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Optimization of drying temperature for enhanced physical and mechanical properties of potato and rice starch-based bioplastic

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Abstract
The widespread use of conventional plastics has led to environmental worries since they don't break down naturally. To address this issue, biodegradable plastics made from natural materials like potato and rice starch have been created. This study investigates the impact of drying temperature on the physical and mechanical properties of bioplastic derived from potato and rice starch, combined with glycerol as a plasticizer. Potato and rice starch were extracted through a process of washing, blending, filtering, and drying at 105 ℃. Bioplastic samples were developed using an optimized blend of 23.57g potato starch, 18.00g rice starch, and 2ml glycerol, heated and cast into 2mm thick films. These films were dried at various temperatures (55, 60, 65, and 70 ℃) to assess changes in physical, water-related, optical, and mechanical properties. Results show that the thickness of bioplastics decreases with increasing drying temperature, with the thinnest films at 70 ℃. Water absorption and solubility were lowest at 65 ℃, indicating denser, less porous structures. Colour values (L*, a*, and b*) also peaked at 65 ℃, while opacity decreased with higher temperatures. Mechanical tests revealed that tensile and bursting strengths were highest at 65 ℃, suggesting enhanced density and cohesiveness at this temperature. The drying temperature significantly influences the structural integrity and performance of bioplastic, with 65 ℃ being optimal for achieving superior mechanical properties.

Keywords: Biodegradable plastics, potato starch, rice starch, drying temperature

Introduction

The widespread use of plastic materials has resulted in adverse effects on the environment, landscapes, and human health. Plastic garbage is damaging ecosystems, blocking waterways, and harming wildlife due to the exponential increase in plastic consumption over the past few decades. In 2015, a staggering 275 million metric tons of plastic waste were generated in 192 coastal countries, with an estimated 4.8 to 12.7 million metric tons of this plastic finding its way into the ocean (Zhu *et al*., 2023) [15]. Approximately 4% of the world's petroleum reserves are utilized in the production of plastics, a finite resource that is depleting rapidly. India generates a substantial amount of municipal solid waste, totalling 36.5 million tons per year, equating to approximately 36.5 kg per individual (MecyOrenia *et al*., 2018) [8]. Due to their potential to lessen their impact on the environment and improve biodegradability, bioplastics have drawn a lot of attention among these alternatives as a prospective solution.

Potato peels, which are frequently seen as agricultural trash, have the potential to be an important source of sustainable materials. The goal of bioplastic is to raise awareness of this underutilized resource and show how important it is for solving waste management problems. The use of potato peels prevents agricultural byproducts from ending up in landfills and encourages waste valorisation, which is consistent with the concepts of the circular economy (Sasria *et al*., 2021) [13]. Bioplastic, a biodegradable alternative to traditional plastic, has found diverse applications across various industries, retaining many of the specific properties of conventional plastic. The development of bioplastics has addressed this issue to a considerable extent. However, in doing so, certain essential properties such as tensile strength and ductility, which are critical for protective storage applications, have been compromised. Presently, ongoing research aims to enhance these essential properties in bioplastics, thereby optimizing their functionality and usability (Ni'mah *et al*., 2023) [9].

India is the second largest producer of rice in the world, after China, with an estimated 130 million metric tons of rice produced in 2023, accounting for about 20% of the world's total rice production. India is also a major producer of potatoes, ranking fourth in the world, with an estimated 59.74 million metric tons of potatoes produced in 2023, which accounts for about 8% of the world's total potato production (Madhu *et al*., 2023) [7]. Potato peels, containing an average of 15-20% starch content, hold a significant starch reserve that can be harnessed for bioplastic production, contributing to waste valorisation and reduced environmental impact. Industrial processes generate between 70 to 140 thousand tons of potato peels worldwide annually, highlighting the substantial availability of this resource (Alhambra *et al*., 2019) [1]. The development of bioplastics derived from a combination of potato peel and rice starch represents a significant step towards mitigating the adverse impacts of potato and rice biowaste accumulation in landfills. Through the utilization of potato peel and rice starch in bioplastic production, this initiative effectively converts these biowastes into valuable resources, transforming them into biodegradable and environmentally sustainable bioplastics rather than allowing them to contribute to methane emissions and soil contamination in landfills (Berenguer *et al*., 2023) [5].

