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Development of kiwi fruit leather incorporated with hydrocolloids and betacyanin microcapsules: Rheological behaviour and release kinetics of betacyanin

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ABSTRACT

The kiwi fruit leather incorporated with betacyanin microcapsules was prepared using three hydrocolloids namely xanthan gum, gellan gum, and guar gum. The four-kiwi fruit puree prepared for the study were kiwi fruit puree without hydrocolloid (CP), with xanthan gum (XE), with gellan gum (EP), and with guar gum (UP). The influence of various hydrocolloids and temperatures on rheological properties of kiwi fruit puree was investigated using the Cross, Carreau, and modified Powell model. The apparent viscosity was decreased with increase in shear rate and rise of temperature. The incorporation of hydrocolloid also increased viscosity of prepared puree. Cross model (R^2>0.989) found to fit the apparent viscosity with respect to shear rate. The flow behaviour index of four kiwi fruit puree samples was found to be less than one depicting pseudoplastic fluid with shear thinning behaviour. For dynamic rheology study in the frequency range of 1–60 rad/s, the storage modulus was higher than loss modulus at specific frequency that implies, elastic properties of puree were dominant over the viscous ones suggesting the weak gel-like network of kiwi fruit puree. The glass transition temperature of prepared kiwi fruit leathers ranged from 59 to 64 °C. The in vitro betacyanin release from the leather sample was studied and Peppas-Sahlin model was observed to be one of the ideal model when compared with the other kinetic models. The development of kiwi fruit leather with hydrocolloids and betacyanin microcapsules represented a successful strategy to create a functional snack that combines health benefits with consumer-desirable sensory attributes.

1. Introduction

Kiwi fruit (*Actinidia*) is a tropical fruit belonging to *Actinidiaceae* family, and the fruit is oval in shape with fuzzy brown color peel (Wang et al., 2018). The pulp appears green in color, containing numerous edible tiny black seeds with sweet and bitter taste (Pinto, 2018; Sarita Ramesh Khutare & Amol Sampat Deshmukhs, 2023). The pulp of kiwi fruit is rich in vitamin C, whereas seeds contain vitamin D (Li et al., 2023; Vahedi Torshizi, Khojastehpour, Tabarsa, Ghorbanzadeh & Akbarzadeh, 2020). Aside from these vitamins, the kiwi fruit is a nutritious fruit consisting of bioactive compounds such as polyphenols, flavonoids, saponins, alkaloids, tannins, carotenoids, and chlorophyll. The fruit exhibits antioxidant activity, anticancer, antilipidemic effects, anti-inflammation, and antimicrobial activity, as well as medicinal and nutraceutical properties (An et al., 2016; Sarkar et al., 2022). Aside from its high nutritional content, the kiwi fruit is underutilized, and because of its perishable nature, it experiences higher post-harvest losses (Öztürk & Ayhan, 2023; Prithani & Dash, 2020). The various studies have revealed that the post-harvest losses of kiwi fruit ranges approximately between 25% to 30%, depending on the region and the effectiveness of the post-harvest handling processes (Dai et al., 2022). So, drying the fruit at a low temperature to produce fruit leather or bars is simple and cost-effective means of lowering the water content to an acceptable level while also adding value to the fruit (Kumar, Madhumathi, Sadarunnisa & Latha, 2017; Tiwari, 2019).

Fruit leather is a ready-to-eat snack that may be appreciated by

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people of all ages, which can be an alternative to undesirable high-calorie snacks that are intense in sugars, fats, artificial colors, flavors, and chemical preservative (Aggarwal, Kaur & Kaur, 2022; Ciurzyńska et al., 2019). Fruit leather is a healthy products that contain the nutrients like phenolic compounds, antioxidants, dietary fibre, vitamins, minerals, and pigments of the utilized fruit which impart natural color and flavor to the leather (Bandaru & Bakshi, 2020; Sarma, Kundlia, Chutia & Mahanta, 2023). The primary processing phases involved in the formulation of the fruit leather include (i) converting the fruit into puree or concentrate juice, (ii) mixing with hydrocolloid and sugar (as per the requisite), and (iii) drying at 30 - 80 °C to a moisture content level of 12 - 20% (Mai et al., 2016). Many researchers formulated fruit leather with different nutritious fruits as well as mixing two or more fruits to complement each of the fruits in terms of physico-chemical and nutritional value. Some of the recent studies include the formulation of fruit leather using *Annona muricata L.* fruits (Ayalew & Emire, 2020); papaya and banana (Ubbaonu et al., 2020); peach (Franco et al., 2020); apple and plum (Nizamlioglu, Yasar & Bulut, 2022); roselle and fig (Aslam et al., 2023). Hydrocolloids are hydrophilic polymers derived from the sources such as plants, algal, microbial, animal, and chemically modified polysaccharides (Gómez-Pérez, Navarrete, Moraga, Rodríguez & Vega-Gálvez, 2020).

Hydrocolloids are gelling and thickening agents used in leather processing to improve rheological and textural characteristics of the leather, as well as their ability to bind and hold water to varying degrees (da Silva Simão, de Moraes, Carciofi & Laurindo, 2020; Yousuf, Mir, Bhardwaj, Gul & Wani, 2019). Xanthan gum is a water-soluble anionic natural polysaccharide that have been broadly used in numerous applications in food industry for the preparation of sauces, dairy products, and desserts due to its ability in creating high viscous solution even used at low concentrations (Hosseini et al., 2020; Sabaa et al., 2019). Guar gum has an affinity to create a effective hydrogen bond with water, that makes it a unique thickener and stabilizer agent in the food processing sector (Mudgil et al., 2014). Extracellular polysaccharide gellan gum is a linear anionic heteropolysaccharide with a high molecular weight that is utilized in food items as a gelling agent for various purposes (Fernández-Ferreiro et al., 2015).

