functional groups) were evident in all samples. It is worth noting that BP3 peaked at 1742 cm -1, and further, this could be an indication of partial esterification between citric acid and starch or glycerol which was probably part of its increased flexibility and durability. Sensory analysis preferred BP3 because of its smooth texture, appealing look and general acceptability. BP1 had the highest degradation rate; however, it is not useful in packaging because of the dark colour and that it has a low mechanical strength. In general, BP3 was detected as the most promising alternative to short-term sustainable food packaging, which was the strongest, biodegradable, and acceptable by users. The study was implemented with the aim of creating and describing the biodegradable and edible bioplastic films using agro-waste (banana peel extract and cornstarch). Three mixtures (BP1, BP2 and BP3) were developed by varying the ratio of banana peel and starch whilst holding the concentrations of glycerol, citric acid, vinegar, and water level constant. The objective was to assess their mechanical, functional and chemical properties with the view of making them viable in short term sustainable packaging. Every formula was effective in the formation of films of different natures.

The banana peel extract was added to the fiber content and biodegradability, whereas cornstarch was added to the structural strength and reinforcement. Glycerol and citric acid were used as plasticizers to enhance the appearance and flexibility of films. The moisture (13.5) and ash level (1.3) of BP1 were the highest since they contained more banana peel, whereas the figures shown by BP3 were the lowest ones, which implies that it was more stable. Water absorption, solubility, and index of swelling were also greatest in BP1 and least in BP3 which shows that starch-rich films resist the moisture less. The tensile strength of the mechanical testing showed that BP3 was the strongest (8.2 MPa), which confirms the fact that the higher the starch content, the stronger the film matrix. Using the biodegradability tests, BP1 was found to degrade the quickest (70% weight loss in 28 days) and BP3 (50% weight loss) was found to degrade slowly, but to exhibit eco-friendly behavior.

The FTIR spectroscopy revealed that polysaccharide components (OH, C O, C O C and C H functional groups) were evident in all samples. It is worth noting that BP3 peaked at 1742 cm -1, and further, this could be an indication of partial esterification between citric acid and starch or glycerol which was probably part of its increased flexibility and durability. Sensory analysis preferred BP3 because of its smooth texture, appealing look and general acceptability. BP1 had the highest degradation rate; however, it is not useful in packaging because of the dark colour and that it has low mechanical strength. In general, BP3 was detected as the most promising alternative to short-term sustainable food packaging, which was the strongest,biodegradable, and acceptable by users.

REFERRENCES

1. Shafqat, A., Al-Zaqri, N., Tahir, A., & Alsalme, A. (2021). Synthesis and characterization of starch-

based bioplastics using varying plant-based ingredients, plasticizers, and natural fillers. *Saudi Journal of Biological Sciences, 28*(3), 1739–1749.
2. Sadeghizadeh-Yazdi, J., Habibi, M., Kamali, A., & Banaei, M. (2019). Application of edible and biodegradable starch-based films in food packaging: A systematic review and meta-analysis. *Current Research in Nutrition and Food Science Journal, 7*(1), 100–110.
3. Meshram, B., Wasnik, P., Shaikh, A., & Datir, R. (2022). Edible and bioplastics packaging: A review. *Journal of Packaging Technology and Research, 6*(1), 12–20.
4. Hirpara, N. J., Dabhi, M. N., & Rathod, P. J. (2022). Development of potato starch-based biodegradable packaging film. *Journal of Food Science and Technology, 59*(5), 1583–1591.
5. Habibi, Y., Lucia, L. A., & Rojas, O. J. (2010). Cellulose nanocrystals: Chemistry, self-assembly, and applications. *Chemical Reviews, 110*(6), 3479–3500.
6. Narancic, T., Verstichel, S., Chaganti, S. R., Morales-Gamez, L., Kenny, S. T., De Wilde, B., & O'Connor, K. E. (2020). Recent advances in bioplastics: Sustainability and environmental impact. *Current Opinion in Green and Sustainable Chemistry, 21*, 1–6.
7. Song, J. H., Murphy, R. J., Narayan, R., & Davies, G. B. (2009). Biodegradable and compostable alternatives to conventional plastics. *Philosophical Transactions of the Royal Society B, 364*(1526), 2127–2139.
8. Yates, M. R., & Barlow, C. Y. (2013). Life cycle assessments of biodegradable, commercial bioplastics: A critical review. *Resources, Conservation and Recycling, 78*, 54–66.
9. Reddy, R. L., Reddy, V. S., & Gupta, G. A. (2013). Bioplastics in food packaging: Innovations and sustainability. *Journal of Applied Polymer Science, 130*(3), 1425–1432.
10. Shen, L., Worrell, E., & Patel, M. K. (2011). Environmental impact assessment of bioplastics production and end-of-life options. *Journal of Environmental Management, 92*(3), 2345–2351.
11. Zheng, J., & Suh, S. (2019). Strategies to reduce the global carbon footprint of plastics. *Nature Climate Change, 9*(5), 374–378.
12. Lebreton, L. C., Van der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Scientific Reports, 8*(1), 4666.
13. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), e1700782.
14. Lackner, M. (2015). Bioplastics. In *Kirk-Othmer Encyclopedia of Chemical Technology* (Vol. 1). Wiley.
15. Fortunati, E., Luzi, F., Yang, W., Kenny, J. M., Torre, L., & Puglia, D. (2018). Bio-based nanocomposites in food packaging. In *Nanomaterials for Food Packaging: Materials, Processing Technologies, and Safety Issues* (pp. 71–110). Elsevier.
16. Choubey, V., Fatma, E., Smriti, A., Suman, R., & Rajak, S. K. (2023). Testing and evaluation of potato starch-based bioplastic. *The Pharma Innovation Journal, 12*(11), 5–11.
17. Tamang, S. (2023). Bioplastics: Definition, types, uses, challenges. *Microbiology Info*
18. Ghasemlou, M., Barrow, C. J., & Adhikari, B. (2024). The future of bioplastics in food packaging: An industrial perspective. *Food Packaging and Shelf Life, 43*, 101279.
19. Verma, P., Rani, R., Das, D., Rai, K. K., Gogoi, P., & Badwaik, L. S. (2024). Transformation of banana peel into biodegradable film added with starch and carboxymethyl cellulose. *Sustainable Chemistry and Pharmacy, 37*, 101356.

20. Hasan, H., Shawaqfeh, S., Baha, A., & Salma, M. (2024). Synthesis of biobased plastic from agriculture waste - banana peels. *Journal of Environmental Science and Technology, 67*, 283–289.