Materials and Methods

The development of bioplastic was conducted at the Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra. Potato and rice used in the experiments were sourced from Godhra, Gujarat, India. Standard methods were reviewed and implemented, utilising standard chemicals and reagents from Patel Scientific, Godhra.

Extraction of starch from potato

The potatoes were washed and peeled. The peels will be processed into a paste using distilled water in a blender until a homogeneous consistency is achieved. The paste will be poured onto cheesecloth and placed over a container to filter out solid residue, including fibers and proteins while allowing the starch-rich liquid to pass through. Gentle pressure or gravity will be used to aid filtration. The starch-rich liquid will be left to settle, then the supernatant will be decanted, and the starch sediment will be collected. The collected starch will be dried at 105 ℃ to obtain dry powder potato starch, which will be stored for further use (Bhausaheb, 2022) [6].

Extraction of starch from rice

The rice obtained where powdered first. The rice powder was boiled in water until soft and thoroughly cooked, releasing starch into the water, and resulting in a milky white liquid. After boiling, the rice was separated from the starchy water using a fine mesh or cheesecloth. The starchy water containing the extracted rice starch passed through the filter, while the solid rice grains remained. The starchy water was allowed to settle to obtain starch, which was then dried at 105 ℃ to remove moisture. The rice starch powder was stored for further use (Shafqat *et al*., 2020) [14].

