

A Study on the Utilization of Cooked Rice Waste for Bio-Based Polymer Materials in Sustainable Applications.

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Abstract

Petroleum-based plastics is the main cause of environmental degradation, while the disposal problems are caused by the large amount of waste cooked rice debris, which is discarded without being utilized. This research aims to create bio-based polymer films from cooked rice waste debris collected from school canteens to replace petroleum-based plastics. This research is focused on the extraction of starch from rice, which is mixed with rice waste to enhance the integrity of the bio-based polymer film. Cooked rice starch/polyvinyl alcohol (PVA) mixture films organized by the solution molding with the addition of plasticizers and optional additives were described in terms of their structure, powered, barrier, and thermal assets. Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) were utilized to investigate the interaction between rice starch and PVA, which exhibited good compatibility between the two components. Results of the soil burial test showed good biodegradation of the bio-based polymer film within 60-90 days. The developed rice starch/PVA films showed better mechanical strength (6.2-7.8 MPa), flexibility (12-18%), water solubility (20-28%), and high biodegradability (90-95%), showing promise for environmentally friendly food packaging materials. The research shows that cooked rice waste can be efficiently converted into biodegradable films for use in food packaging materials. The solution for the problem of plastic waste is provided by converting food waste into a biodegradable food packaging material. The solution also valorizes food waste and provides an alternative for food packaging materials.

Keywords: Cooked rice waste, Bio-based polymer, Starch-based biodegradable film, Polyvinyl alcohol (PVA) blend, Waste valorization, Sustainable materials

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Research highlights:

- Using cooked rice debris as a sustainable supply of starch to make biodegradable films.
- Starch-PVA mixing and plasticization result in increased mechanical strength and elasticity.
- Superior to pure starch films in terms of barrier, moisture resistance, and thermal stability.
- Eco-friendly potential of food wrapping applications is indicated by the high biodegradability (up to 90–95%).

1. Introduction

A decomposable substance with potential for use in the food wrapping is starch. Deviations in intermolecular reserves, which are impacted by the condition of the films, are anticipated to affect luminescence intensity. This implies that starch films could serve as basic packaging as well as help with food product quality control during packing [1]. The second most used element for food packaging is plastic, which is essential for extending shelf life and avoiding microbiological contamination. Chemical, biological, and physical variables that preserve sensory qualities during storage have an impact on shelf life. The food packaging industry looks for portable, biodegradable substitutes to reduce waste, material consumption, and the cost of shipping [2]. Starch, a polysaccharide with advantages like affordability, sustainability, and ease of production, is present in all grain crops. It is widely employed as a bio-coating and green packaging material in both native and modified forms, especially

to prolong the freshness of fresh crops [3]. Because of their non-biodegradable nature and potentially dangerous chemicals, the food wrapping part's dependence on petroleum-based plastics has damaged habitats, including landfills and oceans. Biodegradable food packaging films have been proposed as eco-friendly alternatives to counter environmental pollution and plastic waste accumulation problems in the future [4]. The ecological properties of starch biopolymers include their mechanical and thermal stability, biodegradability, and their influence on the environment during processing, which involves activities such as crystallization, gelatinization, and water diffusion. The potential of biodegradable food packaging films can be improved through chemical modification, despite the problems of hydrophilicity and brittleness when used as plastic substitutes [5, 6]. Transparent, biodegradable, and non-toxic, poly (vinyl alcohol) (PVA) has barrier and film-forming qualities. It is frequently used as an adhesive in medicinal and

nutritional products [7]. Wrapping, polymer utilization, sheath setup, and regulated drug distribution organizations are just a few of the uses for PVA. Although polyvinyl alcohol (PVA) is a biodegradable polymer, it does not possess inherent biological activity. The addition of Chitosan (CS), an organic polysaccharide, can increase PVA's antibacterial action. A promising method for producing organic polymers with better properties, like improved durability and retained water, is blending CS with PVA [8, 9]. A PVA is a synthetic, biodegradable, and biocompatible polymer recognized for its outstanding film-forming capacity and optical transparency. The -OH groups in its assembly aid in the construction of hydrogen bonds inside the polymer medium. Because PVA is non-toxic and has good chemical and thermal stability, it can be used in the nutrition wrapping manufacturing [10]. Glycerol is commonly employed as a secondary plasticizer in the food industry due to its low harmfulness and favorable safety profile. Despite their ability to improve elasticity in films, an excessive amount of these additives can undermine mechanical properties by reducing durability and tensile strength, in addition to increasing hydrophilicity and reducing water vapor transmission. [11].

