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RESEARCH ARTICLE

Investigation of Tensile and Soil Degradation Properties of Pure and Hybrid Homemade Bioplastics

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ABSTRACT: This study investigates the tensile strength and soil biodegradability of bioplastics made from potato starch, agar, and gelatin-based formulations. The aim was to determine whether hybrid bioplastics could improve tensile strength while maintaining biodegradability. Bioplastics were prepared using household methods and tested for tensile strength, as well as mass loss over 28 days of soil burial. Results showed that the potato starch and gelatin hybrid had the highest tensile strength at 5151 Pa, attributed to enhanced hydrogen bonding between polymer chains. Agar-based bioplastics exhibited the lowest tensile strength at 1818 Pa due to weaker intermolecular interactions. In terms of biodegradability, gelatin fully degraded within 3 days, while the potato starch and gelatin hybrid retained 85.9% of its original mass after 28 days. These results confirm that the potato starch and gelatin hybrid possesses the strongest mechanical properties while maintaining a relatively slow degradation rate. Therefore, for high strength and extended durability, the potato starch and gelatin hybrid is the most suitable option. However, for the other combinations, there is a more pronounced trade-off between the two properties. This results in other pure or hybrid bioplastics to serve either short-term or long-term applications, depending on strength and degradation needs.

KEYWORDS: Chemistry, Materials Chemistry, Bioplastics, Tensile, Soil Degradation.

Introduction

Plastic pollution is currently an outstanding global problem, a field where major research is taking place to counter plastic pollution.[1,2] By 2015, global plastic production had reached approximately 6300 million tons, of which only 9% is recycled, and nearly 79% accumulates in landfills or the natural environment.[3] Conventional plastics play a major role in plastic pollution as they can persist in the natural environment for centuries, producing microplastics that can threaten ecosystems and human health. As a potential solution, bioplastics, which are polymers derived from renewable biomass such as starch, cellulose, and protein, have gained attention due to their eco-friendly capabilities, including having a low carbon footprint and being easily biodegradable.[4]

In recent years, there has been a growing interest in bioplastics. A review by Yadav *et al*. showcases an in-depth assessment of bioplastics, from feedstock cultivation to production as well as disposal.[5] This review highlighted both the environmental promise and trade-offs of various bioplastic systems.[5] Another authoritative review by Rosenboom *et al*. discusses how bioplastics can help shift plastic systems toward circularity and describes key challenges, such as recycling complexity and performance limitations.[6] On the other hand, bioplastics are widely used in a lot of different applications, including food and beverage packaging, biodegradable films and bags, but also medical or pharmaceutical uses such as drug delivery or scaffolds for tissue engineering.[7]

Bioplastics' advantages include reduced reliance on fossil feedstocks and often have lower greenhouse gas footprints.6 They also offer potential for biodegradation or compostability under specific situations.[8] However, bioplastics can still have limitations. Properties such as mechanical strength and thermal stability are often not as strong as conventional plastics.[9] Furthermore, recycling or trying to reuse bioplastics can be challenging because existing waste streams may hamper the ability to recycle bioplastics efficiently.[5]

This paper will specifically investigate three renewable biomasses, namely: potato starch, agar, and gelatin. Starch-based bioplastics, including those derived from potatoes, are widely used due to their natural abundance and biodegradability.[4] To enhance flexibility, plasticisers such as glycerol are commonly added; however, the addition of glycerol can reduce tensile strength and increase water sensitivity.[10] Glycerol has the same effect on all materials of bioplastics.

To provide a valid quantitative comparison between the different combinations of bioplastics, the mechanical performance of these materials is typically evaluated through tensile testing, which encompasses measuring the maximum stress a material can withstand before breaking. Additionally, soil degradability will also be measured, and is often assessed through soil burial, where mass loss over time serves as an indicator of environmental degradation.[11] The paper predicts that a hybrid of potato starch and gelatin-based bioplastics will produce a polymer that has strong properties in both tensile strength and degradability, representing an ideal combination of mechanical properties with environmental benefits. Starch materials tend to become brittle when used alone,[10] but have promising tensile and degradability properties. Gelatin, on the other hand, creates hydrogen bonds in biopolymer matrices, which result in increased elasticity and tensile strength.[12] A combination of these two components should produce a bioplastic that is both strong in tensile strength and soil degradability, providing a balance environmentally, but also mechanically.

