Nutrition & Food Science
International Journal
ISSN 2474-767X

Juniper PUBLISHERS key to the Researchers

Research Article
Volume 14 Issue 1 - January 2025
DOI: 10.19080/NFSIJ.2025.14.555877

Nutri Food Sci Int J

Synthesis and Characterization of Biofilms using Native and Acid Modified Jackfruit Seed Starch

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Submission: January 15, 2025; **Published:** January 29, 2025

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Abstract

In this current study, native and modified jackfruit seed starch (hydrolyzed with three different concentrations of malic acid and HCl separately), and glycerol were used to produce biofilms. The biofilms were characterized by measurement of moisture, film thickness, solubility, color values, and opacity. The film properties were statistically investigated using Principal Component Analysis (PCA). The findings showed solubility of the biofilms was increased and showed a reduction in moisture content and thickness due to the modification of the starch. The results showed that opacity of the modified films was significantly different those of native films and increased with an increase in the concentration of malic acid in cultivar Hadiyava. In contrast, the ΔE of the HCl acid films were lower than the native film while slight increment was recorded after starch modified with malic acid. Variations among the films was based on native and modified jackfruit seed starch, and from multivariate analysis with respect to the variables, 87.8% were supported by principal component analysis PC1 and PC2. This study demonstrates the application of native and chemically modified jackfruit seed starches can be successfully utilized for the development of biofilms. Those suggested that the biofilm of jackfruit seed starch would be a better alternative material to be used as packaging materials along with significant reduction of the environmental effect.

Keywords: Jackfruit; Seed; Starch; Modification; Starch film

Introduction

The intensifying environmental issues and legislative measures to minimize the use of synthetic plastics, has move the interest towards the research for the development of biofilms packaging materials [1]. As the biofilms made from natural materials and renewable resources do not contribute major environmental pollutant. Starch as a polymer has achieved special interest by researchers due to its availability, low cost, biodegradability, and renewability, additionally they have good film-forming property. Ultimately, starch has become the primary choice for the development of biofilms in the food [2-6]. Due to the differences in starches properties their granule shape and size, amylose/amylopectin ratio, crystallinity, viscosity etc. from different plants, the properties of the films also showed a difference among them [7-8]. Starch composed of two fractions i.e., amylopectin (up to 80%, major portion) and a smaller amount of amylose content. These fractions of starches affect to its film casting/coating and its properties. The ratio of both the fractions of starches may vary according to botanical sources and so it brings obvious significance towards the exploration of novel and alternative sources [9-12]. Researchers have traditionally used corn, potato, cassava, and wheat starch to formulate biofilms. However, recent research has shifted towards exploring nonconventional sources such as lotus rhizome and seeds, yam, water chestnut, litchi, faba bean, and mango kernel for the development and characterization of these films. Jackfruit seed starch is one of them and very few information is available on the structure, properties, and practical applicability of jackfruit seed starch (Table 1). The jackfruit seed starch could be a worthwhile option to produce biofilm due to its vast abundance and consider as byproduct, starch yield of extraction (up to 80% dry basis) and has high amylose proportion (≈30%), which is mostly responsible for the film casting capability of starches, than other sources of starches viz. cereals, roots and tubers. The jackfruit seed starch exhibits physicochemical, functional and digestibility characteristics somewhat similar to those of conventional sources such as corn, wheat, rice and potato. As jackfruit seed starch has ample amount of indigestible or resistant starch fractions, which gives several health benefits and physiological improvements, even sometimes restricting or preventing diseases, with imperative applications in processed foods, makes them more nutritious and commercially valuable [13-15].

Table 1: Sequence and type of modification of jackfruit seed starch.