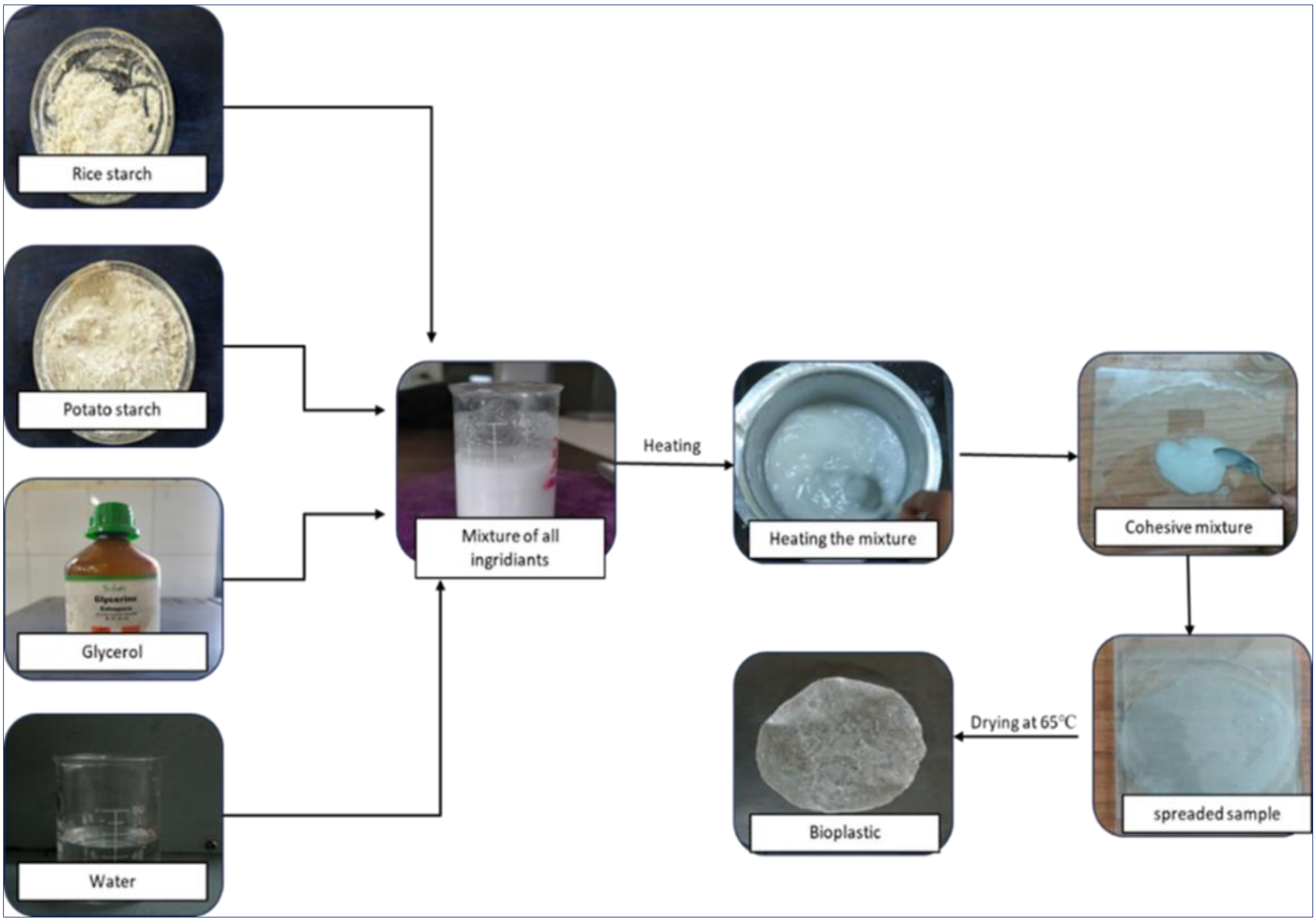

Fig 1: Flow chart for the preparation of bioplastic

Development of bioplastic

After obtaining potato starch and rice starch, 23.57g potato starch, 18.00g rice starch, 2ml glycerol, and 84.36 ml, which was the optimized combination obtained from experiments. This will be heated and stirred continuously till we obtain a cohesive mixture. It is then poured into a glass surface and spread using another glass to a thickness of 2mm. This is then dried in a hot air oven at a temperature of 55, 60, 65, and 75 ℃ to study the effect of different drying temperatures on the characteristics of bioplastic. After the plastics are formed, they are extracted carefully from the glass surface and subjected to the tests (Rajak *et al*., 2023) [12].

Measurement of Physical Parameters

Thickness

The thickness of the samples was measured using a digital Vernier Calliper For each sample thickness from 5 different positions were taken to obtain an accurate reading.

Measurements of water absorption

The evaluation of water absorption in bioplastics adheres to the ASTM D570-81 standard. Bioplastic samples of size 1.5×1.5 cm was used for the measurement of water absorption. The initial weight (W_1) is recorded. Subsequently, the bioplastics are immersed in 50 ml distilled water. After 24 h, the bioplastics are taken out, excess surface water is dried with cotton, and the immediate weight (W_2) is measured. The water absorption (A_w) is calculated as a percentage of the initial weight using the formula (Shafqat *et al*., 2021) [14].

$$A_W = \left(\frac{w_2 - w_1}{w_1}\right) \times 100 \quad (1)$$

Measurements of water solubility

The solubility of bioplastic samples, each with a surface area of 1.5 cm². Initially, the bioplastic specimens underwent a drying process in an oven set at 105 °C for 24 h to determine their dry weight (W_1). After this, the dried bioplastic samples were immersed in 50 ml of distilled water at room temperature for 24 h. Following the immersion period, the separation of the bioplastic residue was accomplished by filtering the water, and the residue was subjected to an additional 24 h of drying in an oven set at 105 °C. The final weight (W_2) of the bioplastic residue was then measured (MecyOrenia *et al*., 2018) [8].

$$\text{Solubility in Water \%} = \left(\frac{w_1 - w_2}{w_1}\right) \times 100 \quad (2)$$

Colour values

Colour measurements were conducted using a colourimeter (M/S 3nh, China, model-NH310) based on the CIE Lab scale. The instrument was calibrated beforehand using a white standard. The L* value indicates the range from black to white, the a* value indicates the range from green to red, and the b* value indicates the range from blue to yellow. The samples are placed over a white paper and then the colour readings are measured.

Opacity

For measuring opacity, the samples were cut into a size of 4 × 1cm size. The measurements were made by Spectrophotometer at 600 nm. The samples were placed inside the quartz cuvette and analysed. The readings were noted and replications were done to eliminate errors (Olagundoye & Morayo, 2022) [11].

$$\text{Opacity} = \frac{absorbance\ at\ 600(nm)}{thickness\ of\ film(mm)} \quad (3)$$

Measurement of Mechanical Properties

Tensile strength and elongation

To perform the tensile strength and extension test on bioplastics, samples measuring 10 x 2.5 cm, first ensure the sample is defect-free and its dimensions are precisely measured. Use a digital tensile tester for the test. Secure the sample evenly between the grips, then start the test, observing the sample's behaviour under stress until it breaks. Record the maximum load and the elongation at the breaking point, making detailed notes. If necessary, repeat the test for reliability. Analyse the data to determine the tensile strength and extension (Olagundoye & Morayo, 2022) [11].

