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RESEARCH PAPER

Development Edible Films from Jackfruit Seed Starch and to Study its Physico-mechanical Properties

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ABSTRACT

This study aimed characterizing five formulations (5, 10, 15, 20 and 25 % w/v) of jackfruit seed starch, glycerol, sorbitol and acetic acid-based edible films evaluating their thickness, solubility, water vapour permeability, transparency, mechanical properties such as tensile strength and elongation at break. Among the formulations evaluated, the formulation with higher starch content did promote an effective barrier to water vapour. The thickness of jackfruit seed starch films increases from 0.217 ± ± 0.014 mm to 0.658 ± 0.059 mm; the film solubility of jackfruit seed starch films were in the range of 49.36 ± 03.60 to 65.55 ± 02.29 %; the water vapour permeability of films decrease from 0.290 ± 0.006 to 0.182 ± 0.018 g/m^2-hr; the tensile strength of films decreases from 40.56443 ± 10.496 N to 13.3239 ± 2.3159 N; the elongation at break of films decreases from 105.21 ± 28.48 % to 57.28 ± 14.62 %. The transparency of films decreases from 7.96 ± 0.46 to 1.37 ± 0.19 with increase in starch content from 5 to 25% (w/v) respectively.

Keywords: Edible films, Jackfruit seed starch, Glycerol, Sorbitol, Properties of film

The quantity of packaging materials has been increasing by 8 % annually (Muizniece *et al.* 2011). Less than 5% of the plastics are being recycled, leading to a high accumulation of plastics in the environment (Espitia *et al.* 2014). Increasing consumer concerns on food safety has led to the development of biodegradable, edible, and renewable films and coatings suitable for food and non-food packaging applications (Alves *et al.* 2010; Espitia *et al.* 2014). The synthetic polymers due to its low cost being used highly in the packaging industry ignoring the biodegradable materials (Hambleton *et al.* 2011). Today the traditional agricultural commodities being a source of film forming material, wide commercialization of biopolymer films has gained more significance (Arvanitoyannis, 2010). Studies of alternative systems for food protection that utilise biopolymers have increased significantly because these substances are entirely biodegradable and often edible and protect against environmental effects. The package also play an active role in the food (nutrition and carrier substances of interest) (Mayachiew and Devahastin, 2010).

Petroleum-based synthetic polymers (plastics) which are non-biodegradable polymers have been

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used widely in food packaging due to their low cost, durability and water resistance properties. However, concerns over the disposal of these non-biodegradable plastic-based packaging materials, growing environmental problems and safety issues have led to an increase interest in the development of biodegradable and eco-friendly materials for use in food packaging (Spotti *et al.* 2016; Sukhija *et al.* 2016). In the development of edible and biodegradable materials, starches are among the most important biopolymers due to their great processability and abundance (McHugh, 2003).

In recent times, there has been a mounting interest is focused to replace petroleum based products i.e. plastics with biodegradable materials due to their economical nature and good physico-mechanical properties. Biopolymers such as polysaccharides, proteins and lipids are considered as the possible substitute materials for replacement of petrochemical based products. The use of biopolymers based material in the packaging of foods and non-food products has been progressing at hasten rate (Sirvio *et al.* 2014). These materials can be used for packaging and enhancing the shelf life of foods and vegetables. Biopolymers, mostly polysaccharides based films are frequently used for the preparation of edible films with good mechanical and water barrier properties. The defensive covering or barrier provided during processing, storage and handling not only inhibits harmful deterioration of food, but may also maintain its quality (Huq *et al.* 2012).

Several researchers have demonstrated that edible films can be prepared from different structural materials such as lipids (Hambleton *et al.* 2011), polysaccharides (Jridi *et al.* 2014) and proteins (Ramos *et al.* 2013) or by combining two or several of these compounds. Protein based films have received considerable attention because they have advantages over others, in particular, due to their mechanical properties that are generally better since proteins have a distinctive structure, which confers a wider range of functional properties (Alves *et al.* 2010).

Edible films based on starch have been mainly developed because they exists the physical properties similar to those of synthetic polymers. However these films are brittle and weak, leading to inadequate mechanical properties. They are transparent, odourless, tasteless, semi-permeable to CO_2 and resistant to O_2 diffusion, while they can be edible, biocompatible, non-toxic, non-polluting and low costing (Vasconez *et al.* 2009).

Plasticizers are an important class of low molecular weight non-volatile compounds that are widely used in polymer industries as additives (Sejidov *et al.* 2005). The primary role of such substances is to improve the flexibility and processability of polymers by lowering the second order transition temperature, the glass transition temperature (T_g). Plasticizers are generally small molecules such as polyols like sorbitol and glycerol that intersperse and intercalate among and between polymer chains, disrupting hydrogen bonding and spreading the chains apart, which not only increases flexibility, but also water vapour and gas permeability (Vieira *et al.* 2011). These substances reduce the tension of deformation, hardness, density, viscosity and electrostatic charge of a polymer, at the same time as increasing the polymer chain flexibility, resistance to fracture and dielectric constant (Rosen, 1993). Other properties of the films are also affected, such as degree of crystallinity, optical clarity, electric conductivity, fire behaviour and resistance to biological degradation, amongst other physical properties (Białecka and Florjan, 2007). The type of plasticizer and its concentration are critical factors affecting the properties of films (Jost *et al.* 2014). Thus, in order to improve film properties i.e. adequate mechanical strength and good barrier properties, the suitable concentration and type of plasticizer must be added to overcome brittleness caused by the high intermolecular forces.