Type of modification	Concentration	Sample name
Chemical Modification	0.1M HCl (40% starch solution)	HCl 1
	0.2M HCl (40% starch solution)	HCl 2
	0.3M HCl (40% starch solution)	HCl 3
	0.5M Malic acid (40% starch solution)	Malic 1
	1.0M Malic acid (40% starch solution)	Malic 2
	1.5M Malic acid (40% starch solution)	Malic 3

Despite its benefits, starch has some techno-functional issues that limits the use of starch in biofilms formulations, like lower resistance to temperature and tension, and high hydrophilicity. To conquer these restrictions modifications of starches can be done using physical, chemical, enzymatic treatments or a combination of them to change their properties and enable greater functionality. Chemical modification of starches can be done by several ways acid hydrolysis, is one of them which can be applied by varying acids and their concentrations. It was previously reported that the acid hydrolysis modifies physicochemical properties of starches, without dissipating its granular structure. There are very few studies in literature available on the impact of acid hydrolysis on the jackfruit seed starches competency to form biofilms. Kushwaha et al. [16] concluded that modifying starches with inorganic and organic chemicals alters their pasting, physicochemical properties, and thermal properties.

The objective of this study was to develop biofilms using jackfruit cultivar seed starch (*Artocarpus heterophyllus L.*), both in its native form and chemically modified through acid hydrolysis. The goal was to investigate the impact of chemical modification (acid hydrolysis) on the properties of the biofilms.

Materials and Methods

Jackfruits (*Artocarpus heterophyllus Lam.*) were collected from an orchard in Khusroobagh (under the Department of Horticulture and Food Processing, Uttar Pradesh Government) during May to July. Each fruit was identically selected considering the quality parameters in terms of shape, size, and color. Two cultivars were selected namely, Hadiyava, and Safeda, for the present study. The ripe fruits were cut, opened and seeds were collected. All the chemicals used were of analytical grade (Merck, Himedia, Fischer Scientific Co.).

Isolation of Starch

The isolation of jackfruit seed starch from seed flour was done by using distilled water method explained by Noor et al. [17] with minor modifications. A 50 g portion of jackfruit seed flour slurry was prepared by addition of 1000 mL distilled water and soaked at room temperature for 6-8 h with constant stirring. This slurry was filtered through 150 mesh sieve and flour cake was washed with distilled water for three times and filtrates were combined and left for overnight to precipitated at refrigerated temperature. The clear supernatant was discarded, and precipitate was washed with distilled water to get the starch and this procedure was done thrice. The precipitated starch was collected and dried at 45 °C in cabinet dryer till moisture content below 13%. The starch flakes were ground with a grinder, filtered, and stored for further analysis.

Chemical modification of native starch by acid hydrolysis (using HCl and Malic acid)

Jackfruit seed starch was dispersed in 0.1, 0.2, 0.3 M hydrochloric acid for inorganic acid modification while, three different concentrations of malic acid in 0.5 M, 1.0 M, and 1.5 M acid solution and kept in rotating water bath for 2½ h at 45 °C. After the hydrolysis time was complete the solution was neutralized using alkali and washed with distilled water for the removal of chemical traces. Starch was centrifuged to remove excess of water and dried in a hot air oven at 45 °C for 48 h [18].

Starch film preparation

Starch films were prepared from native and modified (HCl and Malic acid) jackfruit seed starch from cultivar Hadiyava and Safeda. Films prepared by the casting method with 4% film-forming solution of native/modified jackfruit seed starch in 30% glycerol (a plasticizer). The mixture was heated in magnetic hot plate to boiling and stirred constantly for 10 min with magnetic stirrer. The mixture was cooled till bubbles was completely dissolves and poured (25 mL) homogenously onto petri dishes. The petri dishes were dried in a cabinet drier, at 45 °C, for 6 h. Then the dry films were peeled off from the petri dishes and stored in airtight polyethylene bags [19].

Testing of starch-based films

Moisture content, Thickness and Solubility

Sample (5 g) was taken in a tared dish and kept in a hot air oven maintained at 105 ±3 °C for 90 min. Samples were removed, cooled in desiccator and weighed. Moisture was determined as weight loss and expressed as percent moisture [20].

$$\%\text{Moisture} = \frac{\text{Loss in weight}}{\text{weight of sample}} \times 10 \qquad (1)$$

The thickness of the film was measured using a vernier caliper

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from the average of ten random measurements taken form the films. Film solubility of the starch-based films was denoted in percentage of undissolved weight of the film in the distilled water. The film was pre dried (105 ± 2 °C for 24 h) and weighed before soaking in to distilled water (15 mL) at 25 ± 2 °C for 24 h. Then the undissolved portions of the film were removed, dried at same conditions, weighed and calculated as follows [7].

$$\text{Solubility}(\%)=\frac{w_i - w_f}{w_i}\times 100 \quad (2)$$

Where, w_i and w_f are initial and dried weight of insoluble samples, respectively.