$$\text{Tensile strength (MPa)} = \frac{(Maximum\ load\ in\ kg \times g)}{Area\ of\ the\ sample\ in\ mm} \quad (4)$$

Where, g = acceleration due to gravity

Bursting strength

To measure the bursting strength, 6×6 cm samples were prepared and inspected to ensure they were defect-free before being labelled. A bursting strength tester was employed for the measurements. Each sample was carefully positioned in the tester, and the machine was calibrated to a zero reading. The test proceeded with continuous monitoring of the sample until it ruptured. Upon rupture, the machine automatically shut off, and the readings were recorded.

Results and Discussions

Bioplastics were developed successfully in different drying temperatures of 55,60,65 and 70 ℃ and the samples are shown in Fig 2.

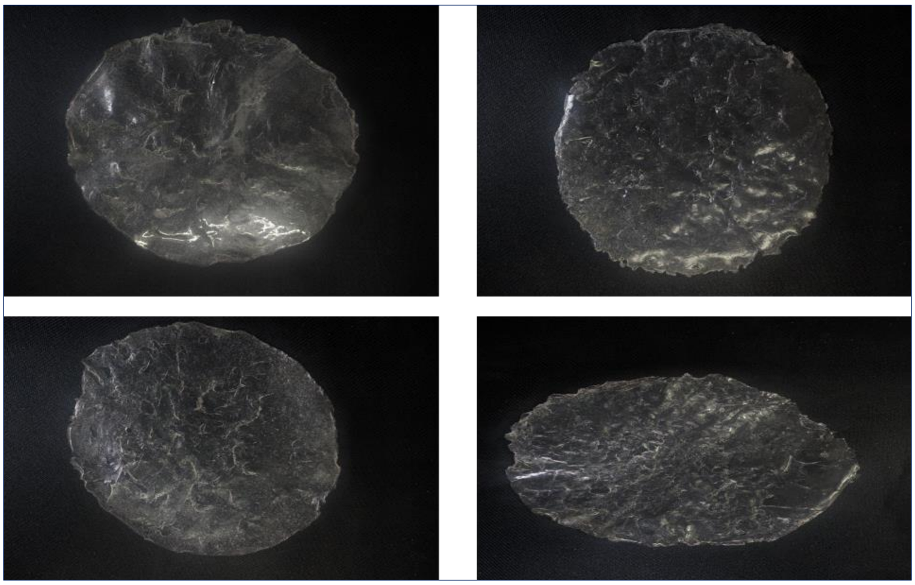

Fig 2: Bioplastic samples developed at (a) 55 °C, (b) 60 °C, (c) 65 °C and (d) 75 °C

Thickness

The Fig. 3(a)shows how the drying temperatures affect the thickness of bioplastic, which ranges from 0.39 to 0.71 mm. According to Table 1, bioplastic is thinnest at 70 °C and thickest at 55 °C, with thickness decreasing as temperature increases. This trend is likely due to the evaporation of water during the drying process. Higher temperatures accelerate water evaporation, leading to quicker moisture removal from the bioplastic mixture. Consequently, the material becomes more compact and denser, resulting in thinner sheets. In contrast, lower temperatures slow water evaporation, giving the material more time to spread and form thicker sheets. Al-Harrasi *et al*. (2022) [2] had similar findings regarding the effect of drying temperature on the thickness of bioplastic.

Table 1: Results of physical parameters, colour values and opacity

Drying Temperatur e	Thick ness (mm)	Water absorption (%)	Water solubility (%)	Colou r L*	Col our a*	Colou r b*	Opa city (A/ mm)
T_1 (55 °C)	0.69	95.74	24.17	70.33	1.60	3.76	0.6
T_2 (60 °C)	0.63	92.03	21.5	71.7.	1.61	3.84	0.55
T_3 (65 °C)	0.44	84.07	13.69	75.73	1.72	4.08	0.48
T_4 (70 °C)	0.41	88.11	16.31	73.39	1.65	3.94	0.42