Several benefits to using bio-based polymers rather than synthetic ones, including the fact that they are renewable, harmless, and reusable, making them an excellent alternative to commercial plastics. Associated with other biopolymers, starch has a longer history in the market and has shown promise as a bio-based polymer for use in bioplastics applications [12]. Biopolymer-based compounds, such as CS, have promise due to their natural abundance, biodegradability, and antibacterial characteristics. By creating a low-oxygen environment that inhibits microbial activity and lipid oxidation, nanocomposites in food packaging contribute to excellence maintenance [13]. In the food industry, wrapping is vital for protective diet safety, excellence, and longevity while fostering consumer contact. As consumers' knowledge of food safety has grown, revolutions have caused in the growth of smart wrapping. However, because synthetic polymers are not biodegradable, they provide disposal problems and contribute to health problems in landfills [14]. Due to harmful emissions during destruction and ongoing microplastic pollution, traditional plastic wrapping presents thoughtful pressures to the setting and human health. Although bio-based polymers have become viable substitutes, their low mechanical strength, poor water resistance, and barrier qualities have hindered their widespread use [15].

Research purpose: With cooked rice waste in school canteens as a sustainable source of starch, this research

aims to produce recyclable film polymer. This research also aims at adding mechanical barrier, and thermal properties through PVA mixing and plasticizers, promoting the use of ecologically friendly wrapping, reducing plastic pollution, and facilitating the use of the circular economy and food waste valorization.

Research organization: The research is structured as follows: Background and aims are presented in the Introduction; previous research is reviewed in the Related Work; experimental procedures are described in the Materials and Methods; findings are analyzed in the Results and Discussion; and outcomes and future scope are summarized in the Conclusion.

2. Literature review

An intelligent packaging sensor based on a sheet of ammonia was designed using starch/polyaniline (starch/PANI) [16]. The films were analyzed by Fourier Transform Infrared Spectroscopy (FTIR), Ultraviolet-Visible Spectroscopy (UV-Vis), X-ray Diffraction (XRD), and Differential Scanning Calorimetry (DSC); they presented a change in color, but it is sensitive and needs validation. Research [17] develops bioplastics using starch to package goods in environmentally friendly packages. Taguchi optimization was used to add starches of potatoes and corn with plasticizers and calcium carbonate. The results showed improved strength and degradation, but variable rates of degradation and differences in moisture absorption remain a challenge. Indeed, carboxymethyl starch/polyvinyl alcohol (CMS/PVA) films were produced with the help of Cu-tryptophan nanocrystals to make intelligent packaging [18]. Even though scalability and cost can limit its practical use, the findings indicate stronger performance, UV-blocking, barrier, and antibacterial performances with ammonia-detectable color change in spoiling detection. Lignin nanotubes and polyvinyl alcohol (LNT/PVA) develop a barrier layer to package the research [19]. These findings reveal strengthened mechanical properties, thermal stability, UV-shielding, antibacterial, and decreased water/oxygen permeability, yet extensive dispersion and large-scale processing can inhibit the feasibility of applications. The research [20] employs fuzzy optimization in matching the elongation and cost of developing a recyclable flexible using cassava starch. The findings show that it is a perfect composition with improved cost efficiency and enough mechanical performance; however, lower elongation and model dependency can limit the practicality and reproducibility of efficiency in the real world.

Yam starch bioplastic films with enhanced strength and degradation were created by solvent casting glycerol and bentonite; these films were inspected by FTIR and scanning electron microscopy (SEM) [21].