Color properties

Color of films was determined using a colorimeter (X-rite) using the CIELAB color parameters: L, from 0-100 (black to white); a*, from negative to positive green to red; and b*, from negative to positive blue to yellow. Color of films was expressed as the total color difference (ΔE) from a standard white color (L* = 96.74, a* = 0.09, b* = 2.20) and calculated according to the following equation [21].

$$\Delta E=\sqrt{(L-L^*)^2+(a-a^*)^2+(b-b^*)^2} \quad (3)$$

Film opacity

Opacity film was determined using method given by Apriliyani et al. [22]. Film samples cut into a rectangular shape (1.5 x 3.0 cm) and placed on the internal side of the spectrophotometer (Genesis 10S Vis, Thermo scientific). The sample was measured by the opacity with an absorbance of 600 nm using a UV-Visible spectrophotometer:

$$\text{Opacity}=\frac{\text{Absorbance 600}}{\text{Film thickness}}\times 10 \quad (4)$$

Statistical Analysis

The ANOVA was performed using SPSS statistical software version 20.0. The mean was separated by applying the Duncan Multiple Range test at 95% confidence level (p<0.05). Two way ANOVA was used on the data of native and modified jackfruit seed starch biofilms. To express the significance of the variables in every component the multivariate technique Principal Component Analysis (PCA) was applied, and the cluster analysis was also used to grouping the films which is more close to each other on the obtained data basis using JMP® 16 software.

Results and Discussion

Moisture

Moisture of native starch film was 24.77% (Hadiyava) and 22.44% (Safeda) while for acid modified starch films the values were ranged from 17.53-24.85% (Table 2). Higher moisture content was observed for malic acid treated and native starch film as compared to HCl treated starch films. The reduction in moisture content of the films could be dependent on the amylose content and ultimately thickness of films. A two way ANOVA analysis showed that that there was a significant difference ($p < 0.001$) between the native and modified starches and their interaction terms (cultivar* modification) at 95% of confidence limit (Table S1). The results are in agreement with those reported by Wu et al. & Kumar et al. [5-6] in their study of films from cross-linked potato starch and citric acid moth bean starch, respectively.

Table 2: Properties of biodegradable films from native and acid modified jackfruit seed starch.