The film thickness is strongly effect on the transparency of film. Transparency indicates whether the film is clear or not i.e. transparent. Film solubility is an important aspect with respect to biodegradability. Mechanical properties of films are helpful for deciding food products as carry bag use purpose (Ross, 1987).

Jackfruit (*Artocarpus heterophyllus L.*) is a shrub belonging to the family *Moraceae* and widely distributed in tropical countries such as India, Brazil, Thailand, Indonesia, Philippines and Malaysia (Chowdhury *et al.* 1997). In India it is generally found in west and south region of the country. Fruit is rich source of carbohydrate, fibre and total minerals.

Jackfruit seeds contain considerably high amount of starch (20 %) that qualify as a sustainable source of starch for food and pharmaceutical industries. Jackfruit seed starch possesses certain similar and some unique characteristics compared to other starches. The amylose content (24-32%) was comparable to that of potato starch, while the gelatinization temperature was considerably higher compared to other starches. Jackfruit starch granules were reported to tolerate thermal/mechanical shear (Bobbio *et al.* 1978) and it was suggested that this seed starch could possibly be used in a system requiring starch with a high thermal and/or mechanical shear stability (Mukprasirt & Sajjaanantakul, 2004). Jackfruit starch was found to be acid-resistance in solution/paste form and has recently been investigated as thickener and stabilizer in chilli sauce (Rengsutthi & Charoenrein, 2010).

Starch is a natural polymer that can readily be cast into films. It consists of (1-4) linked α-D-glucopyranosyl units, two kinds of chain are present in natural starch: amylopectin and amylose. The linear polymer, amylose, makes up about 20 wt % of the granule, and the branched polymer, amylopectin, the remainder. Amylose is crystalline and can have an average molecular weight as high as 500,000 while amylopectin is highly branched and have very high molecular-weight. Despite their ease of preparation, starch films have poor physical properties. These can be improved by blending with either synthetic polymers to produce biodegradable materials or other natural polymers in edible packaging (Arvanitoyannis *et al.* 1998a; Arvanitoyannis, 1998b).

The objective of this study was development of the edible film from the jackfruit seed starch and to study its physico-mechanical properties i.e. film thickness, film solubility, transparency, tensile strength, elongation at break, and water vapour permeability plasticized with glycerol and sorbitol.

MATERIALS AND METHODS

Materials

Jackfruit seeds for experimentation was procured from the farmer field at Kudal in the jurisdiction of Dr. B.S.K.K.V Dapoli. Glycerol, sorbitol and acetic acid were purchased from Molychem, Ratnagiri, India.

Extraction of Jackfruit seed starch by wet grinding

The seeds of jackfruit were washed with tap water and surface water was removed. The seeds were soaked in Sodium Hydroxide (5g/100 ml) and separately soaked in citric acid (5g/100 ml) for 2 minutes and then washed with water. The seeds were removed from the solution, the brown spermoderm covering cotyledon was removed by peeling it. The cotyledon portion of the seeds after washing in tap water were sliced around 2 mm thickness and mixed with water with 1:2 proportion. The mixture was wet grounded in food processor (mixer cum grinder) (Make: m/s Jaipan industries limited; Model: LX-025). The mixture was screened through a muslin cloth and allowed to settle and decanted. After removing the water the decanted starch was washed 2-3 times with distilled water. The washed starch was taken into pettry dish and dried at 45^0C in a tray dryer up to 7.5 h. The moisture content of the starch was 7.94 % (d.b.). The starch samples so dried were packed in high density polyethylene (thickness 1 mm) and placed in an airtight boxes. The starch was used for preparation of edible films.

Preparation of Jackfruit seed starch films

The flow chart for preparation of edible film was represented in Fig. 1. Edible films were prepared as per procedure reported by Talja *et al*. (2007) using suspensions of binary polyol mixtures i.e. glycerol and sorbitol (food grade), Jackfruit seed starch, aqueous acetic acid 0.1N (food grade) and distilled water. Initially binary polyol mixtures (glycerol 5 %

(w/v) + sorbitol 5 % (w/v) of water) dissolved into distilled water (100 ml) and to this starch was added at (5%, 10%, 15%, 20% and 25% (w/v) of water) to obtain suspension.