However, the applications were limited by their higher hydrophilicity and lower alkaline stability. Kudzu starch films were prepared using glycerol, beeswax, and cinnamon essential oil and analyzed by tests of physicochemical analysis and Field Emission – SEM (FE-SEM) [22]. Although the application is limited by the diversity and accessibility of natural oils, the results demonstrated enhanced barrier, and antibacterial activity. The creation and assessment of starch-founded films used dialdehyde starch, caffeic acid, and quinic acid as the ingredients [23]. The evaluation employed Attenuated Total Reflectance - FTIR (ATR-FTIR), XRD, and Atomic Force Microscopy (AFM). The outcomes displayed better motorized, fence, and antioxidant assets; however, further verification of antioxidant properties is required. Nitrogen-doped carbon quantum dots were added to sago starch layers for use in food containers using solution casting. They were then analyzed by FTIR, XRD, and SEM [24]. The results were exhibitions of high hydrophobicity, antioxidant, and UV protection. An increment of aggregation, however, decreased performance. The starch-blended recyclable materials were investigated using starch dissolved in polybutylene succinate, and polylactic acid, (PBS/PLA) to incorporate starch so as to form sustainable plastics [25]. The results showed that there is enhanced biodegradability and reduced environmental impact; however, poor durability and inconsistencies with industrial processes are constraints. In the case of bio-based packaging, caseinate-coated stainless steel sheets, which included sorbitol (SO) and glycerol (GY), were developed [26]. Glycerol was superior to the other materials in the flexibility, power, and air barrier properties. Limitations are scalability problems and a lack of thermal stability. Rice husk (RH) was extracted into carboxymethyl cellulose that was then blended to form starch-based biodegradable films [27]. Good solubility and structural integrity were observed in the films, and moderate crystallinity and scalability were still issues. Differential Scanning Calorimetry (DSC) is one technique that improves the capabilities and uses of starch-rich coatings and FTIR [28], yet there are still issues concerning about powered strength and moisture resistance of sheets made of starch, as well as their implementation in large-scale industry. It was possible to prepare starch-chitosan films with anthocyanins of eggplant and copper nanoparticles and analyze them with FTIR, SEM, and XRD by using an optimal composition [29]. The movies showed superior barrier, antioxidant, and anti-bacterial properties. Barriers are the scalability of industrial applications, stability, and the complexities of formulation. To enhance the packaging properties, NH₂-MIL-101(Cr), which is green-synthesized, was

combined into starch films [30]. The 3% loading was shown to have optimal strength, thermal stability, and Ultraviolet (UV) protection. Scalability was reduced by agglomeration caused by increased loading, and flexibility was diminished.

3. Materials and methods

The waste cooked rice was collected from school canteens. Then, a systematic pre-treatment of the rice waste for starch extraction was carried out. The rice waste was subjected to a thorough wash in distilled water to remove any impurities. Then, drying of the rice waste in a controlled environment followed by grinding into a fine powder for starch extraction was carried out. FTIR, SEM, mechanical evaluation, solubility, and biodegradability tests were systematically accepted to assess the performance of the films, as shown in Figure 1.

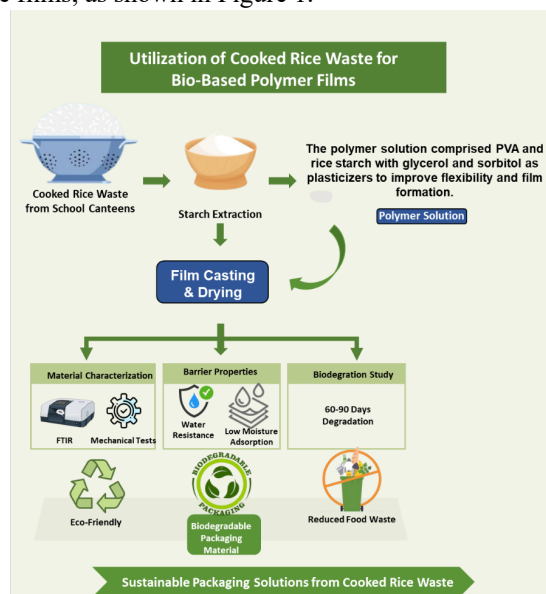


Figure 1: Process illustrating conversion of cooked rice waste into biodegradable polymer films using starch extraction, additives, casting, characterization, and sustainability evaluation.

3.1 Collection of Raw Material

Cooked rice wastes were collected on a daily basis from three school canteens over a five-day sampling period. The daily collection ranged from 2.5 to 3.2 kg, making a total of 14.6 kg of fresh cooked rice wastes. Freshly collected garbage was picked up an hour or two after serving to reduce decay. The purity level of 96.8% was achieved through hand-sorting impurities from the wastes. Prior to laboratory processing for starch recovery and biopolymer film development, fresh wastes were kept in sterile polyethylene containers at 4 °C.

3.2 Pre-Treatment of Waste

To get rid of surface pollutants and soluble impurities, the collected cooked rice waste (~14.6 kg) was cleaned

three to four times using distilled water. After draining, it was roasted for a full day at 60 °C until the moisture content was $8.5 \pm 0.3\%$. Equation (1) represents the moisture content.

$$\text{Moisture content}(\%) = \frac{W_j - W_d}{W_j} \times 100$$

(1)

Where W_d is the model's ultimate mass following drying (g), and W_j is the tester's initial heaviness before drying (g). For efficient starch extraction and polymer processing, the wet substance was smashed and sieved (250 µm mesh) to obtain 92.4% particle homogeneity.