The fruit leathers can be incorporated with the encapsulated extracts of fruit waste, that has the ability in improving the nutrient value of the product. Generally, lower values were observed for the bio-accessibility and bioavailability associated with bioactive compounds from native food matrix as compared to extracts. Thus, encapsulation techniques and materials which increases gastric emptying and enhance sustained release, like hydrocolloids which forms acid gels, are required (Gidley, 2013; Puligundla & Lim, 2022). Bio-accessibility is the fraction of bioactive compounds which are released from food matrices into gastrointestinal tract for luminal absorption and can be evaluated using in vitro methods (Nolasco, Baraka, Yang, Ciftci & Majumder, 2024). Bioavailability is also the fraction of ingested bioactive compounds which reaches the circulatory system and helps in storage and bioprocesses (Tenore, Campiglia, Ritieni & Novellino, 2013). The kinetic and food matrix effects can help to understand microencapsulated materials and provides impetus to manufacture and consume. Release kinetics is mostly qualitatively discussed using concentration-time profile, considering the amount released after a specific phase (Giroux, Robitaille & Britten, 2016). However, additional information could be collected using mathematical treatment of kinetics data on release behavior could be analyzed using theoretical, or empirical equations.

The properties of fruit puree, such as physicochemical properties and flow behaviour, can affect the preparation and properties of fruit leather prepared (Makroo, Prabhakar, Rastogi & Srivastava, 2019). The flow characteristics of the fruit pulp, namely viscosity and yield stress can be correlated to large-scale transfer processes including spreading, pouring, and pumping (Raghunath, Hoque & Foster, 2023). Furthermore, analyzing flow properties of the pulp, as well as the applicability of rheological models, helps in quality control, scaling up product standardization, and appropriate process equipment selection. Dragon fruit peel extract contains natural pigment known as betacyanin and has the ability to impart color to food products, improve antioxidant property of the leather, provide unique flavour as well as marketing appeal (Thaiudom, Oonsivilai & Thaiwong, 2021). In addition to antioxidant activity betacyanin also has anticarcinogenic, hepatoprotective, antibacterial, and anti-inflammatory activities as well as intestinal and immune regulatory impacts (Rahimi et al., 2019). The pigment compounds present in the peels of dragon fruit was unstable in its crude form due to changes in temperature, pH, exposure to light, and enzymatic reactions (Gengatharan et al., 2015; Herbach et al., 2006; Rahayuningsih et al., 2021). So, the microencapsulation method improves the stability of the betacyanin and can be used in different value-added food products.

Studying the interactions between various hydrocolloids and other components, such as sugars, acids, and preservatives, in kiwi fruit leather formulations can reveal potential synergistic effects that enhance the quality of the product. Research analysing the impact of hydrocolloids on the stability and availability of bioactive substances in kiwi fruit leather can offer valuable information on improving the nutritional value of the product. Based on this, the aim of current study was to investigate the rheological properties of betacyanin microencapsulate incorporated kiwi fruit puree prepared with various hydrocolloids (gellan gum, xanthan gum, and guar gum) and their influence on preparation of kiwi fruit leather. Cross, Carreau, and the Modified Powell Eyring model were used to simulate the rheological behaviour of hydrocolloid (xanthan gum, gellan gum, and guar gum) incorporated kiwi fruit puree. The potential effect of the hydrocolloid on the physical properties of fruit leathers and the release kinetic study of betacyanin from microcapsule into the simulated gastric juice (in vitro) was investigated.

2. Materials and methods

2.1. Raw material

Fresh kiwi fruit (variety- *Actinidia deliciosa*) and dragon fruit (variety- *Hylocereus undatus*) were collected from the local market of Malda, West Bengal (coordinates of 25° 0′ 39.0276′' N and 88° 8′ 27.9528′' E). The fruits were sorted by size and maturity (total soluble solids of 7 °Brix) before being rinsed in water to remove the foreign contaminants. The fruits were washed then peeled to separate the peel from pulp. The pulp of kiwi fruit was sliced into small pieces and peels of dragon fruit were dried using freeze drier (Lyolab Freeze Lab, Lyophilization Systems Inc., USA).

2.2. Extraction of betacyanin from dragon fruit peel and encapsulation of extract

The phytochemicals were extracted from freeze-dried dragon fruit peel powder using ultrasonic assisted extraction (UAE) technique (Bhagya Raj & Dash, 2020). Briefly, ethanol of concentration 60% was added to the peel powder in 25:1 ml/g ratio and the extraction process was conducted using ultrasonic homogenizer with probe (U500, Takashi, Japan) operated at 100 W of power. The extraction was conducted for 20 min under 60 °C temperature. Betacyanin was separated from the UAE crude extract using aqueous two-phase extraction method using ammonium sulfate and polyethylene glycol (PEG) according to the procedure described by Neelwarne and Rudrappa (2012). The stability of the betacyanin extract was improved by entrapping it in a microcapsule prepared from gum arabica (1%), sodium alginate (1%), and calcium chloride (0.5 M). The microcapsule was formed by ion gelation method using encapsulator (Buchi B-390, CIENTEC Instrumentos Cientıficos, S.A., Chile) (Sharma, Dash & Badwaik, 2022).

2.3. Preparation of kiwi fruit puree and leather

The kiwi fruit pieces were crushed in a mixer grinder (Prestige Elegant, 750 Watts, Prestige, India) and the juice concentrate of pulp was homogenised to achieve a homogeneous consistency of 13.71 °Brix. The juice concentrate of kiwi fruit was blended with 10 % (w/w) sugar and then thickened with each hydrocolloid namely xanthan gum, gellan gum, and guar gum to make fruit puree. Hydrocolloid was mixed with kiwi fruit juice in the ratio of 1:50 (w/w) i.e., 1 part of hydrocolloid was mixed with 50 parts of kiwi fruit juice. To measure the effect of hydrocolloid on rheological behaviour of the kiwi fruit puree, one control sample was also prepared without adding hydrocolloid. The puree formed without hydrocolloid was labelled as CP, while three fruit purees containing three hydrocolloids, xanthan gum, gellan gum, and guar gum, were named as XP, EP, and UP. The four different types of fruit purees (CP, XP, EP, and UP) were combined with 1% microcapsule containing betacyanin. The puree was used for the rheological study to analyze the rheological behaviour at different temperature and shear rate. The prepared kiwi fruit puree, weighing roughly 250 g, was poured onto a greased stainless-steel moisture dish, and a specified amount of microcapsules was gently stirred in to ensure even distribution. The container was dried using conductive hydro drying, which involves placing the container to be dried in a water bath (Castoldi, Zotarelli, Durigon, Carciofi & Laurindo, 2015; Raj & Dash, 2022). The fruit leather developed from the kiwi fruit puree CP, XP, EP and UP were designated as L_C, L_X, L_E and L_U respectively. The formed leather was kept in a glass jar till further analysis.