Binary polyol (Glycerol 5% (w/v)) + Sorbitol 5% (w/v) + Acetic acid (0.1 N) 10 ml

↓

Jackfruit seed starch (5, 10, 15, 20 and 25 % w/v)

↓

Stirring (10 minutes)

↓

Suspension

↓

Heating with stirring in water bath (90° C for 20 minutes)

↓

Cooling (50 **°C**)

↓

Degassing (vacuum desiccator)

↓

Casting of film (Hand pouring with beaker (5 mm) thickness on Teflon sheet)

↓

Drying (50° C for 24 hours)

Peeling of film

↓

Storage (25 °C & 53 ± 1 % R.H. saturated $MgCl_2$ salt solution) in desiccator

Fig. 1: Flow Chart of Preparation of Edible film

The solution at various concentrations of starch: water (5%, 10%, 15%, 20% and 25% w/v) were heated in a water bath at 90 ± 2 °C for 20 minutes. The mixture was stirred continuously by hand, till the sample gelatinize, the process was continued till the milky gel was formed. The mixture was kept up to 5 minutes for proper gelatinization at 90 ± 1 °C. The sample was allowed to cool up to 50 °C. Air bubbles formed during heating were removed by placing in a vacuum desiccator (degassing) in which the film forming solution was kept until there was no bubble formation. Film forming solution was casted by hand pouring on Teflon sheet (45 cm × 30 cm × 0.03 cm) with the 5 mm thickness. The Teflon sheet was placed on the acrylic plate (5 mm thick). The formed films were placed in tray dryer at 50° C for 24 hours for drying. The final moisture content of the film was 21.55 % (d.b.). Dry films were peeled off and stored at 53 ± 1% RH and 25 ± 1°C in desiccators containing saturated Magnesium Chloride ($MgCl_2$) for at least 7 days prior to any testing. Table 1 shows different compositions for jackfruit seed starch edible film. The each experiment was repeated for 3 times.

Physico-mechanical properties of developed film

All the film samples of various treatments were equilibrated at 53 % RH using saturated solution of $MgCl_2$ and the testing of the film was performed as per following procedure.

1. Film thickness

Film thickness of jackfruit seed starch of various concentrations (5% to 25% w/v) was measured as per the procedure discussed (Sarmah *et al*. 2015) with a Digital micrometer (Make: Mitutoyo Corporation

Table 1: Jackfruit seed starch edible film

Treatments	Ingredients				
	Jackfruit seed starch (%)	**Distilled water (ml)**	**Glycerol (%)**	**Sorbitol (%)**	**Acetic acid 0.1N (%)**
T_1	5	100	5	5	10
T_2	10	100	5	5	10
T_3	15	100	5	5	10
T_4	20	100	5	5	10
T_5	25	100	5	5	10