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Although many studies have evaluated starch or gelatin-based bioplastics individually or even hybrid bioplastics, few works analyse how, under household-scale, low-cost preparation conditions, the mechanical performance and degradability properties can change. Previous work often depends on lab-grade reagents but also specialized equipment, which can limit the reproducibility and accessibility for smaller-scale or resource-limited environments.

This study addresses these gaps by evaluating multiple feedstocks (potato starch, agar, gelatin, and hybrids) under reproducible methods that can be undertaken with household materials and equipment. Furthermore, analysis will be conducted on tensile strength and soil degradability across those feedstocks, under realistic environmental conditions.

Methods

Materials:

All the materials were store-bought and/or household pantry items. The materials that were used in the making of the materials include: potato starch, agar powder, gelatin powder, white vinegar, and glycerol. When determining which specific brand of each material had to be used, it was based on materials that were already present in the household kitchen, except for the glycerol.

Table 1: Description of the brands that were used for each type of material and substance that was used in the making of each of the bioplastics.

Material	Brand
Potato Starch	POTATO STARCH GU FU 454G
Agar	Equagold Agar Agar
Gelatin	Mckenzies Gelatine Powder
Vinegar	DYC Vinegar White
Glycerol	Home Essentials Glycerol 100%

When producing pure samples of the bioplastics, different methods were taken depending on the type of bioplastic being made. Exact measurements for each bioplastic are given in Table 2:

Table 2: This is a list of the materials used when making each bioplastic. All materials were bought at the supermarket.

Potato Starch	Agar	Gelatin	PS + Agar	PS + Gelatin	Agar + Gelatin
280cm³ water 28.0g potato starch 18.7g glycerol 20cm³ white vinegar	280cm³ of 1% glycerol solution 5.6g agar powder	280cm³ of 1% glycerol solution 5.6g gelatin powder	280cm³ water 14.0g potato starch 2.8g agar powder	280cm³ water 14.0g potato starch 2.8g agar powder	280cm³ of 1% glycerol solution 2.8g gelatin powder 2.8g agar powder

The steps for making each of the pure bioplastics, not including proportions, were taken from an online YouTube video by Giestas.[13,14]

Potato Starch:

For potato starch, it was mixed with water and white vinegar before being heated over a water bath while being mixed. Then, once a clear paste was formed, it was poured into an oven tray to cool down for 7 days.

Agar and Gelatin:

The making of agar and gelatin required a solution of 1% glycerol (which was made by mixing 10cm^3 of glycerol with 1000cm^3 of water), to be heated up to a maximum of 50°C. For gelatin, the powder was added after the solution reached the temperature of 50°C, while the agar powder was added before the solution reached 50°C. For both solutions, the mixture was heated up for 5 minutes while constantly stirring. The mixture was poured into an oven tray to cool down for 3 days.

Mixed Materials:

Potato Starch:

To produce a combination of the materials containing potato starch (i.e, potato starch and agar, potato starch and gelatin), the following steps were taken. First, the steps for making the potato starch bioplastic were followed, except that after the white paste was formed, the agar/gelatin powder was added to the paste, and the temperature was maintained at 50°C. The paste was mixed for 5 minutes until it was poured into an oven tray mold to cool for 7 days.

Agar and Gelatin:

To produce the agar and gelatin combined bioplastic, the following steps were taken. A solution of 1% glycerol was heated up to 50°C, with the agar powder added to the solution at the start. After 5 minutes of mixing, the gelatin powder was added to the already heated solution and mixed for a further 5 minutes. Then the solution was poured into an oven mold to cool for 3 days.

Testing:

Tensile Strength Testing:

To test the tensile strength with available equipment, identical strips of bioplastics with dimensions of 0.203m x 0.001m x 0.0165m were cut out. Then a newton meter was held up by a portion of the strip of bioplastic, with weights added until the bioplastic broke. Each weight was held up for 10 seconds before more mass was added. Due to the unavailability of sizes of weights, the lowest mass that could be added was in increments of 50g.

Each piece of bioplastic was tested 3 times, and an average was taken with the following formula:

$$Average\ mass\ held = \frac{mass\ held\ in\ trial\ 1 + mass\ held\ in\ trial\ 2 + mass\ held\ in\ trial\ 3}{3}$$

Tensile strength of the plastic was calculated using the following formula:[16]

$$Tensile\ strength = \frac{(Average\ mass\ held \div 1000)\ \times\ 9.81}{Surface\ area}$$

The value of 9.81 stems from the assumption that the gravitational pull of Earth is around $9.81ms^{-2}$.[17]

Soil Degradation Testing:

Squares of the made bioplastics were buried under soil in outside conditions to mimic hypothetical degradation in the natural environment.