2.4. Rheological measurement

2.4.1. Static rheological properties

The rheological measurements for the kiwi fruit puree were conducted with a controlled shear rate Rheometer (Physical MCR 72, Anton Paar, Austria). The flow behaviour of kiwi fruit puree was investigated by monitoring the relation between apparent viscosity or shear stress and shear rate with concentric cylinder geometry attachment (Basumatary, Bhattacharya & Das, 2020; Y. Kumar, Bhardwaj, Kheto & Saxena, 2022). The rotating bob with 16.66 mm diameter, while the inner diameter of stationary cup with 18.92 mm was maintained. 1 mm gap was kept between the rotator and stator on bottom side. Around 3 g of kiwi fruit puree was kept inside the cup for each test. All measurements were measured at temperatures of 25 °C, 30 °C, 35 °C, and 40 °C, with shear rates ranging from 0.1 - 300 s^{-1}. To determine the reproducibility of results, three experimental runs were checked for all samples, and a new sample was used each time. The relation between apparent viscosity or shear stress and shear rate was determined using three rheological models, such as, Cross (Eq. (1)), Carreau (Eq. (2)), and Modified Powell Eyring (Eq. (3)) model.

$$\eta = \eta_\infty + \frac{\eta_0 - \eta_\infty}{1 + \left(\frac{\gamma}{\gamma_b}\right)^n} \tag{1}$$

$$\eta = \eta_\infty + \frac{\eta_0 - \eta_\infty}{\left[1 + \left(\frac{\gamma}{\gamma_b}\right)^2\right]^N} \tag{2}$$

$$\eta = \eta_\infty + \frac{(\eta_0 - \eta_\infty)\ln(\lambda\gamma + 1)}{(\lambda\gamma)^n} \tag{3}$$

Where η is apparent viscosity, η_0 is initial viscosity, η_∞ is viscosity to infinite time, *m* is cross exponent which tends to a value (1-n), N represents the Carreau constant, *n* is flow behavior index, γ is shear rate, $\gamma_b$and λ represent time constant.

2.4.2. Dynamic frequency sweep test

The dynamic frequency sweep test was conducted to study the effect of frequency (ω) on the dynamic viscoelastic properties of the kiwi fruit puree: loss modulus (G″) and storage modulus (G′). The test was conducted with Rheometer (Physical MCR 72, Anton Paar, Austria) at a specific temperature of 40 °C. The power law equation presented in Eq. (4-5) helps to examine the relationship between the frequency and the observed viscoelastic parameter G″ and G′ (Moniri, Farahmandfar & Motamedzadegan, 2020). The complex viscosity (η^*) of the kiwi fruit puree was calculated using loss modulus (G″) and storage modulus (G′) by the equation Eq. (6) (Dash, Ali, Das & Mohanta, 2019).

$$G' = K'(\omega)^{n'} \tag{4}$$

$$G'' = K''(\omega)^{n''} \tag{5}$$

$$\eta^* = \frac{\sqrt{(G'')^2 + (G')^2}}{\omega} \tag{6}$$

Where G′ is elastic behaviour and is defined as the deformation energy stored in sample during shear process (Pa), G″ is the viscous behaviour of sample and is defined as the deformation energy used up and lost during shearing (Pa), ω is frequency (Hz), K′ represents storage modulus constant (Pa.$s^{n'}$) and K″ is loss modulus constant (Pa.$s^{n''}$), and n′ and n″ (dimensionless) depicts the power low exponent for storage and loss modulus respectively.

2.5. Glass transition temperature of kiwi fruit leather

The glass transition temperature (Tg) of the formed kiwi fruit leather with different hydrocolloids was studied using differential scanning calorimetry (DSC 214 NETZSCH, India). Leather sample weight of around 15 mg was conditioned and hermetically sealed in aluminium pans. The temperature range used for the heating of pan was in between −20 °C and 300 °C with a nominal heat rate of 10 °C/min and the heating was done using nitrogen atmosphere with the flow rate of 50 ml/min Sharma et al. (2022).

2.6. Release kinetics

In vitro release of betacyanin from the formed kiwi fruit leather sample was examined under simulated gastric juice formed by mixing hydrochloride, sodium chloride and pepsin as per the procedure given by Dag et al. (2017) with slight alterations. In this, appround100 mg of each leather sample was mixed with 1.4 mL of simulated gastric juice followed by incubation in water bath at 37 °C. Small amount of test sample was taken out from the solution at 0.083, 0.25, 0.5, 1 and 2 h time to examine the release of betacyanin in the solution. Betacyanin release from microcapsule incorporated kiwi fruit leather was plotted against time and was fitted with four release kinetic models, such as Higuchi (Eq. (7)), Korsmeyer-Peppas (Eq. (8)), Weibull (Eq. (9)), and Peppas-Sahalin Eq. (10). The betacyanin content was measured using UV-spectrophotometry method given by Bhagya Raj and Dash (2020).

$$Q = k_h\sqrt{t} \tag{7}$$

$$Q = k_k\sqrt[n]{t} \tag{8}$$

$$\frac{Q}{Q_\infty} = 1 - \exp\left(-\left(\frac{t}{a}\right)^b\right) \tag{9}$$

$$\frac{Q}{Q_\infty} = k_d \times t^m + k_r \times t^{2m} \tag{10}$$

Where Q is quantity of compound released at time t; Q/Q_∞ is the fraction of active compounds released until time t; k_h, and k_k are Higuchi constant, and Korsmeyer-Peppas constant respectively; k_d and k_r depicts diffusion and relaxation constant for Korsmeyer-Peppas model respectively; n is release diffusional exponent; a and b are scale and shape parameters of Weibull model; m is fickian diffusion exponent.