Cultivar and modification		Moisture (%)	Thickness (mm)	Solubility (%)	Opacity	L*	a*	b*	ΔE
Hadiyava	Native	24.77±0.10^e	0.38±0.02^c	17.88±0.45^c	3.04±0.04^c	92.24±0.19^b	-0.66±0.10^c	4.54±0.10^b	5.13±0.21^b
	HCl 1	19.34±0.11^a	0.13±0.02^a	28.33±1.12^f	1.00±0.03^a	93.53±0.42^c	-0.60±0.06^d	4.47±0.10^a	4.00±0.29^a
	HCl 2	21.49±0.17^b	0.18±0.02^b	25.57±1.19^e	1.39±0.03^b	93.84±0.04^c	-0.41±0.06^e	4.34±0.02^a	3.64±0.04^a
	HCl 3	22.70±0.16^c	0.26±0.03^d	23.26±1.12^d	1.98±0.03^d	93.92±0.06^c	-0.58±0.05^d	4.22±0.03^a	3.54±0.06^a
	Malic1	23.77±0.28^c	0.35±0.02^e	19.77±0.89^a	2.96±0.02^g	92.62±0.33^b	-0.80±0.03^b	4.86±0.03^c	4.99±0.26^b
	Malic2	23.84±0.35^d	0.33±0.03^c	19.75±0.71^b	2.86±0.01^e	92.42±0.33^b	-0.83±0.02^b	5.27±0.16^d	5.38±0.35^b
	Malic3	24.85±0.16^e	0.36±0.02^d	18.29±1.09^a	3.09±0.04^f	91.61±0.29^a	-1.28±0.05^a	8.50±0.43^e	8.24±0.42^c
Safeda	Native	22.44±0.05^e	0.21±0.03^c	25.00±0.89^c	2.19±0.01^c	93.74±0.08^b	-0.52±0.05^c	4.65±0.12^b	3.93±0.03^b
	HCl 1	17.53±0.03^a	0.15±0.02^a	27.74±0.93^f	1.17±0.02^a	94.56±0.37^c	-0.45±0.03^d	4.34±0.02^a	3.11±0.27^a
	HCl 2	18.78±0.11^b	0.27±0.02^b	25.77±1.24^e	2.70±0.10^b	94.67±0.29^c	-0.44±0.03^e	4.22±0.03^a	2.94±0.19^a
	HCl 3	20.39±0.21^c	0.41±0.01^d	22.52±0.94^d	3.46±0.02^d	94.88±0.88^c	-0.38±0.02^d	4.56±0.03^a	3.09±0.45^a
	Malic1	19.77±0.27^c	0.43±0.02^e	15.11±1.45^a	3.53±0.02^g	93.58±0.27^b	-0.54±0.03^b	4.87±0.10^c	4.19±0.18^b
	Malic2	20.69± 0.27^d	0.26±0.01c	19.60±0.95^b	2.87±0.03^e	93.45±0.34^b	-0.56±0.03^b	4.88±0.17^d	4.30±0.32^b
	Malic3	22.71± 0.44^e	0.30± 0.01^d	16.35± 1.02^a	2.95±0.03^f	92.70±0.22^a	-0.69±0.02^a	5.28±0.08^e	5.14±0.09^c

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Thickness

The film thickness of native jackfruit seed starch was 0.21 mm for cultivar Safeda and 0.38 mm for cultivar Hadiyava (Table 2). Thickness of chemically modified starch films using HCl and malic acid in different concentrations was in the range from 0.13-0.26 mm (cultivar Hadiyava) and from 0.15-0.41 mm (cultivar Safeda). The thickness of the biofilms, from native starches is useful for evaluation of the equability and to ascertain the repeatability of their measurements and to validate the comparisons among the various films produced from modified starches. Besides, after evaluation of film thickness, it is possible to get a brief idea for permeability of gases and water vapor as well as mechanical strength of the film. Because, the thickness of the film is highly influenced by the type and amounts of starches, plasticizers and sometimes techniques used in the preparation of biofilms [23]. The thickness of the native jackfruit seed starch was higher than the modified starch films in cultivar Hadiyava, this fact could be related to higher amylose content of the native starches which contribute high viscosity. A two way ANOVA analysis showed that that there was a significant difference ($p < 0.001$) between the native and modified starches and their interaction terms (cultivar* modification) at 95% of confidence limit (Table S2). Differences appeared in terms of the amylose/amylopectin ratio and viscosity of starches obtained from five different cultivars. According to Della Valle et al. & Della Valle and Buleon [24-25], film produced with higher amylose content (nonhydrolyzed) showed large number of tangles that promotes an increase in the viscosity. Less amylose content causes reduction of thickness and heterogeneity of films due to the reduction in the formation of starch gel during drying. While the amylopectin favors to get thinner, denser, and less heterogeneous films [7]. Similar results were reported on films using native and modified starches from water chestnut starch [2], pinhao starch [22]. Amylose forms films with good spread ability and delivers suppleness to the films and lowered amylose content in the starches may act as a reason for hardness of films [2].