Each piece of plastic was buried in the soil of a dirt backyard with a depth of approximately 5cm. This allowed for easy retrieval of the plastic, as well as enough depth to completely cover the bioplastic. The extent of biodegradation in bioplastics was based on the mass of the plastic, expressed as a percentage of the initial mass. The formula used to find this percentage is:[18]

$$Percentage\ of\ mass\ remaining(\%) = \frac{Mass\ on\ day\ \#}{Intial\ mass} \times 100$$

Experimental Conditions:

Due to the nature of the biodegradation testing, where plastics are placed in the natural environment, factors such as weather parameters of rainfall and temperature can have an influence on biodegradation.[18] Therefore, to establish the notion of possible explanations for data in biodegradation, the average temperatures and rainfall data will be recorded for the duration of time when the bioplastics were buried in the ground. All the average temperatures and rainfall data were obtained through the World Weather Online website.[19]

Table 3: The weather conditions for the range of days that match the days' ranges of biodegradability. Temperature was measured by taking the average of one day, then averaging again with its respective range of days. Rainfall was calculated by adding total rainfall per day, then averaging again with its respective range of days.

Day Range	Average Temperature (°C)	Average rainfall (mm)
0	12.00	0.50
1-3	10.80	1.03
4-7	14.50	1.87
8-14	12.10	6.20
15-21	13.10	0.19
22-28	13.60	4.87

Limitations:

In this investigation, there still exist limitations due to the variability caused by access to equipment and the number of experiments. For example, especially for tensile strength, only three trials were conducted for each type of bioplastic; hence, only one value for tensile strength could be found. This limits the potential accuracy of the experiment, as more samples would allow deeper insight into whether varying samples did in fact have different properties. This could be considered when doing further research on bioplastics.

Furthermore, for tensile strength, the smallest weight that could be used had a value of 50g. This is a very big increment and can be both an underestimation and an overestimation of true values. Due to the inability to access tensile strength testing machines, home-made testing kits made from newton meters can be used instead.

Results

Tensile strength:

Preliminary Measurements:

The strips used for tensile strength had the following measurements and surface area:

Table 4: Exact dimensions for the size of bioplastics that were used for tensile strength testing.

Width (cm)	Base (cm)	Height (cm)	Surface area (cm²)
0.1	0.165	20.3	0.108

Table 5: The raw data was collected for the tensile strength of the plastics. All pieces of plastic were measured 3 times, and average values were calculated afterward. Potato starch + Gelatin shows the largest average mass held, at 567g, while agar shows the lowest mass held at 200g.

Mass held before breaking (g)				
Bioplastic Type	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
Potato Starch	450	400	450	433
Agar	200	200	200	200
Gelatin	350	350	400	367
Potato starch + Agar	300	300	300	300
Potato starch + Gelatin	550	600	550	567
Agar + Gelatin	250	250	250	250

Table 6: Processed data using the average values, calculating the average mass, total force held, tensile strength of the plastic, and the absolute uncertainty of tensile strength. Uncertainties are calculated using the respective uncertainties in the equipment. Then calculated with respect to the tensile strength formula. PS + Gelatin shows the highest tensile strength, while Agar shows the lowest tensile strength, reflecting the values found in Table 5.

Bioplastic Type	Average mass held (g)	Force (N)	Tensile Strength (Pa)	Absolute Uncertainty (Pa)
Potato Starch	433	4.251	3939	±822
Agar	200	1.962	1818	±404
Gelatin	367	3.597	3333	±704
PS + Agar	300	2.943	2727	±584
PS + Gelatin	567	5.559	5151	±1063
Agar + Gelatin	250	2.453	2273	±487

Graphical representations:

Below are the graphs for the measurements taken and calculated, using data from Tables 5 and 6.