2.7. Statistical analysis

The model adequacy was validated using different statistical parameters including coefficient of determination (R^2), root mean square error (RMSE), and chi-square (χ^2), relative deviation percentage values measured using Eq. (11)-(13).

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Y_{pre} - Y_{exp})}{\sum_{i=1}^{n} (Y_m - Y_{exp})} \tag{11}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (Y_{pre} - Y_{exp})^2}{n}} \tag{12}$$

$$\chi^2 = \sum_{i=1}^{n} \frac{(Y_{pre} - Y_{exp})^2}{Y_{exp}} \tag{13}$$

where Y_{pre} is predicted value from the model, Y_{exp} is observed values, Y_m is an average response value, and n is total number of experiments conducted.

3. Results and discussion

3.1. Rheological properties of kiwi fruit pulp

Three flow rheological models namely Cross model, Carreau model, and Modified Powell Eyring model were fitted to the experimental data of shear rate Vs apparent viscosity of prepared four kiwi fruit leather puree (CP, XP, EP and UP) and compared with each other to find the best fit model. The change of apparent viscosity data with respect to shear rate for each puree sample was tested at temperature of 25 °C, 30 °C, 35 °C, and 40 °C and illustrated in Fig. 1. The flow behaviour index estimated by the used three models (Carreau model, Cross model, and Modified Powell Eyring model) for different samples was less than 1, indicating that the kiwi fruit puree has non-Newtonian behaviour with pseudoplastic properties. Comparable results of flow behaviour index less than 1 was reported for the ohmic heated mulberry puree during the study of rheological properties (Hardinasinta, Mursalim, Muhidong & Salengke, 2021).

At a temperature of 35 °C and shear rate of 1 s^{-1}, the apparent viscosity was 3766.344 mPa.s, and apparent viscosity was observed to be decreased with an increase of shear rate. The apparent viscosity was reduced by 99.14 % at a shear rate of 300 s^{-1}. Similarly, when kiwi fruit

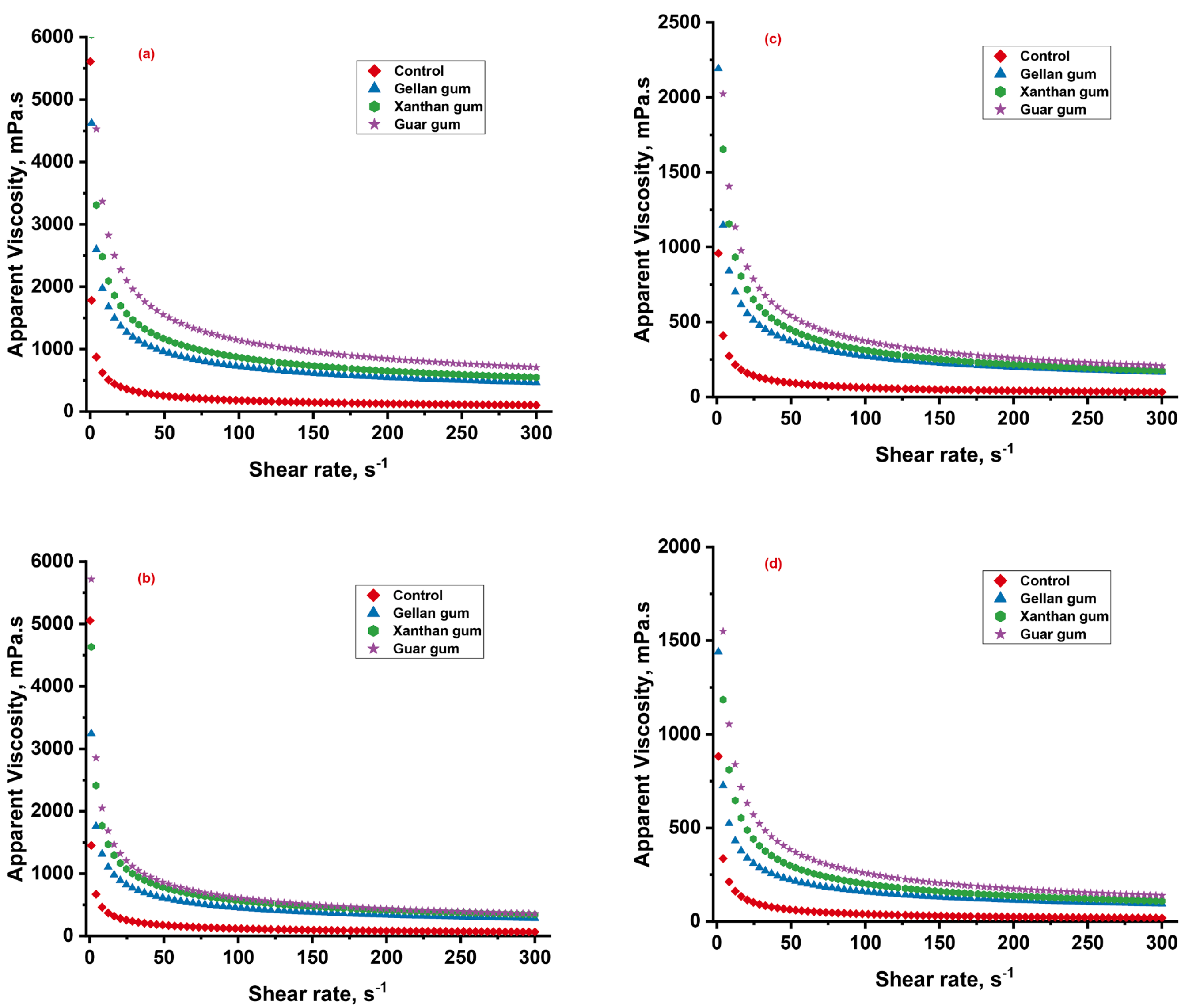

Fig 1. Flow curves of the four kiwi fruit purees for apparent viscosity Vs shear rate at different temperatures (a) 25 °C, (b) 30 °C, (c) 35 °C and (d) 40 °C.