Fig. 2: Jackfruit seed starch (5%) film

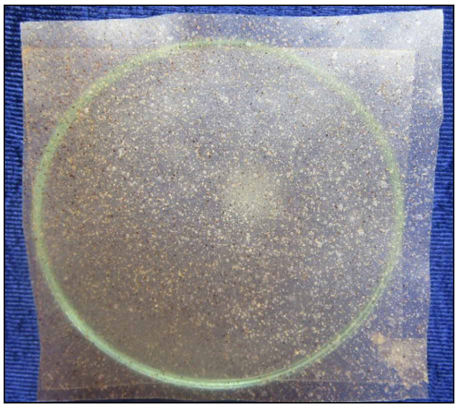

Fig. 3: Jackfruit seed starch (10%) film

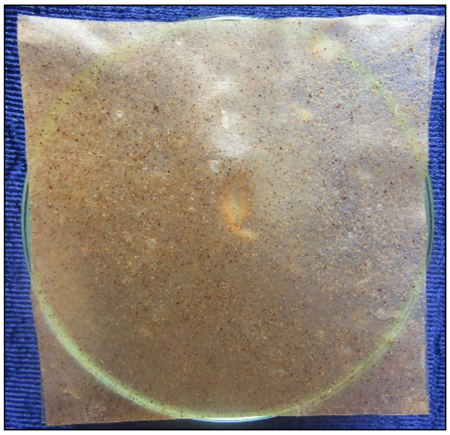

Fig. 4: Jackfruit seed starch (15%) film

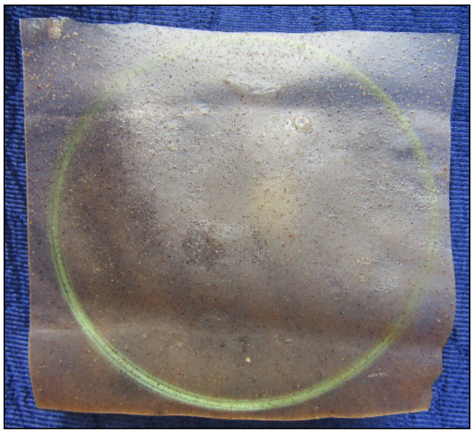

Fig. 5: Jackfruit seed starch (20%) film

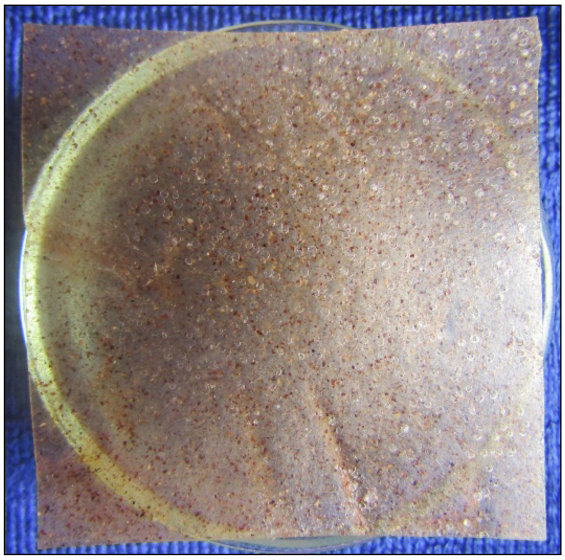

Fig. 6: Jackfruit seed starch (25%) film

Model: 293-561-30) with Least count: 0.001 mm. Thickness of each film was measured just after peeling from the Teflon plate after the equilibration in room conditions. Measurements were done in five places (one in the centre of the film and four around its perimeter). The average values have been reported.

2. Tensile strength and percentage elongation

Tensile strength and percentage elongation of developed jackfruit seed starch film of various concentrations (5% to 25% w/v) samples of various treatments were measured by using as per IS 2508 Standard using Universal testing machine. A film sample specimen of dimension 100 mm × 30 mm was taken for determination of tensile strength and percentage elongation. Self-tightening roller rings were used to perform tensile tests. Initial grip separation and crosshead speed were set at 300 mm and 300 mm/min. A stress as a function of distance was applied until the rupture occurred. The results of tensile strength and elongation at break (EAB) tests were expressed in N and percentage (%).The equipment gives the tensile strength (N) and percentage elongation (%) directly. The tests were repeated three times, the average values were reported (Sarmah *et al*. 2015).

3. Film solubility

Film solubility (FS) of various concentrations of jackfruit seeds starch films (5 % to 25 % w/v) was measured by gravimetric method as per procedure discussed by Colla *et al*. 2006. Film specimen of 25 mm × 25 mm dimension was cut, and its fresh weight was recorded. The sample was then immersed in 20 ml of distilled water in 50 ml screw-cap tube. The tube was then capped and placed in the room for 24 hours at average temperature of 23 ± 1 ºC. The solution and film piece was then poured over Whatman No. 1 filter paper and dried at 70 ºC in a hot air oven till constant weights was obtained which was observed through two constant readings. The experiment was repeated three times and the mean value was calculated. Total soluble matter was calculated from the initial gross mass and final dry mass using following equation:

$$FS(\%) = \frac{F_B - F_A}{F_B} \times 100 \qquad \ldots(1)$$

Where,

F_B = Film mass before test, and

F_A = Film mass after test.

4. Film transparency

Transparency of the films prepared with various concentration of jackfruit seed starch film (5% to 25%) was determined according to the method described by Han and Flores (1997). The film specimen was cut into a rectangular shape (4 cm × 1 cm) and placed inside a spectrophotometer cell, and then the percent light transmittance of the film was analysed at 600 nm by using a UV spectrophotometer (Make: m/s Systronics India Limited; Model No: 6072). The transparency was calculated by the equation (2). The experiment was repeated for three times and average value was reported.

$$\text{Transparency} = \frac{\log(T\%)}{b} \qquad \ldots(2)$$

Where,

($T\%$) is the light transmittance at 600 nm and b is the thickness of film (mm).

5. Water vapour permeability

Water vapour permeability of films prepared with various concentration of jackfruit seed starch film (5% to 25%) was measured using water vapour permeability tester (Make: m/s Lyssy Switzerland; Model: L80-5000) using ASTM E 96 standard. Film samples of 10 × 10 cm were cut and placed between two rubber rings on the top of glass cell containing silica gel, sodium chloride or distilled water to fix the internal relative humidity (RH) of the permeation cells at 100%.

6. Optimum product quality based on desirable properties

The film thickness of jackfruit seed starch film should be low, high in tensile strength and elongation at break, the film solubility should be low as if film goes contact to water it should not be soluble. The film transparency should be high so that product inside the film can be seen from outside. Water vapour permeability of jackfruit seed starch film should be low for minimizing moisture migration.

7. Cost Economics of developed film of desirable properties

The cost economics of the developed jackfruit seed starch (15% w/v) film was worked out by considering existing rates of various inputs such as cost of raw materials, labour and electricity charges.

3. RESULTS AND DISCUSSION

Film thickness

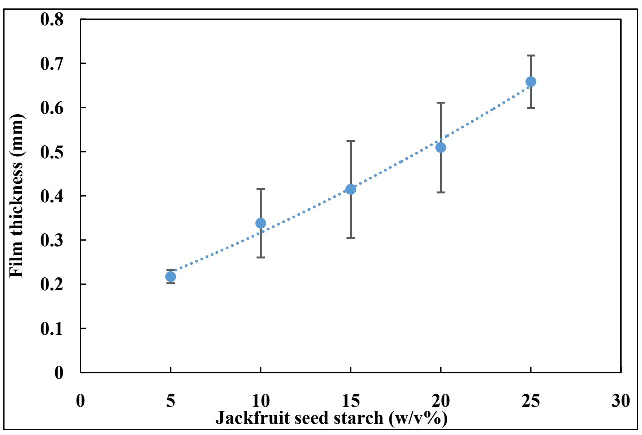

Fig. 7: Effect of incorporation of Jackfruit seed starch on the thickness of film