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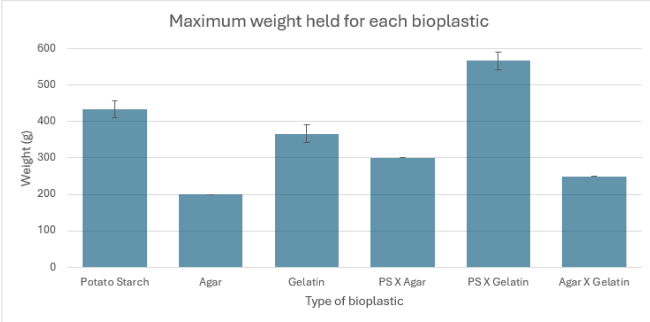

Figure 1: Raw data graph for maximum weight held using the average values in Table 3. PS, Gelatin, and PS X Gelatin all have visible uncertainty error bars. Graphs with no error bars are not visible as the uncertainty was minor.

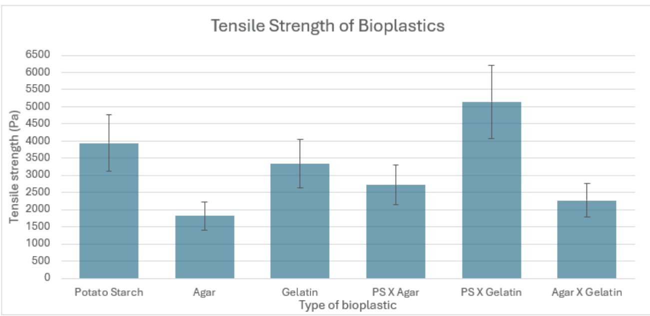

Figure 2: Processed data graph for the final tensile strengths of each bioplastic, along with standard deviations for each value. Standard deviations were found using the Excel function and then plotted on the graph.

From Table 6, the tensile strength of the bioplastic samples ranged from 1818 to 5151 Pa. The potato starch and gelatin bioplastic produced the highest tensile strength at 5151 Pa, meaning that the potato starch and gelatin blend could hold the most mass out of any other combination. On the other hand, the agar-based bioplastic showed the lowest tensile strength at 1818 Pa. Additionally, the tensile strength of pure gelatin and potato starch samples reached 3333 Pa and 3939 Pa.

Soil Degradation:

Table 7: Raw data for the weight of each sample of pure bioplastic. Each was measured using the electronic scale, and any impurities, such as dirt, were washed off until no visible dirt could be seen. All pure bioplastics except for Potato Starch have completely degraded within 28 days.

	Weight of bioplastic (g)					
Bioplastic Type	**Initial Mass**	**Mass after 3 days**	**Mass after 7 days**	**Mass after 14 days**	**Mass after 21 days**	**Mass after 28 days**
Potato Starch 1	6.91	8.01	6.16	5.05	4.65	4.21
Potato Starch 2	6.38	7.38	6.83	5.50	5.04	4.56
Potato Starch 3	6.63	7.77	6.70	5.86	5.35	4.89
Agar 1	2.51	2.98	2.62	0.00	0.00	0.00
Agar 2	2.17	2.56	2.16	0.00	0.00	0.00
Agar 3	2.44	2.87	2.50	0.00	0.00	0.00
Gelatin 1	0.77	0.00	0.00	0.00	0.00	0.00
Gelatin 2	0.82	0.00	0.00	0.00	0.00	0.00
Gelatin 3	0.82	0.00	0.00	0.00	0.00	0.00

Table 8: Raw data for the weight of each sample of hybrid bioplastic. Each was measured using the electronic scale, and any impurities, such as dirt, were washed off until no visible dirt could be seen. Only the Agar and Gelatin combination had completely degraded by 28 days, while the remaining hybrid bioplastics did not completely degrade within 28 days.

	Weight of bioplastic (g)					
Bioplastic Type	**Initial Mass**	**Mass after 3 days**	**Mass after 7 days**	**Mass after 14 days**	**Mass after 21 days**	**Mass after 28 days**
PS X Agar 1	6.02	7.34	6.98	6.21	5.44	5.13
PS X Agar 2	6.35	7.66	6.78	6.09	5.34	4.98
PS X Agar 3	6.11	7.50	6.40	5.79	5.24	4.82
PS X Gelatin 1	5.65	6.22	5.62	5.23	4.97	4.78
PS X Gelatin 2	5.34	6.08	5.41	5.09	4.77	4.61
PS X Gelatin 3	5.44	6.10	5.49	5.13	4.83	4.72
Agar X Gelatin 1	4.11	5.14	3.21	1.76	0.32	0.00
Agar X Gelatin 2	4.35	5.25	3.45	1.88	0.41	0.00
Agar X Gelatin 3	4.05	4.82	3.19	1.51	0.26	0.00

Table 9: Processed data for the average mass of each type of bioplastic over 28 days. Averages were taken from the 3 separate samples of each type of bioplastic. Agar, Gelatin, and Agar X Gelatin have completely degraded within 28 days, while the remaining samples have still not completely degraded.