was mixed with hydrocolloid gellan gum, xanthan gum, and guar gum at a shear rate of 0.1 s^{-1} and 35 °C temperature, the apparent viscosity was increased by 65.185 %, 212.464 %, and 292.218 %, respectively, when compared with control sample under same conditions (Fig. 1c). The apparent viscosity of kiwi fruit puree at temperature 35 °C and shear rate of 300 s^{-1} added with gellan gum, xanthan gum, and guar gum was reduced to 165.390, 174.791, and 207.548 mPa.s, respectively. The increased shear rate tend to decrease the apparent viscosity of puree samples and suggesting the shear thinning behaviour, a shear-induced breakdown of inter particulate bridges (Fernández Farrés, Douaire & Norton, 2013). For samples incorporated with gellan gum, the apparent viscosity varied from 11,680.545 - 4335.447 mPa.s at shear rate of 0.1 s^{-1} with temperature of 25 °C – 40 °C. The initial apparent viscosity value of this sample at temperature 25 °C (Fig 1(a)) and a shear rate of 0.1 s^{-1} was observed to be maximum value and reduced to a percentage of 25.673, 46.737, and 62.883 as the temperature was increased to 30 °C (Fig 1(b)), 35 °C (Fig 1(c)) and 40 °C (Fig 1(d)) respectively. The same trend was obtained for control sample with apparent viscosity ranging from 5608.954 −4161.772 mPa.s, for the sample with xanthan gum, the apparent viscosity ranging from 15,901.276 - 9499.816 mPa.s and guar gum the apparent viscosity of range 22,881.406 - 12,759.526 mPa.s at a shear rate of 0.1 s^{-1} in the temperature of 25 °C – 40 °C. The apparent viscosity was observed to be decreased with increased temperature from 25 °C to 40 °C and the incorporation of hydrocolloid increased sample viscosity.

3.1.1. Cross model steady shear rheology parameters of kiwi fruit pulp

The Cross model depicted the good correlation with higher R^2 values (>0.989) and overall χ^2 and RMSE values was less than 1.743 $\times 10^{-4}$ and 0.875 $\times 10^{-2}$ respectively. The parameters of the Cross model: viscosity to infinite time, initial viscosity, cross constant, and time constant are shown in Table 1. Flow behaviour index for the sample can be calculated using cross constant (m) where n = 1-m and the flow behaviour index observed to be increased with the incorporation of hydrocolloid and the value ranged from 0.313 to 0.587. For control sample, the n value was observed to be 0.492, 0.448, 0.395, and 0.313 at temperatures 25 °C, 30 °C, 35 °C, and 40 °C, respectively. In kiwi fruit puree with gellan gum, there was an increase in flow behaviour index, which was found to be 19.303%, 25.572%, 36.087%, and 63.182% at temperature of 25 °C, 30 °C, 35 °C, and 40 °C respectively as compared to n values corresponding to the control sample at the respective temperatures. Similarly, as compared to the control, the n value of kiwi fruit puree prepared by adding xanthan gum hydrocolloid increased in a percentage of 15.684, 19.353, 17.533, and 37.705 at temperatures of 25 °C, 30 °C, 35 °C, and 40 °C, respectively. The n value was enhanced by 13.043, 12.565, 15.751, and 35.452 percent in the case of guar gum integrated samples at respective temperatures. It can be seen from Table 1 that the kiwi fruit puree made with gellan gum is highly viscous than kiwi fruit puree made from guar gum, xanthan gum, and the control sample (kiwi fruit puree without hydrocolloid). The results showed that the 'n' value decreased with increased temperature from 25 °C to 40 °C. The apparent viscosity of kiwi fruit puree was dependent on shear rate, temperature and the type of hydrocolloid. The reduction in η_0 with increase in temperature was observed for kiwi fruit puree made without hydrocolloid (151,122.870 - 91,471.128 mPa.s), gellan gum (285,380.700 - 116,501.312 mPa.s), xanthan gum (402,102.787 - 249,638.011 mPa.s) and guar gum (608,214.080 - 341,351.762 mPa.s). A similar pattern of decreasing η_0 from 23.763 to 15.040 Pa.s while raising the temperature from 20 to 40 °C was seen in Cross model during preparation of raspberry jam, and the same trend was observed for the jams made from prune, strawberry, apricot and peach (Álvarez, Cancela & Maceiras, 2006). The parameter η_∞ followed an identical pattern of η_0, which also decreased with the increase in temperature for all samples. There was decrease in η_∞ for control from 5.605 - 1.709 mPa.s, with increased temperature from 25 °C to 40 °C for kiwi fruit puree with, gellan gum from 22.763 to 4.855 mPa.s, xanthan gum from 26.796 to 6.912 mPa.s and guar gum from 33.807 to 8.755 mPa.s. Similar trends in cross parameters η_0 and η_∞ were observed with respect to temperature, with η_0 and η_∞ decreasing from 2.922 $\times 10^6$ to 2.84 $\times 10^5$ mPa.s and from 6.79

Table 1
Estimated Cross model parameters for kiwi fruit leather mixture.