Water absorption

Figure 3(b) illustrates the impact of drying temperature on the water absorption of bioplastic, with values ranging from 95.29% to 83.49% across different temperatures. The data indicate that water absorption is lowest at 65 °C and highest at 55 °C. As the drying temperature increases up to 65 °C, water absorption decreases, but it rises again at 70 °C. This trend could be attributed to the accelerated drying rate at higher temperatures like 65 °C, which promotes faster evaporation of surface moisture and potentially leads to the formation of a denser, less porous structure in the bioplastic, thereby reducing water absorption. The rise in water absorption may be due to the weakening of molecular bond due to the thermal decomposition and there by forming free hydrophilic starch molecule to absorb water. Al-Harrasi *et al*. (2022) [2] had similar findings regarding the effect of drying temperature on the water absorption of bioplastic.

Water solubility

Figure 3(d) illustrates the impact of drying temperature on the water solubility of bioplastic, with values ranging from 13.62% to 23.52% at various temperatures. The data indicates that water solubility is lowest at 65 °C and highest at 55 °C. As the temperature increases up to 65 °C, water solubility decreases, but it rises again at 70 °C. This pattern is likely due to higher temperatures enhancing bonding and cross-linking among starch molecules, resulting in a denser, more cohesive bioplastic structure that is less soluble in water. The rise in water solubility at 70 °C may be caused by the thermal decomposition of bioplastic leading to the formation of more water-soluble compounds which dissolves in water. Al-Harrasi *et al*. (2022) [2] and Nury *et al*. (2023) [10] had similar findings regarding the effect of drying temperature on the water solubility of bioplastic.

Colour values

Figure 3(e) illustrates the impact of drying temperature on the L* value of bioplastic, with values ranging from 70.15 to 76.03 across different temperatures. The L* value is highest at 65 °C and lowest at 55 °C. The L* value increases with temperature up to 65 °C, then decreases at 70 °C. This trend suggests that the L* value rises until 65 °C and then drops at 70 °C, likely due to thermal degradation of the bioplastic components.

Figure 3(c) depicts the effect of drying temperature on the b* value of bioplastic, which ranges from 3.61 to 4.15 across various temperatures. The b* value is highest at 65 °C and lowest at 55 °C. The b* value increases with temperature up to 65 °C and then decreases at 70 °C. The rise in b* values, indicating a shift towards blue hues, at 65 °C compared to 55 °C, could be due to chemical reactions or structural changes within the bioplastic matrix at higher temperatures.

From Table 1 we can observe that the colour a* value ranges from 1.60 to 1.72. The minimum a* value was observed at 55 °C and the maximum was obtained at 65 °C The drying temperature didn't show any significant effect on the colour a* value of the developed bioplastic.