Solubility

Solubility in water is related to the amylose content of the starch. The results showed that the film solubility of native Hadiyava and Safeda starch was 17.88% and 25.00%, respectively, while after chemical modification the solubility of films were in the ranged between 15.11-28.33% (Table 2). A two way ANOVA analysis showed that that there was a significant difference ($p < 0.001$) between the native and modified starches and their interaction terms (cultivar* modification) at 95% of confidence limit (Table S3). According to Mehyar and Han [25], biofilms prepared from starches having high amylose content, the intermolecular force between the molecules of polysaccharides increased, due to the greater interaction between amylose molecules. Native starches films showed lower water solubility comparing with modified starches films, as native starches had higher amylose content. The malic acid modified starches from both the cultivars had lower water solubility as compared to hydrochloric modified starches due to its higher amylose content. Similar results were reported in films using native and modified starches from water chestnut starch [1], pinhao starch [23], and sorghum [27] starch. Similar results were reported by [7] for the edible films developed from wheat, corn, and potato starches. While Pérez-Gallardo et al. & Biduski et al. [28-29] had reported insignificant difference among solubility of acid thinned and oxidized sorghum and acetylated-cross linked modified waxy corn starches, respectively. According to the Bourtoom & Chinnan [30] higher solubility used to indicate the lower water resistance. Considering the solubility results possible applications can be suggested, films produced from native and modified jackfruit seed starches with low solubility can be utilized in packing of candies, cake, and breads, while those have high water solubility, can be used in coating of fruits and vegetables, therefore it can be removed easily by washing.

Opacity

The opacity of the seed starch based films prepared from both selected jackfruit cultivars Hadiava and Safeda was 3.04 and 2.19, respectively, and there was a clear significant difference ($p < 0.05$) among them. While the films prepared after the modification the opacity ranged from 1.00-3.53. Results showed that cultivar Safeda had low opacity while cultivar Hadiyava has the higher opacity and lower transparency (Table 2). Malic acid treated starch showed high opacity (lower transparency) as compared to hydrochloric acid treated starch. The opacity of the films depends on the starch origin is their amylose/amylopectin ratios. The greater the thickness, the more opaque the films appear. This might explain the transparency and opalescence of starch films, and this is related to the amylose content of the starch as the higher the amylose content higher the thickness. Results showed that the films prepared from the jackfruit seed starches were shinny and glossy at the support side (surface in contact with the petri dish) and dull from the air side (surface exposed to air during drying), and similar results were also observed by Basiak et al. [7] in wheat, corn and potato starches. A two way ANOVA analysis showed that that there was a significant difference ($p < 0.001$) between the native and modified starches and their interaction terms (cultivar* modification) at 95% of confidence limit (Table S4). Previous study reported on wheat, corn and potato starch based film showed higher opacity in corn and wheat starch based film due to their higher amylose content and the thickness of the [7]. Similar results have been reported by Jiménez et al., Sun et al., Gutiérrez et al. & Campos et al. [31-34] in corn, pea, waxy and normal corn, and jackfruit seed starches, respectively. The results reported by researchers also explains that percent transparency of all chemically modified starches increased significantly as compared to native starches (which resulted in the most opaque film) obtained from various botanical sources like corn, and sorghum [27-29].

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Color Properties

The appearance of packaging materials is very important for the consumer acceptance [3]. The results of the color measurements performed for the starch based films were expressed in accordance with CIELAB system and the rectangular coordinates (L*, a*, and b*) and the total color difference ΔE was calculated. The L* value of native starch from cultivar Safeda (93.74) was higher as compared to than those of obtained in cultivar Hadiyava (92.25) and this pattern was similar after the modifications too. The L* value ranged from 91.61-94.88 after chemical modification with HCl and malic acid in starch based biofilms from cultivar Hadiyava and Safeda (Table 2). L* value of starch films dependent on both sources and properties of starch (amylose:amylopectin, size, and shape of granules) and thickness. Films those contain high amyloses are very thick and consequently more opaque. The current findings showed, the lightness of the films was closer to the white standard. Both a* and b* parameters of native and modified starch films were also different significantly ($p < 0.05$). The negative a* value surfaces of starch based films had showed greenness and positive b* value denotes the yellowness of the films. The malic acid treated jackfruit seed starch based films had higher a * and b* values in cultivar Hadiyava. The ΔE of films were in the ranged between 3.11-8.24. the results showed that the ΔE was lower in HCl modified starches as compared to native and malic acid modified starches. Therefore, it can be concluded that the films prepared from hydrochloric acid modified starch was closer to the standard color values. A two way ANOVA analysis showed that that there was a significant difference among on L*, a*, b* and ΔE ($p < 0.001$) between the native and modified starches and their interaction terms (cultivar*modification) at 95% of confidence limit (Table S5-S8). Similar results were reported for jackfruit seed starch film: L*=92.00, a*=-0.80, b*= 2.50, and ΔE = 2.50 [34]. and for tapioca starch films: L* = 85.42, a* = −1.08 and b* = 5.02 [35].