Kiwi fruit puree	Parameters	Temperature			
		25 °C	30 °C	35 °C	40 °C
Control	η_0 $\times 10^2$(mPa.s)	1511.229 ± 174.510	1380.566 ± 159.653	981.211 ± 113.506	914.711 ± 118.792
	m	0.508 ± 0.001	0.552 ± 0.001	0.605 ± 0.001	0.687 ± 0.002
	η_∞(mPa.s)	5.605 ± 0.737	3.866 ± 0.517	2.252 ± 0.307	1.709 ± 0.243
	$\gamma_b \times 10^{-4}$ (s^{-1})	1.639 ± 0.412	2.674 ± 0.617	4.883 ± 1.029	10.100 ± 1.909
	R^2	0.984	0.992	0.995	0.998
	$\chi^2 \times 10^{-4}$	0.213	0.062	0.054	0.189
	RMSE $\times 10^{-2}$	1.419	0.766	0.718	1.339
Gellan gum	η_0 $\times 10^2$(mPa.s)	2853.807 ± 327.812	2219.452 ± 255.465	1641.759 ± 189.263	1165.013 ± 134.456
	m	0.413 ± 0.001	0.438 ± 0.001	0.463 ± 0.001	0.489 ± 0.001
	η_∞(mPa.s)	22.763 ± 2.879	13.862 ± 1.773	8.257 ± 1.068	4.855 ± 0.634
	$\gamma_b \times 10^{-4}$(s^{-1})	0.478 ± 0.149	0.663 ± 0.195	0.921 ± 0.255	1.280 ± 0.335
	R^2	0.981	0.983	0.996	0.992
	$\chi^2 \times 10^{-4}$	2.868	0.601	0.167	0.028
	RMSE $\times 10^{-2}$	5.206	2.386	1.257	0.515
Xanthan gum	η_0 $\times 10^2$(mPa.s)	4021.028 ± 462.597	3602.972 ± 415.718	3139.391 ± 362.698	2496.380 ± 288.550
	m	0.431 ± 0.001	0.466 ± 0.001	0.536 ± 0.001	0.568 ± 0.001
	η_∞(mPa.s)	26.796 ± 3.417	16.725 ± 2.166	10.108 ± 1.343	6.912 ± 0.929
	$\gamma_b \times 10^{-4}$(s^{-1})	0.604 ± 0.180	0.892 ± 0.245	2.346 ± 0.558	3.402 ± 0.763
	R^2	0.984	0.980	0.992	0.997
	$\chi^2 \times 10^{-4}$	12.507	3.153	10.178	5.453
	RMSE $\times 10^{-2}$	10.882	5.465	9.821	7.191
Guar gum	η_0 $\times 10^2$(mPa.s)	6082.141 ± 700.926	4664.291 ± 538.305	3928.966 ± 453.969	3413.518 ± 394.799
	m	0.444 ± 0.001	0.496 ± 0.001	0.543 ± 0.001	0.576 ± 0.001
	η_∞(mPa.s)	33.807 ± 4.339	18.944 ± 2.480	12.231 ± 1.630	8.755 ± 1.181
	$\gamma_b \times 10^{-4}$(s^{-1})	0.668 ± 0.193	1.436 ± 0.370	2.552 ± 0.599	3.531 ± 0.782
	R^2	0.995	0.983	0.988	0.994
	$\chi^2 \times 10^{-4}$	109.000	66.102	39.644	28.606
	RMSE $\times 10^{-2}$	32.143	25.024	19.379	16.464

to 6.18 mPa.s, respectively, as temperature increased from 15 to 45 °C (Basumatary et al., 2020). The η_0 and η_∞ value increased with the incorporation of hydrocolloids in kiwi fruit puree at given temperatures which can be due to the establishment of a large number of links among biopolymer molecules and on interchain interactions (Torres, Hallmark & Wilson, 2014). The time-dependent (γ_b) represented the onset of the shear-thinning region and was found to be in the range of 1.639 × 10^{-4}–1.010 × $10^{-3}s^{-1}$, 4.781 × 10^{-5}–1.280 × $10^{-4}s^{-1}$, 6.039 × 10^{-5}–3.402 ×$10^{-4}s^{-1}$ and 6.680 × 10^{-5}–3.531 ×$10^{-4}s^{-1}$ for kiwi fruit puree prepared without hydrocolloid, with gellan gum, xanthan gum, and guar gum, respectively.

3.1.2. Carreau model steady shear rheology parameters of kiwi fruit pulp

Carreau model fitted the experimental data with overall R^2 value higher than 0.988 and the χ^2 and RMSE value lesser than 34.349 ×10^{-2} and 5.704 × 10^{-1} respectively, shown in Table 2. The dimensionless exponent (N) of the Carreau model was less than one and in the range of 0.201 - 0.337 for all the samples. This demonstrates that the kiwi fruit puree behaves as non-Newtonian shear-thinning fluid. The results indicated that Carreau parameter N increased with increased temperature. As a function of temperature, the parameters of Carreau model for kiwi fruit puree prepared without hydrocolloid predicted N value ranged from 0.249 to 0.337. The initial viscosity (η_0) was varied between 59,389.497 and 85,135.214 mPa.s, the viscosity to infinite time (η_∞) was changed between 0.002 to 0.005 mPa.s. The time constant (γ_b) ranged between 6.78 ×10^{-4} to 0.001 s^{-1}. Similarly, the Carreau model predicted the N values were ranged between 0.201 - 0.239, 0.210 - 0.279, and 0.217 - 0.282 or kiwi fruit puree with gellan gum, xanthan gum, and guar gum, respectively. The initial viscosity (η_0) ranged from 50,505.7 to 71,320.344 mPa.s, 96,044.755 to 103,828.7 mPa.s and 114,321.616 to 125,019.433 mPa.s. and the viscosity to infinite time (η_∞) was in the range of 0.002 - 0.025 mPa.s, 0.019 - 0.049 mPa.s and 0.042 - 0.135 mPa.s., The time constant (γ_b) was in the range of 5.922 × 10^{-4}–11.200 × $10^{-4}s^{-1}$, 10.9 × 10^{-4}–16.1 ×$10^{-4}s^{-1}$ and 20.0 × 10^{-4}–20.6 ×$10^{-4}s^{-1}$ respectively as the function of temperature (Table 2).