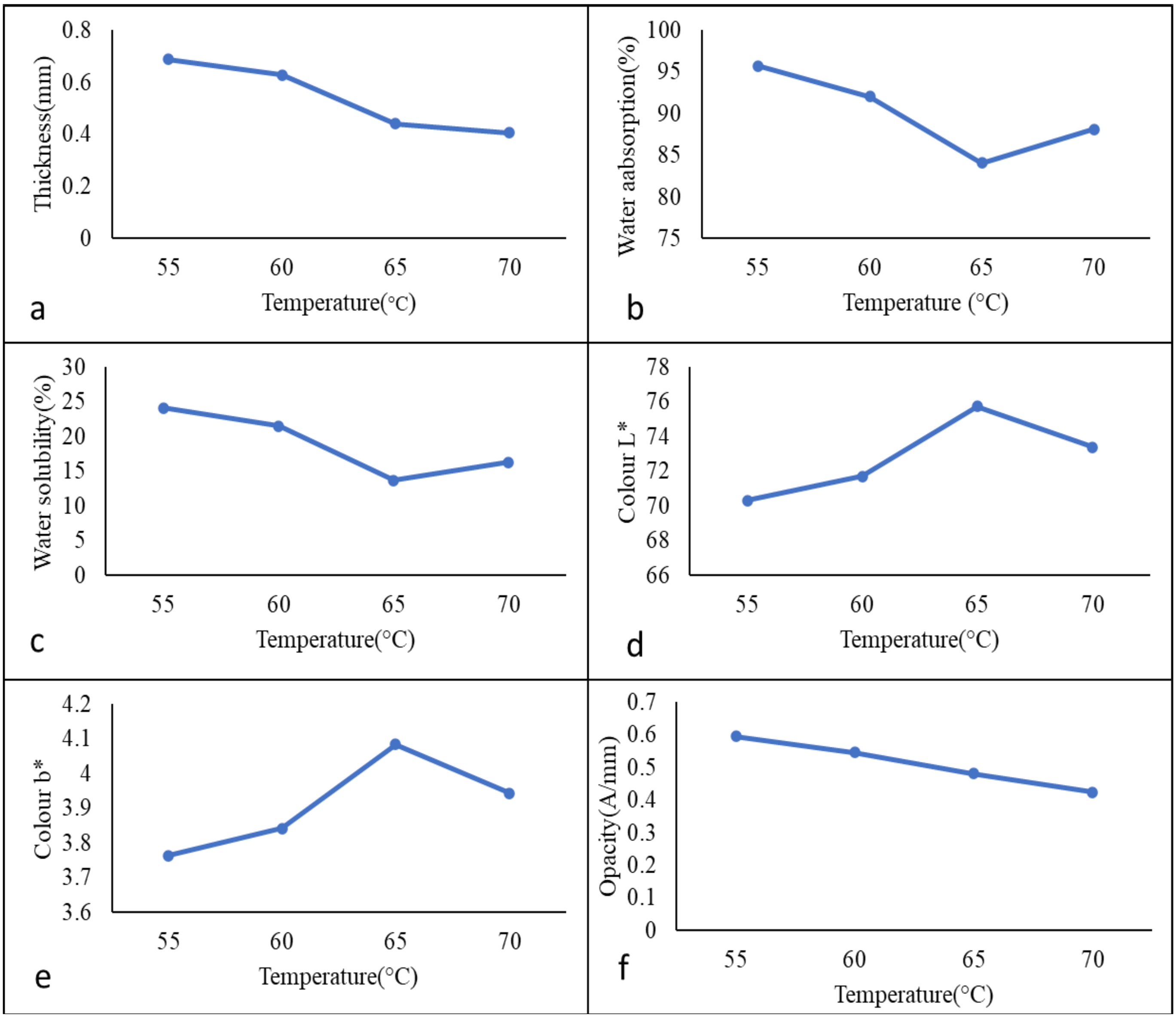

Fig 3: Variation of different properties of bioplastic with drying temperature (a) Thickness, (b) Water absorption, (c) Water solubility, (d) Colour L*, (e) Colour b* and (e)Opacity

Opacity

Fig. 3(f) shows how drying temperature influences the opacity of bioplastic, which ranges from 0.593 to 0.421 A/mm across different temperatures. The data shows that opacity is highest at 55 ℃ and decreases at 70 ℃. This trend indicates that higher temperatures lead to lower opacity. This reduction in opacity at elevated temperatures could be due to more extensive drying, resulting in a tighter molecular structure that scatters less light. Furthermore, higher temperatures might cause the degradation or alteration of certain components within the bioplastic matrix, thereby affecting its optical properties and decreasing its opacity.

Measurement of Mechanical Properties

Table 2: Results of measurement of mechanical properties of the bioplastic

Drying Temperature	Tensile strength (MPa)	Elongation (mm)	Bursting strength (bar)
T_1 (55 °C)	0.03	17.37	2.14
T_2 (60 °C)	0.04	16.89	2.48
T_3 (65 °C)	0.06	15.84	3.10
T_4 (70 °C)	0.05	15.21	2.67