Fig. 7 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the developed film thickness. The film thickness of jackfruit seed starch films at 5%, 10%, 15%, 20% and 25% were 0.217 ± 0.01, 0.338 ± 0.07, 0.414 ± 0.10, 0.509 ± 0.10 and 0.658 ± 0.05 mm respectively. The film thickness of jackfruit seed starch film was in the range of 0.217 ± 0.01 to 0.658 ± 0.05 mm. The lowest thickness values were observed for films with lower starch concentration (5 % w/v) and more thickness value observed at higher starch concentration (25 % w/v). Table 1 (a) shows the ANOVA for the film thickness of the jackfruit seed starch based edible film. Increase in film thickness with respect to increase in incorporation of starch (5% to 25% w/v) was significant at $p \leq 0.05$ (Table 1). Effect of incorporation of jackfruit seed starch with respect to the film thickness indicated that there is polynomial relationship with $r^2 = 0.991$. Equation (3) shows the relationship between the incorporation of jackfruit seed starch on the film thickness. Films at 5, 10, 15, 20 and 25 % were significant at $p \leq 0.05$.

$$F_{TJSS} = -0.0002x^2 + 0.0147x + 0.1483 \quad R^2 = 0.9913 \quad \ldots(3)$$

Where,

F_{TJSS} = film thickness in mm,

x = jackfruit seed starch concentrations (w/v)

The more starch in film forming solution the films are thicker. The increase of thickness might be attributed to the amount of starch content per unit area poured in tray. Similar observations have been reported by

Table 2: ANOVA for Physico-mechanical properties of jackfruit seed starch films

Treatments	Properties of Jackfruit seed starch film					
	(a) Film Thickness (mm)	**(b) Tensile strength (N)**	**(c) Elongation at break (%)**	**(d) Film Solubility (%)**	**(e) Film transparency**	**(f) WVP (g/m²-hr)**
T_1	0.217 ± 0.01	40.56 ± 10.49	105.21 ± 28.48	49.36 ± 3.60	7.96 ± 0.46	0.290 ± 0.006
T_2	0.338 ± 0.07	33.599 ± 5.72	90.82 ± 11.42	53.13 ± 2.36	4.85 ± 1.10	0.258 ± 0.010
T_3	0.414 ± 0.10	28.85 ± 4.80	85.18 ± 28.54	58.37 ± 2.04	3.57 ± 0.87	0.236 ± 0.011
T_4	0.509 ± 0.10	22.08 ± 4.75	76.29 ± 6.51	63.09 ± 1.14	2.44 ± 0.41	0.201 ± 0.018
T_5	0.658 ± 0.05	13.32 ± 2.31	57.28 ± 14.62	65.55 ± 2.29	1.37 ± 0.19	0.182 ± 0.018
SE	0.01874060	0.1480565	4.62643713	1.039967	0.610952	0.003723
CD	0.072582	0.57342	17.91811	4.027777	3.259654	0.01295

Significant ($p \leq 0.05$) (T_1=5% w/v; T_2=10% w/v; T_3=15% w/v; T_4=20% w/v; T_5=25% w/v).

Garcia *et al.* (1999) the thickness increases of cassava starch film with the amylose and the starch content in solution.

Tensile strength and Elongation at break

Fig. 8 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the tensile strength of developed film. Fig. 9 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the elongation at break of developed film.

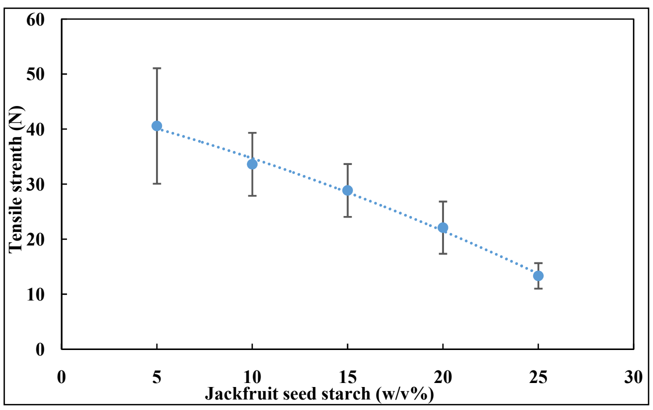

Fig. 8: Effect of incorporation of Jackfruit seed starch on the tensile strenth of film

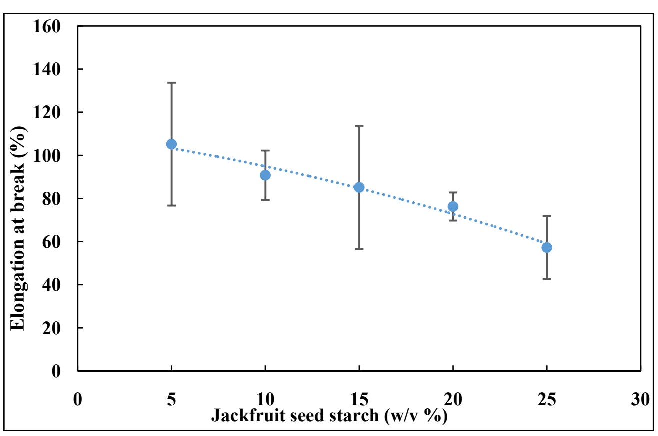

Fig. 9: Effect of incorporation of Jackfruit seed starch on the elongation at break of film