Principle component Analysis (PCA)

The variations among the films formed from native and modified jackfruit seed starch, with respect to the variables was analyzed, 87.8% were described by two principal components (Figure 1 & Table 3). For the first component (PC1), the variables present the most significance to describe the variations among the films were moisture content L, a*, b*, and ΔE. For second component (PC2) the variables were thickness, solubility, and opacity. The Fig. 2 showed that all the variables had significance to express the differences among the biofilms prepared from native and modified jackfruit seed starches as they showed high autovectors for all the principal components. The similarities among the biofilms, they were separated into 5 groups using cluster analysis. In the first group the films of acid hydrolyzed starches using HCl i.e., HCl 1, HCl 2 and HCL 1 from cultivar Hadiyava and Safeda, respectively were separated from the others since they presented greater solubility, lower values for the moisture content and thickness [36].

Table 3: Autovectors of the two principal components (PC1, PC2) for the variables analyzed in the biodegradable films based on native and modified jackfruit seed starches.

Variables	Autovectors	
	Factor 1	Factor 2
Moisture	**0.679925**	0.325083
Thickness	0.171311	**0.946983**
Solubility	-0.416301	**-0.79093**
Opacity	0.157767	**0.966592**
L*	**-0.89554**	-0.208296
a*	**-0.95295**	-0.161415
b*	**0.891574**	0.202019
ΔE	**0.972983**	0.230664

Conclusion

The biofilms produced homogeneous and stable from native and modified jackfruit seed starches. Chemical modification by acid hydrolysis (using HCl and malic acid) is considered as a substitute to modify biofilm properties of native jackfruit seed starch, due to the changes in amylose content and apparent viscosity of starches. Among the treatments, the malic acid modification showed extensive variation in thickness of the film compared to other modifications, leading to greater changes in solubility, and opacity when compared to native starch biofilms. Therefore, acid hydrolysis can be a substitute to produce biofilms for edible packaging. However, further studies on the application of biofilms on food products (like fruits, vegetables, ready-to-eat foods, desserts, and meat products) to verify the performance in the form of pH indicators, along with optimizing the results obtained till date. Consequently, to develop a film having unique attributes, biofilms, active and intelligent packaging need to combine.

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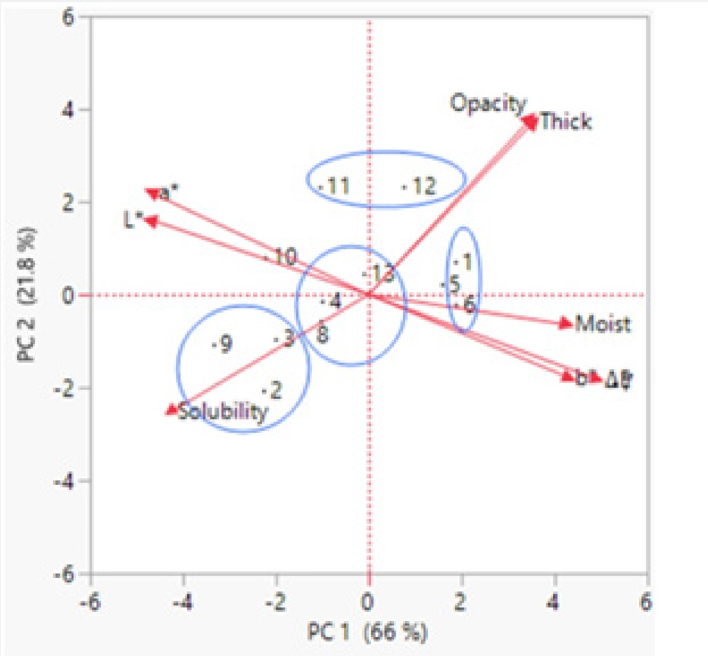

Figure 1: Autovectors assembled into groups according to the variables analyzed in the biofilms based on native and modified jackfruit seed starches from different cultivars.