3.3 Starch Extraction

The method of recovery of starch in the pre-treated cooked rice trash was done by a controlled aqueous separation procedure. In order to safeguard the whole disintegration of the starch granules, the mixture of 100 g of dried rice powder and 1000 mL of purified water in the proportion of 1:10 was initially mixed at 8000 rpm after 20 minutes. The starch slurry formed was filtered using a muslin cloth to remove any rough and fibrous particles. The starch-rich particles and the liquid phase were separated using the centrifugation method for 15 minutes at 5000 rpm. The supernatant containing the soluble impurities was decanted. For the purpose of purity, the starch sediment formed was washed thrice using pure water. It is assumed that the recovery efficiency of starch is 94.6, as shown in Equation (2).

$$\text{Starch yield}(\%) = \frac{\text{Weight of extracted starch}}{\text{Weight of raw material}} \times 100$$

(2)

Where *the weight of extracted starch* represents the final dry mass of starch gained after extraction (g), and *the weight of raw material* denotes the initial weight of the pre-treated rice sample used for extraction (g). After cleansing, the starch was dehydrated for 12 hours at 50 °C in a warm appearance range until a reliable mass was reached. For the purpose of creating and characterizing biopolymer films, the dried starch was gently crushed into a fine powder and kept in sealed vessels.

3.4 Polymer Blending

Polyvinyl alcohol (PVA) was mixed with rice starch that had been extracted. This produced a stable homogenous biopolymer system that was appropriate in creating films. To ensure that there was homogeneity in the solution, 5 g of rice starch was first melted in 100 mL of purified water, which was then put under constant mixing. The solution made up of PVA in distilled water at 80 °C was clear and had viscosity since 5 g of PVA had been dissolved in the solution. It was then stirred at all times in another

beaker. The solutions were then mixed while being stirred at 70-80 degrees Celsius for 30-40 minutes in order to ensure homogeneity. This enabled starch and PVA to form strong intermolecular bonds with the hydroxyl group. This was significant in enhancing acceptability since it provided structural integrity. The strong intermolecular hydrogen bonding between the hydroxyl groups of starch and PVA was made possible by this blending procedure. The polymer matrix formed showed better dispersion, viscosity, and film-forming properties, which made it fit for the integration of the plasticizer and the production of biodegradable films for packaging purposes.

3.5 Plasticizer Addition

Plasticizers such as sorbitol and glycerol were incorporated into the starch-PVA polymer matrix at concentrations of 20-30% (w/w of the total polymer content). The plasticizers were incorporated to improve the plasticity and minimize the brittleness of the materials. For this purpose, the mixture was constantly stirred at temperature range of 60-70°C. The plasticizers made the biodegradable materials flexible, smooth, and mechanically stable materials that can be used in the packaging industry.

3.6 Technique of Solution Casting

The homogeneous starch-based plasticized films were prepared by subjecting the synthesized starch PVA blend to a well-controlled solution casting process. The solution, which was thick, was placed in clean, level glass, or Teflon plates in which the solution was uniformly spread to a depth of 2 to 3 mm. The solution was left to slowly evaporate, with the dried-up cast solution left in a hot air oven at 45-50 °C for a period of 24 hours. After the solution was dried, the films were subjected to a process of careful elimination, followed by conditioning at 25 °C, $50 \pm 5\%$ relative humidity, for a period of 48 hours.

3.7 Film Characterization

The films thus produced were assessed to verify their structural, mechanical, and functional properties, thus confirming their potential for recyclable wrapping films, along with their enhanced performance compared to conventional starch-based films.

● Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR [31] was carried out to classify the practical collections and the connections of the rice starch and the PVA in terms of the molecules. The characteristic peaks in the spectra designated the attendance of –OH, C–H, and C–O groups. The shift and widening in the –OH region at around $3200\text{--}3400\text{ cm}^{-1}$ indicated the presence of strong hydrogen bonding in the starch and PVA molecules. This confirmed the presence of a stable polymer in the film.

● Scanning Electron Microscopy (SEM)

The surface and cross-sectional morphology of the films thus produced were analyzed using SEM [32, 33] analysis. The films were found to possess a uniform, thick, and smooth structure, along with no specific pores, fissures, or phase segregation. This uniformity indicated strong adhesion and efficient blending of rice starch and PVA.

3.8 Mechanical Characteristics

The mechanical properties of films, such as strength and flexibility when subjected to stress, were also tested. These properties are important in determining if biodegradable films can be used for packaging purposes where they need to be flexible and strong at the same time. The mechanical possessions of films remained tested by tensile testing. The tensile strength was determined using Equation (3).

$$\text{TensileStrength} = \frac{F}{A}$$

(3)

Where A is the cross-sectional area (mm^2), and F is the applied force (N).