The tensile strength and elongation at break of films produced with jackfruit seed starch, glycerol, sorbitol and acetic acid are presented in Table 1(b&c). It is obvious that the tensile strength and elongation at break were strongly influenced by starch concentration. As increasing the amount of starch, the tensile strength decreases, similar in the elongation at break which shows decreasing trend with increase in jackfruit seed starch. The mean tensile strength values of starch films containing 5, 10, 15, 20 and 25 w/v % starch were about 40.564 ± 10.496, 33.599 ± 5.752, 28.850 ± 4.804, 22.084 ± 4.746 and 13.323 ± 2.315 N respectively. Table 1 (b) shows the ANOVA of tensile strength of the jackfruit seed starch edible film. Decreased in tensile strength with respect to increase in incorporation of starch (5% to 25% w/v) was significant at p≤0.05. Effect of incorporation of jackfruit seed starch with respect to the tensile strength of film indicated that there is polynomial relationship with $r^2 = 0.995$. Equation (4) shows the relationship between the incorporation of jackfruit seed starch and tensile strength. Films at 5%, 10%, 15%, 20% and 25 % were significant at p≤0.05.

$$T_{SJSS} = -0.016x^2 - 0.8392x + 44.679 \quad R^2 = 0.9954 \quad \ldots(4)$$

Where,

T_{SJSS} = tensile strength in *N*,

x = jackfruit seed starch concentrations (w/v)

Fig. 9 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the elongation at break of developed film. Elongation at break of jackfruit seed starch films ranged from 57.28 ± 14.62 to 105.21 ± 28.48 %. The Elongation at break of jackfruit seed starch films of 5%, 10%, 15%, 20% and 25% concentrations were 105.21 ± 28.48, 90.82 ± 11.42, 85.18 ± 28.54, 76.29 ± 6.51 and 57.28 ± 14.62 % respectively.

Table 1 (c) shows the ANOVA of elongation at break of the jackfruit seed starch edible film. Decrease in elongation at break with respect to increase in incorporation of starch (5% to 25% w/v) was significant at p≤0.05 (Table 1). Effect of incorporation of jackfruit seed starch with respect to the elongation at break of film indicated that there is polynomial relationship with $r^2 = 0.971$. Equation (5) shows the relationship between the incorporation of jackfruit seed starch and elongation at break. Films at 5%, 10%, 15%, 20% and 25 % were significant at p≤0.05.

$$E_{SJSS} = -0.0357x^2 - 1.1379x + 109.84 \quad R^2 = 0.9716 \quad \ldots(5)$$

Where,

E_{SJSS} = elongation at break in %,

x = jackfruit seed starch concentrations (w/v)

Similar results have been observed for Mali *et al.* (2004) and Mali *et al.* (2005) that cassava starch films with high starch concentration showed low tensile strength (Table 1).

Film solubility

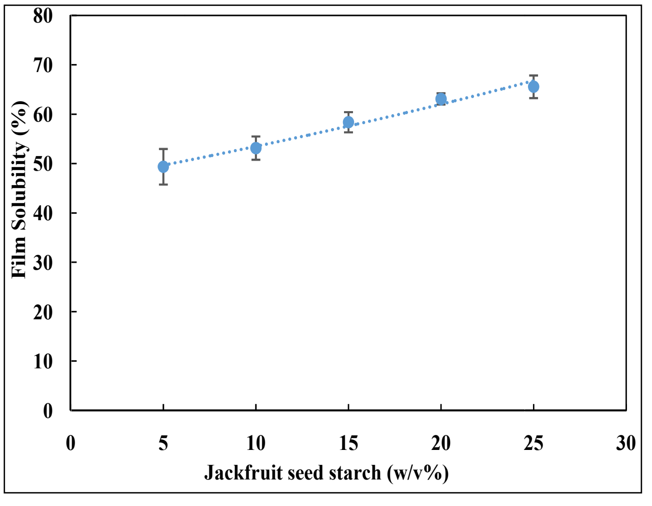

Fig. 10: Effect of incorporation of Jackfruit seed starch on the solubility of film

Fig. 10 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the film solubility of developed film. Water solubility of jackfruit seed starch films ranged from 49.36 ± 03.60 to 65.55 ± 02.29 %. The film solubility of jackfruit seed starch films of 5%, 10%, 15%, 20% and 25% concentrations were 49.36 ± 3.60, 53.13 ± 02.36, 58.37 ± 02.04, 63.09 ± 01.14 and 65.55 ± 02.29 % respectively. Table 1 (d) shows the ANOVA for the film solubility of the jackfruit seed starch edible film. Increase in film solubility with respect to increase in incorporation of starch (5% to 25% w/v) was significant at p≤0.05. Effect of incorporation of jackfruit seed starch with respect to the film solubility indicated that there is exponential relationship with r^2=0.983. Equation (6) shows the relationship between the incorporation of jackfruit seed starch and the film solubility. Films at 5, 10, 15, 20 and 25 % were significant at p≤0.05.