	Average Weight of bioplastic (g)					
Bioplastic Type	**Initial Mass**	**Mass after 3 days**	**Mass after 7 days**	**Mass after 14 days**	**Mass after 21 days**	**Mass after 28 days**
Potato Starch	6.64	7.72	6.56	5.47	5.01	4.55
Agar	2.37	2.80	2.43	0.00	0.00	0.00
Gelatin	0.80	0.00	0.00	0.00	0.00	0.00
PS X Agar	6.16	7.50	6.72	6.03	5.34	4.98
PS X Gelatin	5.48	6.13	5.51	5.15	4.86	4.70
Agar X Gelatin	4.17	5.07	3.28	1.72	0.33	0.00

Table 10: Processed data for the percentage of mass with respect to the initial mass of each respective bioplastic on Day 0.

	Percentage of Mass Remaining (%)					
Bioplastic Type	**Initial**	**Day 3**	**Day 7**	**Day 14**	**Day 21**	**Day 28**
Potato Starch	100	116	98.8	82.4	75.7	68.6
Agar	100	118	102	0.00	0.00	0.00
Gelatin	100	0.00	0.00	0.00	0.00	0.00
PS X Agar	100	122	109	97.9	86.7	80.8
PS X Gelatin	100	112	101	94.0	88.7	85.9
Agar X Gelatin	100	122	78.7	41.2	7.91	0.00

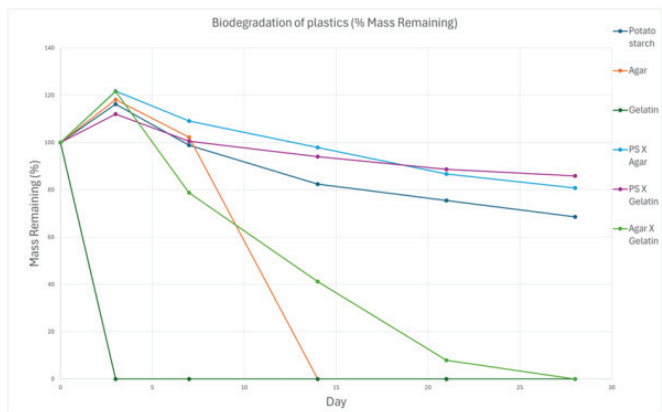

Figure 3: Plotted graph for the values obtained in Table 10, showing the change in mass of bioplastics from Day 0 to Day 28. Each color line has been color-coded to its respective biomaterial. Gelatin shows the fastest disappearance, while any bioplastic with potato starch shows relatively slow rates of degradation.

Over the 28 days that the bioplastics were buried, there were trends in the degradation behaviour of the bioplastics. From Graph 3, other than the gelatin bioplastic, all other bioplastics showed an initial increase in mass. This increase is likely due to the absorption of rainwater during the first few days, which is a common phenomenon in hydrophilic polymers.[1] On the other hand, gelatin did not gain mass during the first 3 days and was completely degraded. This fast degradation could result from enzymatic hydrolysis and microbial assimilation.[2]

However, the overall degradation rates varied between each bioplastic. The gelatin and agar bioplastics degraded in the shortest amount of days, completely degrading by days 3 and 14, respectively. On the other hand, both potato starch hybrid bioplastics followed a slower degradation trend. Specifically, the potato starch and gelatin hybrid retained 85.9% of its original mass, while the potato starch and agar blend retained 68.6% of its original mass. Through these results, it may be taken away that utilizing potato starch in a hybrid bioplastic with other biomasses can extend the life of the bioplastic.

■ Discussion

Tensile Strength:

The combination of bioplastic materials shows potential to enhance mechanical integrity through improved intermolecular interactions, especially when gelatin is blended with starch. In Figure 2, the uncertainty range for potato starch and potato starch with gelatin overlaps. Statistically, these two types of bioplastics could be considered similar. However, the potato starch and gelatin blend still outperformed all other plastics, even with uncertainties considered. The improved tensile properties in specific bioplastic blends result from better hydrogen bonding and enhanced molecular compatibility between biopolymer chains, which creates a stronger cohesive matrix.[18]

The tensile strength of agar-based films stays low because agar molecules do not form strong intermolecular bonds that would strengthen the polymer network.[2] Hence, the mechanical durability of agar as a single material remains limited because of its molecular structure weakness. However, the mechanical performance of the resulting material improves substantially when biopolymers such as starch or gelatin are blended.