The measure of the stretching or deformation capacity of a material before it breaks when subjected to tensile pressure is called elongation at disruption. This is a key value of the ductility and supple nature of the film. The greater the chain mobility in the polymer matrix is indicated by high values of elongation, which in turn provides greater elasticity and less brittleness for flexible packaging materials. The elongation at break was calculated by Equation (4).

$$\text{Elongation at Break}(\%) = \frac{M_g - M_0}{M_0} \times 100$$

(4)

Where M_0 is the preliminary length, and M_g denotes the length at the end of the break.

3.9 Water solubility analysis

Pre-weighed samples were immersed in distilled water, dried, and then re-weighed to measure the water solubility of the films. Lower water solubility, which indicated better water resistance and suitability for packing, was related to the films. The water solubility of the films in the solution was measured to evaluate the resistance of the films to dissolution. Equation (5) was employed to obtain % solubility.

$$\text{watersolubility}(\%) = \frac{W_j - W_g}{W_j} \times 100$$

(5)

Where W_j is the original dry weight, and W_g is the last dry heaviness following immersion.

3.10 Biodegradability testing

The produced films' biodegradability was assessed under natural environmental settings utilizing a soil committal method. Film samples (2 x 2 cm) were weighed (starting weight ~0.50 g) and buried at a depth of 5-7 cm in moist soil (moisture content ~25–

30%) at room temperature (28 ± 2 °C). Illustrations were composed at regular intervals (15, 30, 60, and 90 days), cleaned gently, dried at 50 °C, and then considered over. To determine the rate of degradation, the % weight loss was computed in Equation (6).

$$\text{WeightLoss}(\%) = \frac{W_0 - W_u}{W_0} \times 100$$

(6)

Where W_0 is the starting weight, and W_u is the mass after time u . The films' significant biodegradation, roughly 65–75% weight loss in 60 days, and nearly complete disintegration (90–95%) by 90 days, confirmed their suitability as eco-friendly packaging materials and their environmental compatibility. The films' substantial biodegradation, with roughly 65–75% weight loss in 60 days and practically total disintegration (90–95%) by 90 days, confirmed their appropriateness as environmentally friendly packaging materials and their compatibility with the environment.

4. Result and discussion

The resulting cooked rice starch/PVA mix films' mechanical, biodegradable, barrier, and physical characteristics were also carefully assessed. From the findings, it is evident that there is an improvement in the conventional starch-based film, which is an indication of the effectiveness of polymer blending and plasticization.

4.1 Structural Analysis (FTIR)

FTIR analysis is used to examine structural links between rice starch and PVA in films. The wide absorption peak in FTIR spectra of 3200-3400 cm^{-1} is due to -OH group vibration. This indicates robust hydrogen bonds among chains of starch and PVA. C-H stretching is found in peaks of 2920 cm^{-1} . Moisture absorption is found in peaks of 1640 cm^{-1} . Compatibility is verified by observing an obvious shift in the discernible shift of -OH peaks. These observations indicate that a stable and uniform polymer network with better structural properties has been achieved. Figure 2 shows FTIR spectra of films of blends of starch and PVA. Various functional groups are indicated by peaks in FTIR spectra. Other peaks indicate the formation of blends and constant films. A wide peak of -OH indicates hydrogen bonds. Table 1 shows FTIR peaks, which indicate functional groups and strong hydrogen bonds between starch and PVA. These observations designate compatibility, creation of a stable polymer network, and constant films.

Table 1: FTIR Peak Assignments of Rice Starch/PVA Biopolymer Films

Wavenumber (cm ⁻¹)	Functional Group	Spectral Interpretation	Observation
3200–3400	–OH stretching	Hydrogen bonding	Broad peak (strong interaction)
~2920	C–H stretching	Alkyl groups	Moderate intensity
~1640	H–O–H bending	Absorbed moisture	Weak band
1000–1150	C–O stretching	Polysaccharide backbone	Confirms starch presence