$$F_{SJSS} = 46.134e^{0.0148x} \quad R^2 = 0.9837 \quad \ldots(6)$$

Where,

F_{SJSS} = film solubility in %,

x = jackfruit seed starch concentrations (w/v)

Muller *et al.* (2008) reported that the biodegradable films solubility is influenced by the starch type and concentration used in its preparation. According to Matta *et al.* (2011), starch addition, has a great influence on the solubility of starch films, due to its hydrophilic character. Amylose interacts with the film matrix by increasing the space between the chains, facilitating the water diffusion and, consequently, increased film solubility.

Film transparency

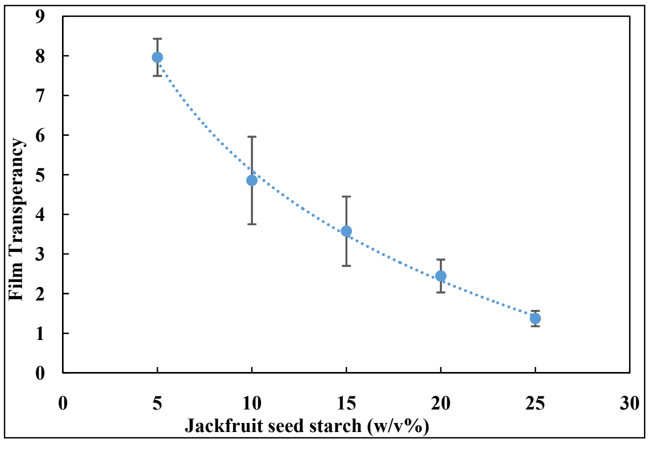

Fig. 11: Effect of incorporation of Jackfruit seed starch on the transperancy of film

Fig. 11 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the transparency of developed film. Transparency of jackfruit seed starch films ranged from 1.37 ± 0.19 to 7.96 ± 0.46 (Table 1(e)). The transparency of jackfruit seed starch films of 5%, 10%, 15%, 20% and 25% concentrations were 7.96 ± 0.46, 4.85 ± 1.10, 3.57 ± 0.87, 2.44 ± 0.41 and 1.37 ± 0.19 respectively. The transparency may be affected by various factors including film thickness. As thickness was increased but the film transparency decreased as the starch content increased. The result suggests that the amount of solids in the film, rather than the viscosity of the film-forming dispersion, was the major factor affecting the thickness and transparency of the films.

Table 1 (e) shows the ANOVA for the transparency of the jackfruit seed starch edible film. Decreased in transparency with respect to increase in incorporation of jackfruit seed starch (5% to 25% w/v) was significant at p≤0.05 (Table 1(e)). Effect of incorporation of jackfruit seed starch with respect to the film transparency indicated that there is logarithmic relationship with $r^2 = 0.996$. Equation (7) shows the relationship between the incorporation of jackfruit seed starch and the film transparency. Films at 5, 10, 15, 20 and 25 % were significant at p≤0.05.

$$F_{TJSS} = -3.998\ln(x) + 14.306 \quad R^2 = 0.9963 \qquad \ldots(7)$$

Where,

F_{TJSS} = film transperancy,

x = jackfruit seed starch concentrations (w/v)

Mali *et al.* (2005) reported that as the solid concentration in the film-forming dispersion increased the films became thicker simply due to the increased total residual mass in the film, regardless of the type of polysaccharide used.

Water vapour permeability

Fig. 12 shows effect of incorporation of jackfruit seed starch (5% to 25% w/v) on the Water vapour permeability of developed film. Water vapour permeability of jackfruit seed starch films ranged from 0.1828 ± 0.0187 to 0.2900 ± 0.0064 g/m^2-hr. The water vapour permeability of jackfruit seed starch films of 5%, 10%, 15%, 20% and 25% concentrations were 0.2900 ± 0.064, 0.2583 ± 0.0101, 0.2360 ± 0.0110, 0.2017 ± 0.0183 and 0.1828 ± 0.0187 g/m^2-hr respectively.