3.1.3. Modified Powell Eyring model steady shear rheology parameters of kiwi fruit pulp

Modified Powell Eyring model fit the experimental data with average R^2 values higher than 0.987, average χ^2 values of less than 24.928 × $10^{-1}$and average RMSE values less than 4.860, presented in Table 3. The n value for the control sample, hydrocolloid added sample with gellan gum, xanthan gum, and guar gum were found to be in the range of 0.557 - 0.727, 0.455 - 0.537, 0.475 - 0.623, and 0.489 - 0.631, respectively, at given temperatures. For all four samples, the n value was observed to be increased with increased temperature, and the incorporation of hydrocolloid decreased the n value, suggesting that the sample incorporated with hydrocolloid is highly viscous. The other parameters of the modified Powell Eyring model for control sample were the initial viscosity (η_0) varied from 1.794 ×10^6 to 77.146 ×10^6 mPa.s, the viscosity to infinite time (η_∞) from 1.243 to 7.307 mPa.s, and the time constant (λ) from 5.453 ×10^7 to 37.898 × 10^7s, with temperature as a function shown in Table 3. For the kiwi fruit puree with gellan gum showed the parameters the initial viscosity (η_0) ranging from 1.434 ×10^6 to 2.147 × 10^6 mPa.s, the viscosity to infinite time (η_∞) from 6.258 to 26.770 mPa.s and the time constant (λ) from 8.683 ×10^7 to 52.178 × 10^7s. The parameter depicted by modified Powell Eyring model for the sample prepared with xanthan gum, the initial viscosity (η_0) varied from 3.460 ×10^6 to 4.833 ×10^6 mPa.s, the viscosity to infinite time (η_∞) from 9.209 to 32.376 mPa.s and the time constant (λ) from 1.276 ×10^7 to 34.743 × 10^7s. The parameters for modified Powell Eyring for the kiwi fruit puree formed with guar gum η_0, η_∞ and λ were in the range of 5.577 ×10^6 to 6.211 ×10^6 mPa.s, 11.964 to 42.827 mPa.s and1.075 ×10^7 to 25.465 × 10^7s respectively.

Table 2
Estimated Carreau model for kiwi fruit leather mixture.

Kiwi fruit puree	Parameters	Temperature			
		25 °C	30 °C	35 °C	40 °C
Control	η_0 × 10^3(mPa.s)	59.389 ± 1.738	75.684 ± 2.536	65.805 ± 2.301	85.135 ± 3.380
	η_∞(mPa.s)	0.005 ± 0.001	0.002 ± 0.0001	0.002 ± 0.00001	0.002 ± 0.00010
	γ_b × 10^{-4}(s^{-1})	8.735 ± 0.514	6.777 ± 0.420	8.109 ± 0.478	11.300 ± 0.669
	n	0.249 ± 0.004	0.271 ± 0.003	0.297 ± 0.004	0.337 ± 0.010
	R^2	0.991	0.983	0.985	0.984
	χ^2 × 10^{-2}	1.869	1.333	0.692	0.712
	RMSE × 10^{-1}	1.331	1.124	0.810	0.821
Gellan gum	η_0 × 10^3(mPa.s)	71.320 ± 1.687	65.664 ± 1.654	56.645 ± 1.510	50.506 ± 1.422
	η_∞(mPa.s)	0.025 ± 0.004	0.010 ± 0.001	0.005 ± 0.001	0.002 ± 0.000
	γ_b × 10^{-4}(s^{-1})	11.200 ± 0.658	8.816 ± 0.520	7.634 ± 0.450	5.922 ± 0.349
	n	0.201 ± 0.006	0.214 ± 0.004	0.227 ± 0.003	0.239 ± 0.002
	R^2	0.993	0.984	0.986	0.992
	χ^2 × 10^{-2}	10.597	5.365	2.550	1.159
	RMSE × 10^{-1}	3.168	2.254	1.554	1.048
Xanthan gum	η_0 × 10^3(mPa.s)	96.045 ± 2.373	103.829 ± 2.800	103.076 ± 3.186	96.327 ± 3.158
	η_∞(mPa.s)	0.049 ± 0.007	0.021 ± 0.003	0.029 ± 0.004	0.019 ± 0.003
	γ_b × 10^{-4}(s^{-1})	13.900 ± 0.818	10.900 ± 0.646	16.100 ± 0.950	15.700 ± 0.925
	n	0.210 ± 0.009	0.228 ± 0.006	0.263 ± 0.011	0.279 ± 0.012
	R^2	0.996	0.981	0.995	0.982
	χ^2 × 10^{-2}	18.410	10.780	7.909	4.875
	RMSE × 10^{-1}	4.176	3.196	2.737	2.149
Guar gum	η_0 × 10^3(mPa.s)	125.019 ± 3.189	115.333 ± 3.294	117.757 ± 3.688	114.322 ± 3.797
	η_∞(mPa.s)	0.135 ± 0.020	0.084 ± 0.012	0.055 ± 0.008	0.042 ± 0.006
	γ_b × 10^{-4}(s^{-1})	20.000 ± 1.178	20.600 ± .215	20.300 ± 1.197	20.600 ± 1.215
	n	0.217 ± 0.009	0.243 ± 0.012	0.266 ± 0.007	0.282 ± 0.009
	R^2	0.984	0.988	0.985	0.993
	χ^2 × 10^{-2}	34.349	18.978	12.324	8.295
	RMSE × 10^{-1}	5.704	4.240	3.417	2.803

Table 3
Estimated Modified Powell Eyring for kiwi fruit leather mixture.