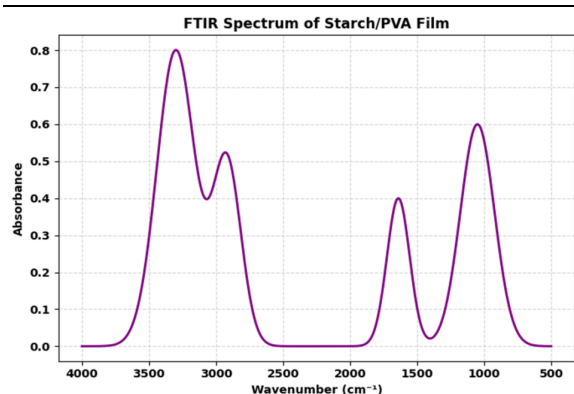


Figure 2: FTIR spectrum of starch/PVA blend film

4.2 Morphological analysis

The external and cross-sectional morphological features of the developed rice starch/PVA films were studied by SEM. The photographs showed the uniform and compact structure of the films without pores and cracks. The uniform construction of the films indicates the strong adhesive and cohesive possessions of the rice starch/PVA blends. The absence of starch grains is indicative of complete gelatinization and proper dispersion in the polymer matrix. Moreover, its small structure suggests a smaller volume of freedom that increases the barrier properties and mechanical integrity. On the whole, the results of the SEM designate that the count of PVA primes to higher structural integrity and the creation of well-integrated biodegradable films, which are suitable for packaging applications. Figure 3(a) shows the morphology of starch in the granular form and the porous structure of

the starch/PVA film Figure 3(b), which implies enhanced mechanical properties, compatibility, and dispersion.

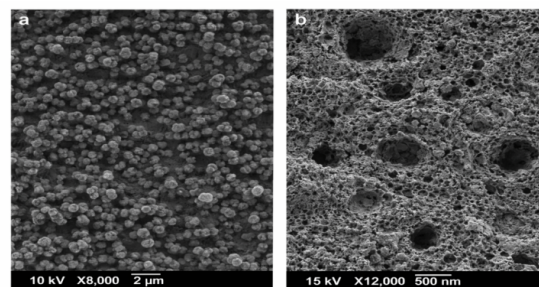


Figure 3: Illustrations of biodegradable starch/PVA films of (a) homogenous polymer blending and strong intermolecular connections are indicated by smooth and homogeneous surface morphology; (b) structural variation and increased biodegradation activity are suggested by rough and porous structure.

4.3 Mechanical Characteristics

The automated assets of the produced rice starch/PVA films were determined using tensile asset and reflection during an interruption. The tensile asset of the films was knowingly increased associated to pure starch films, and the tensile strength of the films was found to lie between 6.2 and 7.8 MPa. This is further supported by strong intermolecular hydrogen bonds that form among starch and PVA, which also improve structural integrity. From the time that sorbitol and glycerol were used as plasticizers, the percentage range of the break caused elongation is between 12% to 18%, which makes it more flexible. The movies were appropriate for packaging work since they were also observed to have good strength and flexibility. The results have also shown that there is an increase in both the strength and suppleness of the blended starch/PVA films, creating them appropriate for use in food packaging. The strong intermolecular interaction of polymers that is appropriate for packaging work is also supported by the fact that there is an upsurge in both the tensile strength (6.2–7.8 MPa) and flexibility (12–18%), as depicted in Figure 4.

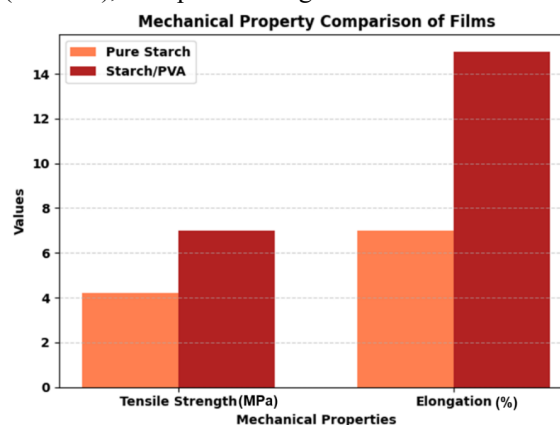


Figure 4: Mechanical property comparison of pure starch and starch/PVA blend films

4.4 Moisture Properties and Water Solubility

The water solubility and characteristics of water moisture were also tested to check the stability of the films. The water solubility of the films was significantly low compared to the pure starch films, ranging between 20% and 28%. This reduction is due to the addition of PVA, which increases the intermolecular forces and hence makes the final product less hydrophilic. This reduction in the swelling index and moisture fascination is also due to the enlarged stability of the film against water. The compact structure of the polymer increases the functionality of the films in the packing conditions in terms of reduced water penetration. Figure 5 shows the moderate water resistance of the film and the increased stability of the film, where the solubility is at the top, followed by moisture absorption and swelling index.