Soil Biodegradability:

The relationship between biodegradability and water absorption is supported by previous studies linking moisture uptake to enhanced microbial colonization and enzymatic activity,[1] helping to explain certain degradation patterns, especially for bioplastics containing agar. Looking at Figure 3, both bioplastics containing agar increase in mass, but are followed by sharp decreases in mass in the following days after day 3. Furthermore, water absorption appears to facilitate degradation in hydrophilic matrices, but the overall rate still depends on the molecular structure and stability of the biopolymer blend.

For the soil degradation tests, water acts as both a swelling agent and a catalyst for degradation. These findings highlight a trade-off in properties, where highly biodegradable bioplastics, like gelatin, are more suitable for short-term disposable applications. Conversely, starch-based hybrids may be well-suited for long-term uses due to having a longer lifespan.

T-testing:

T-testing was only allowed to be done for biodegradable materials and not for tensile strengths. This is mainly because tensile strength values had only one average value per type of bioplastic. Therefore, due to limited replicates for tensile strengths, a t-test was not possible. However, t-testing was available to be done for biodegradability. Earlier in this paper, the hypothesis of "A combination of these two components (potato starch and gelatin) should produce a bioplastic that is both strong in tensile strength and soil degradability" was presented. T-tests were conducted using Microsoft Excel.[20]

The Null Hypothesis is as stated: There is no significant difference in biodegradability, based on mass remaining after 28 days, between the hybrid bioplastics and the pure PS or pure gelatin bioplastics.

The Alternative hypothesis is defined for:

Pure PS: There is no significant difference between the hybrid and pure bioplastic.

Pure gelatin: The hybrid bioplastic is less biodegradable than pure bioplastic.

Based on calculations, it was revealed that for pure PS, the p-value is 0.53, while for pure gelatin, the p-value is 0.0001. Assuming $p<0.05$ as statistically significant,[22] the null hypothesis failed to be rejected for pure PS, while for pure gelatin, the null hypothesis will be rejected, and the alternative hypothesis is accepted. Therefore, this supports the idea that hybrid bioplastics have a stronger resistance to biodegradation.

■ Conclusion

The initial hypothesis stated that a hybrid of potato starch and gelatin-based bioplastic would provide the best balance between tensile strength and degradability. From this investigation, it was seen that the potato starch and gelatin blend demonstrated the highest tensile strength at 5151 Pa, outperforming all other combinations. Furthermore, the potato starch and gelatin hybrid also retained the largest amount of mass after 28 days, which indicates that it has the longest lifespan among the plastics tested in this investigation. Therefore, the initial hypothesis is partially confirmed, based on the potato starch and gelatin hybrid bioplastic being the top performer in tensile strength and biodegradability. The hypothesis was confirmed with respect to the tensile strength, but not biodegradability. Slower degradation, in certain situations such as needing bioplastics to degrade faster to remove waste, does not necessarily make it the "ideal combination".

These findings are able to contribute to further articles that focus on sustainable alternatives to conventional plastics. Other tests involving bioplastics could include adjusting the ratios of starch to gelatin to optimise both strength and degradation. It would also be insightful to extend the burial period beyond 28 days, potentially providing deeper insights into long-term durability in the natural environment. Due to equipment limitations, properties such as water solubility or barrier resistance could also be tested for these hybrid bioplastics. Investigating other properties could help to refine bioplastics for specific commercial applications where environmental impact and material performance must be balanced. In this paper, it has been shown how combinations of bioplastics can enhance material performance, compared to single-material bioplastics.

Potentially, the results found could be useful for real-life applications immediately. It has been showcased how using

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home-grade equipment can form relatively successful alternatives to conventional plastic. More suitably, because of the low tensile strength of homemade bioplastics compared to conventional plastics, such as polypropylene plastics (PP) with a tensile strength of 15-27MPa,[23] these homemade bioplastics could be more suited for applications such as food wrapping or light-weight bags. This could be helpful for regions where plastic wrapping is not widely available and therefore can use feedstock-based bioplastics to help protect goods like food.

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