HD= Hadiyava, SF= Safeda, 1 = HD native; 2 = HD HCl 1; 3 = HD HCl 2; 4 = HD HCl 3; 5 = HD malic1; 6= HD malic2; 7 = HD malic3; 8 = SF native; 9 = SF HCl 1; 10 = SF HCl 2; 11 = SF HCl 3; 12 = SF malic1; 13=SF malic2; 14=SF malic3. Thick = thickness, Moist = Moisture, L = lightness, ΔE = total color difference, solubility, opacity.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors have declared no conflict of interest.

Acknowledgement

The authors are highly thankful to centre of Food Technology, University of Allahabad, for providing facilities to carry out this investigation.

Supplementary materials

Table S1: A two way ANOVA of moisture content of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares		df	Mean Square	F	Sig.
Corrected Model	206.167[a]		13	15.859	174.741	.000
Intercept	19681.149		1	19681.149	2.17E5	.000
Cultivars	72.97		1	72.97	804.011	.000
Modification	128.333		6	21.389	235.672	.000
Cultivars * Modi-fication	4.864		6	0.811	8.932	.000
R^2		0.988				
Adj. R^2		0.982				

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Table S2: A two way ANOVA of thickness content of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.353[a]	13	0.27	83.299	.000
Intercept	3.474	1	3.474	1.07E4	.000
Cultivars	.001	1	.001	2.365	.135
Modification	.243	6	.041	124.192	.000
Cultivars * Modification	.109	6	.018	55.895	.000
R^2	0.975				
Adj. R^2	0.963				

Table S3: A two way ANOVA of solubility of native and chemically modified jackfruit seed starch ased biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	708.277[a]	13	54.483	45.102	.000
Intercept	19922.602	1	19922.602	1.65E4	.000
Cultivars	.122	1	.122	.101	.753
Modification	592.641	6	98.773	81.767	.000
Cultivars * Modification	115.515	6	19.252	15.938	.000
R^2	0.954				
Adj. R^2	0.933				

Table S4: A two way ANOVA of opacity of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	26.756[a]	13	2.058	1.50E3	.000
Intercept	265.358	1	265.358	1.93E5	.000
Cultivars	1.401	1	1.401	1.02E3	.000
Modification	19.269	6	3.211	2.34E3	.000
Cultivars * Modification	6.086	6	1.014	738.356	.000
R^2	0.999				
Adj. R^2	0.998				

Table S5: A two way ANOVA of 'L*' of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	37.194[a]	13	2.861	22.945	.000
Intercept	366477.321	1	366477.321	2.94E6	.000
Cultivars	11.766	1	11.766	94.362	.000
Modification	25.027	6	4.171	33.452	.000
Cultivars * Modification	.401	6	.067	.537	.776
R^2	914				
Adj. R^2	874				

Table S6: A two way ANOVA of 'a*' of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.106[a]	13	.162	80.148	.000
Intercept	16.331	1	16.331	8.08E3	.000
Cultivars	.533	1	.533	263.521	.000
Modification	1.247	6	.208	102.819	.000
Cultivars * Modification	.326	6	.054	26.914	.000
R^2	0.974				
Adj. R^2	0.962				

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Table S7: A two way ANOVA of 'b*' of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	45.760[a]	13	3.52	172.771	.000
Intercept	1020.51	1	1020.51	5.01E4	.000
Cultivars	2.463	1	2.463	120.871	.000
Modification	29.763	6	4.961	243.476	.000
Cultivars * Modification	13.534	6	2.256	110.716	.000
R^2	0.988				
Adj. R^2	0.982				

Table S8: A two way ANOVA of '∆E*' of native and chemically modified jackfruit seed starch based biodegradable film.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	73.204[a]	13	5.631	73.047	.000
Intercept	813.46	1	813.46	1.06E+04	.000
Cultivars	14.469	1	14.469	187.687	.000
Modification	51.695	6	8.616	111.764	.000
Cultivars * Modification	7.041	6	1.174	15.223	.000
R^2	0.971				
Adj. R^2	0.958				

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DOI: 10.19080/NFSIJ.2025.14.555877

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