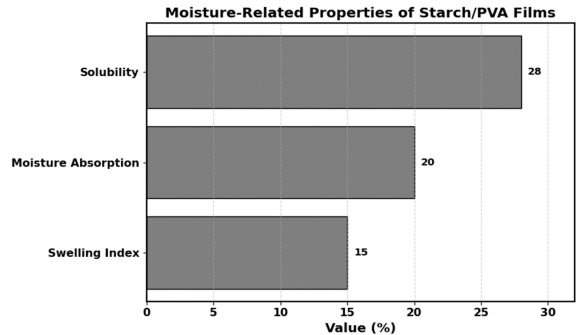


Figure 5: Moisture-Related Properties of Starch/PVA Films

4.5 Barrier Properties (Water Vapor Permeability (WVP))

The fence belongings of the rice starch/PVA merged films were studied by conducting the WVP measurement. The outcomes obtained exhibited that the rice starch/PVA multiple films were more resistant to moisture transfer when compared to the starch films with WVP values ranging from 7.5×10^{-12} to 9.2×10^{-12} g/m·Pa·s. 7.5×10^{-12} to 9.2×10^{-12} g/m·Pa·s. The results were obtained because the rice starch/PVA composite films were thick and dense due to the presence of high hydrogen bonds. The free volume in the polymer matrix was reduced, and this reduced the mobility of the water molecules. Therefore, the rice starch/PVA composite films are promising materials for the development of food packaging materials. The consequences obtained exposed that the developed films were appropriate for the growth of food wrapping resources because the moisture transfer was a critical requirement.

4.6 Thermal Stability

To evaluate the resistance of the films to variations in temperature, the thermal constancy of the films was investigated. The starch/PVA films synthesized in the

study showed improved thermal stability, with initial degradation temperatures of 200 and 220°C. The improved thermal stability of the films can be clarified by the formation of intermolecular hydrogen bonds and the development of a polymeric network, which improves the chain rigidity of the synthesized films and hence improves their thermal stability. The blended films showed improved thermal stability compared to pure starch films, producing them appropriate in real-world applications. The improved thermal properties of the synthesized films ensure that the films do not compromise their properties when subjected to real-world application environments. With a starting degradation temperature ranging from 200 to 220°C and a maximum degradation temperature ranging from 280 to 320°C, and low residual mass, which indicates high thermal resistance and structural stability of the films, Table 2 and Figure 6 illustrate the improvement in thermal stability of the films prepared.

Table 2: Thermal Stability Properties of Rice Starch/PVA Biopolymer Films

Parameter	Value	Interpretation
Initial Degradation Temperature (°C)	200–220	Indicates improved thermal resistance
Maximum Degradation Temperature (°C)	280–320	Suggests a stable polymer backbone
Residual Mass (%)	10–15	Reflects char formation and stability
Thermal Behavior	Enhanced	Due to strong hydrogen bonding

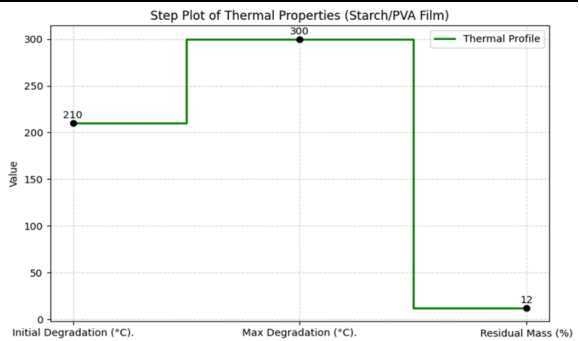


Figure 6: Thermal Properties of Starch/PVA Film

4.7 Biodegradability

The biodegradability of the produced films was tested in a natural environmental condition using the soil

burial method. The movies were too bad to bear after 30, 60, and 90 days of their lifetime, having lost 40-50 percent, 65-75 percent, and 90-95 percent of their weight, respectively. The rapid rate of biodegradability is attributed to the natural origin of starch and hydrophilic polymer architecture. From the results, it is clear that the produced films are highly biodegradable and environmentally friendly, which makes them suitable for use in place of other traditional plastic materials. Table 3 shows the properties of starch/PVA films, where it is clear that there is an improvement in its mechanical properties, flexibility, barrier properties, and thermal stability, which makes it suitable for use in environmentally friendly biodegradable films. Figure 7 shows the weight loss of starch/PVA films during 90 days, which indicates good environmental compatibility.

Table 3: Comparative Performance of Pure Starch and Starch/PVA Films

Property	Pure Starch Film	Starch/PVA Film	Improvement
Tensile Strength (MPa)	3.5–5.0	6.2–7.8	↑ Improved strength
Elongation at Break (%)	5–10	12–18	↑ Increased flexibility
Water Solubility (%)	30–40	20–28	↓ Reduced solubility
WVP (g/m ² ·Pa·s)	~1.2 × 10 ⁻¹¹	7.5–9.2 × 10 ⁻¹²	↓ Better barrier
Thermal Stability (°C)	~180	200–220	↑ Higher stability
Biodegradation on (90 days)	~100 %	90–95 %	Slightly controlled degradation