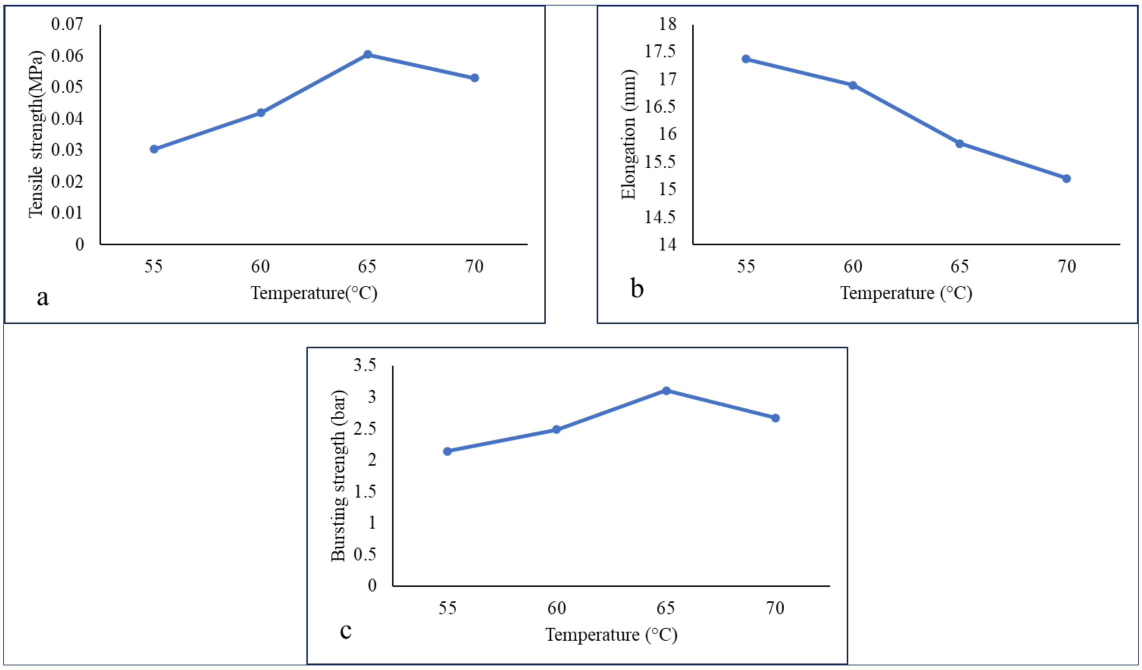

Fig 4: Variation of mechanical properties with different drying temperature (a) Tensile strength, (b) Elongation and (c) Bursting strength

Tensile Strength and Elongation

From Fig 4(a) we can observe how drying temperature affects the tensile strength of bioplastic, which varies from 0.0284 to 0.0624 MPa across different temperatures. The Table 2 data indicates that the tensile strength is highest at 65 °C and lower at 55 °C. As the temperature increases, the tensile strength rises up to 65 °C, then decreases at 70 °C. This pattern might be due to higher temperatures making the bioplastic denser, thus enhancing its tensile strength. The reduction in tensile strength at 70 °C may be caused by the higher temperature which may have caused thermal decomposition which in turn reduced the tensile strength. Alonso-González *et al.* (2021) [3] and Astuti *et al.* (2021) [4] had similar findings on the effect of drying temperature on the tensile strength of bioplastic.

The Fig 4(b) shows how drying temperature affects the tensile strength of bioplastic, which varies from 0.0284 to 0.0624 MPa across different temperatures. From Table 2 we can see that the tensile strength is highest at 65 °C and lower at 55 °C. As the temperature increases, the tensile strength rises up to 65 °C, then decreases at 70 °C. This pattern might be due to higher temperatures making the bioplastic denser, thus enhancing its tensile strength. Nury *et al.* (2023) [10] had similar finding with the effect of drying temperature on the elongation properties of bioplastic.

Bursting strength

The Fig 4(c) represents the impact of drying temperature on the bursting strength of bioplastic, which ranges from 2.02 to 3.22 bar across different temperatures. The data shows that the bursting strength peaks at 65 ℃ and is lowest at 55 ℃. As the temperature rises, the bursting strength increases, reaching a maximum at 65 ℃ before decreasing at 70 ℃. This pattern suggests that higher temperatures cause more moisture to evaporate from the bioplastic matrix, resulting in a denser and more tightly packed structure, thereby enhancing its bursting strength and other mechanical properties. The reduction in the bursting strength at 70 °C may be caused by the thermal decomposition or excess removal of moisture which made the bioplastic structure to weaken.

Conclusion

This study demonstrates that drying temperature significantly affects the physical and mechanical properties of bioplastics derived from potato and rice starch. The optimal drying temperature was found to be 65 ℃, which resulted in the highest tensile strength, bursting strength, and favourable water absorption and solubility characteristics. As the temperature increased, the bioplastic exhibited improved density and mechanical integrity up to this point, likely due to enhanced moisture evaporation and tighter molecular packing. However, temperatures above 65 ℃ led to a decline in these properties, indicating potential thermal degradation or over-drying effects. These findings highlight the critical role of drying temperature in optimizing the performance characteristics of bioplastics, providing valuable insights for their industrial production and application.

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