Table 1 (f) shows the ANOVA for the water vapour permeability of the jackfruit seed starch edible film. Decreased in water vapour permeability with respect to increase in incorporation of starch (5% to 25% w/v) was significant at p≤0.05 (Table 1(f)). Effect of incorporation of jackfruit seed starch with respect to the water vapour permeability indicated that there is polynomial relationship with $r^2 = 0.995$. Equation (8) shows the relationship between the incorporation of jackfruit seed starch and the water vapour permeability. Films at 5, 10, 15, 20 and 25 % were significant at p≤0.05.

$$WVP_{JSS} = 4 \times 10^{-5}x^2 - 0.0066x + 0.322 \quad R^2 = 0.995 \ldots(8)$$

Where,

WVP_{JSS} = water vapour permeability g/m^2-hr,

x = jackfruit seed starch concentrations (w/v)

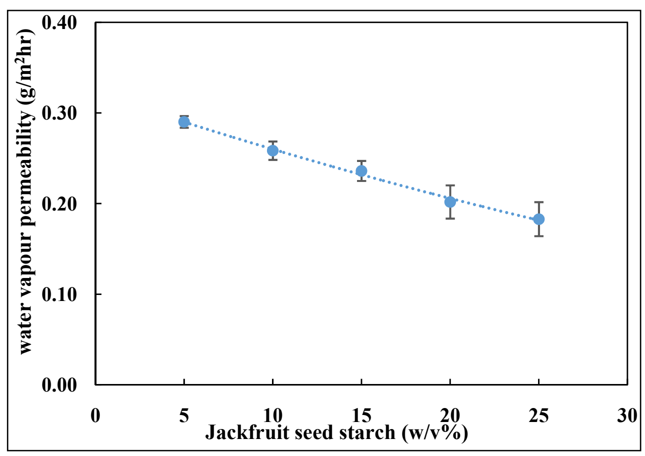

Fig. 12: Effect of incorporation of Jackfruit seed starch on the WVP of film

In food packaging applications, film should to avoid or at least decrease moisture transfer between food and surrounding atmosphere, water vapour permeability should be as low as possible. However, a significant decrease was observed in WVP with the incorporation of starch content. The same behaviour was observed by Martins *et al.* (2010) with the incorporation of a bioactive peptide (nisin) in films of galactomannan. Also for chitosan films it has been shown that the incorporation of soybean trypsin inhibitor extract lead to a decrease of WVP values (Zhang *et al.* 2009).

Optimum product quality based on desirable properties

The film thickness of jackfruit seed starch film should be low, high in tensile strength and elongation at break, the film solubility should be low as if film goes contact to water it should not be soluble. The film transparency should be high so that product inside the film can be seen from outside. Water vapour permeability of jackfruit seed starch film should be low for minimizing moisture migration.

Considering above aspects the 15% (w/v) jackfruit seed starch film have good results as compare to other treatments films. The film thickness of jackfruit seed starch film of 15% (w/v) was 0414 ± 0.10 mm which was moderate as compare to other treatments. The tensile strength of jackfruit seed starch film of 15% (w/v) was 28.85 ± 4.80 N which was good as compare to other treatments. The elongation at break of jackfruit seed starch film of 15% (w/v) was 85.18 ± 28.54 % which was suitable for fulfilling basic requirement of edible film. The film solubility of jackfruit seed starch film of 15% (w/v) was 58.37 ± 2.04 %. Film transparency of jackfruit seed starch film of 15% (w/v) was 3.57 ± 0.87 which was good as compare to other treatments. The water vapour permeability of jackfruit seed starch film was 0.236 ± 0.011 g/m^2-hr which was moderate as compare to other treatments.

Cost Economics of developed film of desirable properties

The economics for the preparation of 1 kg jackfruit seed starch film of 15% (w/v) was shown in Table 3. It could be observed from the Table 3 that the total cost for production of one kilogram jackfruit seed starch film of 15 % (w/v) was ₹ 4556.9. In one kilogram jackfruit seed starch we made 10 films having size of 45 × 30 cm. The cost for preparation of one jackfruit seed starch film of 15% (w/v) was ₹ 455.69.

Table 3: Cost analysis of Jackfruit seed starch film per 1 kg starch

Sl. No.	Particulars	Quantity	Cost (₹)
1	Jackfruit @ ₹ 5/kg	25 kg	125
2	Glycerol @ ₹ 350/ 500 ml	500 ml	350
3	Sorbitol @ ₹ 215/500 ml	500 ml	215
4	Acetic acid @ ₹ 420/ 500 ml	500 ml	420
5	Teflon sheet @ ₹ 1235 / 1 ft. × 10 ft.	1 No	1235
6	Acrylic plate @ ₹ 1250 / 4 ft. × 3 ft.	1 No	1250
7	Labour charges @ ₹ 300 /day	2 days	600
8	Electricity charges @ ₹ 10.34 / unit	35 unit	361.9
	Total cost of production	4556.9	

CONCLUSION

The results of this study provided useful information on the physical and mechanical properties of jackfruit seed starch films. Increasing the incorporation of starch in the film (5-25% w/v) resulted in increase in film thickness from 0.217 ± 0.014 mm to 0.658 ± 0.059 mm and decreased in water vapour permeability from 0.290 ± 0.006 to 0.182 ± 0.018 g/m^2-hr, transparency from 7.96 ± 0.46 to 1.37 ± 0.19, tensile strength from 40.564 ± 10.496 N to 13.323 ± 2.315 N of the resultant jackfruit seed starch films. Additionally, jackfruit seed starch films exhibited high solubility in water, good tensile strength, transparency, and water vapour barrier properties which could provide increased protection to packaged food and have a good potential to be considered as a new source of biodegradable packaging material for food applications.

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