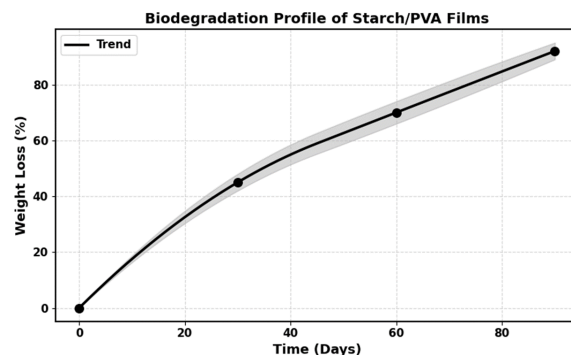


Figure 7: Biodegradation Behavior of Starch/PVA Films Over Time

4.8 Discussion

Cooked rice wastes from school canteens can be valorized as a sustainable source of starch for the growth of bio-based polymers through waste valorization and bio-based polymer engineering. This research proved the usability of the extracted starch for polymerization by showing an “amazing” percentage of extraction, i.e., around 94.6%. The large –OH stretching peak in the FTIR spectra indicated that there was significant intermolecular hydrogen bonding between rice starch and PVA. SEM analysis revealed a smooth shape, confirming that blending was efficient.

Films based on starch-PVA, exhibiting improved mechanical and barrier properties, were fabricated using the solution casting technique [34,35]. Although some of the disadvantages of starch-PVA include incompatibility, moisture sensitivity, and instability in humid environments, developments in mechanical properties have also been observed. The solvent casting technique employed for producing films based on starch, and improvements in functionality were made by incorporating additives. Although improvements in material properties have been observed, challenges still exist in terms of scalability, water resistance, and mechanical instability of the materials, especially when the concentration of the added materials is high. The research [36] focused on the effect of plasticizers in starch-based films using solution casting. It is aimed at improving the mechanical, thermal, and morphological characteristics. However, the process has the disadvantage of reduced scalability and durability. Its disadvantages include its sensitivity to water and inconsistent performance according to the plasticizer content and environmental factors. The research [37] uses solution casting in the manufacture of recyclable PVA-starch-based layers with active antioxidant food wrapping using beetroot waste extract. It measures the mechanical, thermal, antioxidant, and structural properties. Limitations exist at high extract

concentrations, including barrier properties and water vapor transmission.

From the mechanical properties in this research, it is evident that the film possessed greater strength and flexibility compared to native starch-based film. The film exhibited tensile strengths ranging from 6.2 to 7.8 MPa and elongation at break ranging from 12 to 18%. Intermolecular interactions and the plasticizing result of sorbitol and glycerol, which improved the flexibility of the polymer chains, contributed to this improvement. Water-related properties exhibited improved performance, with the swelling index, moisture absorption, and water solubility being decreased to 20-28%. This indicates improved resistance to water contact as the compact polymer matrix is formed. Water vapor penetrability standards ranged from 7.5×10^{-12} to 9.2×10^{-12} g/m²·Pa·s, indicating enhanced barrier characteristics and decreased moisture transfer. Glycerol is frequently used as a secondary plasticizer in the food sector because of its low toxicity. Although plasticizers increase the elasticity of films, too much of them can weaken the films, reducing durability and tensile strength, while giving hydrophilic qualities and poor water vapor barrier effectiveness.

5. Conclusion

By incorporating the use of PVA and placing the proper plasticizers, the current research was successful in showing how to valorize cooked rice waste found in school canteens into the biodegradable polymer films made of starch. Compared to conventional starch film, these films were characterized by improved tensile strength, flexibility, reduced solubility in water, and thermal stability, thus proving the effectiveness of blending and plasticizing polymers in film formation. FTIR and SEM studies were used to determine strong intermolecular bonds and homogeneous morphology, which enhanced the performance of the films. The increased fence possessions and condensed water solubility of the films made them suitable for food packaging. Also, biodegradability studies demonstrated a high environmental compatibility with as high as 90 -95 percent degradation in 90 days in soil conditions. Altogether, this research shows a cost-effective and environmental friendly way of transforming food waste into value-added materials, advancing the principles of the circular economy, and reducing plastic pollution. The produced starch/PVA films show great promise for use as biodegradable food packaging materials, providing an eco-friendly and sustainable substitute for traditional plastic-based packaging.

5.1 Limitations and future scope

The limitations of the study include the fact that it was conducted in the laboratory scale, the heterogeneity of the raw materials used, and the fact that there was no

validation of long-term storage. The recommendations for further studies include performance evaluation, scale-up, incorporation of antimicrobial agents, and shelf life evaluation.

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