Kiwi fruit puree	Parameters	Temperature			
		25 °C	30 °C	35 °C	40 °C
Control	$\eta_0 \times 10^4$(mPa.s)	205.017 ± 94.007	218.287 ± 102.969	179.387 ± 86.227	7714.600 ± 5701.470
	η_∞(mPa.s)	7.307 ± 0.832	5.278 ± 0.610	3.098 ± 0.365	1.243 ± 0.153
	$\lambda \times 10^7(s)$	5.453 ± 0.574	1.861 ± 0.185	0.537 ± 0.050	37.898 ± 4.547
	n	0.557 ± 0.004	0.605 ± 0.004	0.663 ± 0.005	0.727 ± 0.004
	R^2	0.988	0.987	0.989	0.991
	$\chi^2 \times 10^{-1}$	1.490	1.203	0.660	0.176
	RMSE	1.188	1.068	0.791	0.408
Gellan gum	$\eta_0 \times 10^4$(mPa.s)	214.653 ± 87.675	200.734 ± 85.279	174.978 ± 76.820	143.392 ± 64.668
	η_∞(mPa.s)	26.770 ± 2.940	16.905 ± 1.875	10.385 ± 1.163	6.258 ± 0.708
	$\lambda \times 10^7(s)$	52.178 ± 6.129	29.492 ± 3.377	16.155 ± 1.798	8.683 ± 0.937
	n	0.455 ± 0.003	0.482 ± 0.004	0.509 ± 0.004	0.537 ± 0.004
	R^2	0.988	0.984	0.990	0.982
	$\chi^2 \times 10^{-1}$	6.535	3.593	1.840	0.892
	RMSE	2.488	1.845	1.320	0.919
Xanthan gum	$\eta_0 \times 10^4$(mPa.s)	346.025 ± 145.499	379.686 ± 167.252	483.250 ± 225.965	427.358 ± 203.066
	η_∞(mPa.s)	32.376 ± 3.582	21.718 ± 2.435	13.290 ± 1.528	9.209 ± 1.070
	$\lambda \times 10^7(s)$	34.743 ± 4.008	15.116 ± 1.677	2.757 ± 0.280	1.276 ± 0.124
	n	0.475 ± 0.003	0.512 ± 0.004	0.588 ± 0.004	0.623 ± 0.004
	R^2	0.981	0.981	0.994	0.988
	$\chi^2 \times 10^{-1}$	12.065	8.314	6.537	4.238
	RMSE	3.381	2.806	2.488	2.004
Guar gum	$\eta_0 \times 10^4$(mPa.s)	557.744 ± 239.071	602.713 ± 273.652	621.101 ± 291.604	582.967 ± 277.806
	η_∞(mPa.s)	42.827 ± 4.763	24.286 ± 2.753	16.122 ± 1.857	11.964 ± 1.394
	$\lambda \times 10^7(s)$	25.465 ± 2.896	7.317 ± 0.783	2.330 ± 0.234	1.075 ± 0.103
	n	0.489 ± 0.004	0.544 ± 0.004	0.595 ± 0.004	0.631 ± 0.004
	R^2	0.988	0.986	0.986	0.983
	$\chi^2 \times 10^{-1}$	24.928	14.504	10.288	7.632
	RMSE	4.860	3.707	3.122	2.689

3.2. Dynamic rheological properties of kiwi fruit pulp

3.2.1. Power law

The dynamic rheological property of the kiwi fruit puree were measured at angular frequency (ω) range of 1 to 60 rad/s and illustrated in Fig. 2. The experimental data revealed that the G′ and G″ found to increase with increase of angular frequency for all the four-kiwi fruit puree prepared. Similar results were reported for the hazelnut milk where the viscoelastic properties increased with increase of angular frequency during rheological study of the hazelnut milk (Gul, Saricaoglu, Mortas, Atalar & Yazici, 2017). For the kiwi fruit puree CP, the G′ and G″ at the frequency of 1 – 60 rad/s was found to be in the range of 214.639 - 312.188 Pa and 159.868 - 220.411 Pa respectively, illustrated in Fig. 2(a). The storage modulus and loss modulus for the puree added with the hydrocolloid was higher and this may be due to the increase of viscus nature of the puree and can be correlated with the static rheological property of the purees. The highest value of G′ and G″ was found for the UP sample and was approximately twice the value reported for CP at 1 rad/s frequency. For the XP the G′ and G″ were found to be approximately 81% and 52% higher than the respective parameters for CP at 1 rad/s frequency respectively. Whereas for EP the viscoelastic parameter at 1 rad/s of frequency were around 89% and 67% higher than the control puree viscoelastic parameter. For all four purees the storage modulus was higher than the loss modulus at specific frequency which signifies, elastic properties of puree were dominant over the viscous ones suggesting the weak gel-like network of kiwi fruit puree. Similar weak gel behaviour was reported for the mango juice treated by high pressure homogeniser where the storage modulus was higher than loss modulus of mango juice during the study of dynamic rheological properties (Zhou et al., 2017). Comparable results were observed where the G′ was higher than the G″ for the food matrix containing pea protein isolate and refined flour found to have stronger printing stability (Hussain, Arora & Malakar, 2021).

The dynamic rheological parameters were fitted using power law model and the parameters were presented in Table 4. The two models predicted the storage and loss modulus with higher accuracy at different angular frequency which was supported by the statistical parameters of the fit. From the Table 4, the statistical parameters R^2, χ^2 and RMSE was found to be greater than 0.968, less than 32.676 $\times 10^{-4}$ and less than 2.586 $\times 10^{-2}$ respectively. For the kiwi fruit puree CP the power law parameters K′, K″, n′ and n″ was found to be 200.380 Pa.s$^{n'}$, 150.720 Pa.s$^{n''}$, 0.107 and 0.092 respectively. The parameters of power law for other kiwi fruit puree were observed to be increased with increase in apparent viscosity. Maximum values of K′, K″, n′ and n″ was found for the kiwi fruit puree containing guar gum as hydrocolloid which was found to be increasing 89.016%, 76.148%, 120.355% and 63.834% when compared with the kiwi fruit puree prepared without hydrocolloid respectively. The power law parameters for the other kiwi fruit puree prepared using xanthan gum and gellan gum were observed to be in between the kiwi fruit puree and guar gum, showed in Table 4. The complex viscosity (Pa.s) for the kiwi fruit puree CP, XR, UP and EP was found to be in the range of 6.085 - 140.860, 17.855 - 278.355, 15.850 - 256.017 and 14.204 - 241.025 respectively. From the Fig. 2, it can be evident that the complex viscosity (η^*) was found to decrease with increase of angular frequency for all the kiwi fruit puree samples. Similar trends of increase in viscoelastic properties and decrease in the complex viscosity was observed with increase in angular frequency at two temperatures 0 °C and 80 °C, during the dynamic rheological study of siriguela pulp (Augusto, Cristianini & Ibarz, 2012).

3.3. Glass transition temperature of kiwi fruit leather

The glass transition temperature (T_g) of the products that were dried is vital in assessing the drying process as well as the shelf stability of the product and T_g is extremely reliant on moisture content as a plasticizer in food matrix (Huang & Hsieh, 2005). The T_g value was found to be lower for the kiwi leather L_C which was found to be 59 °C. The lower T_g value associated with leather sample L_C can be attributed to the formulation where the leather was prepared without any hydrocolloid

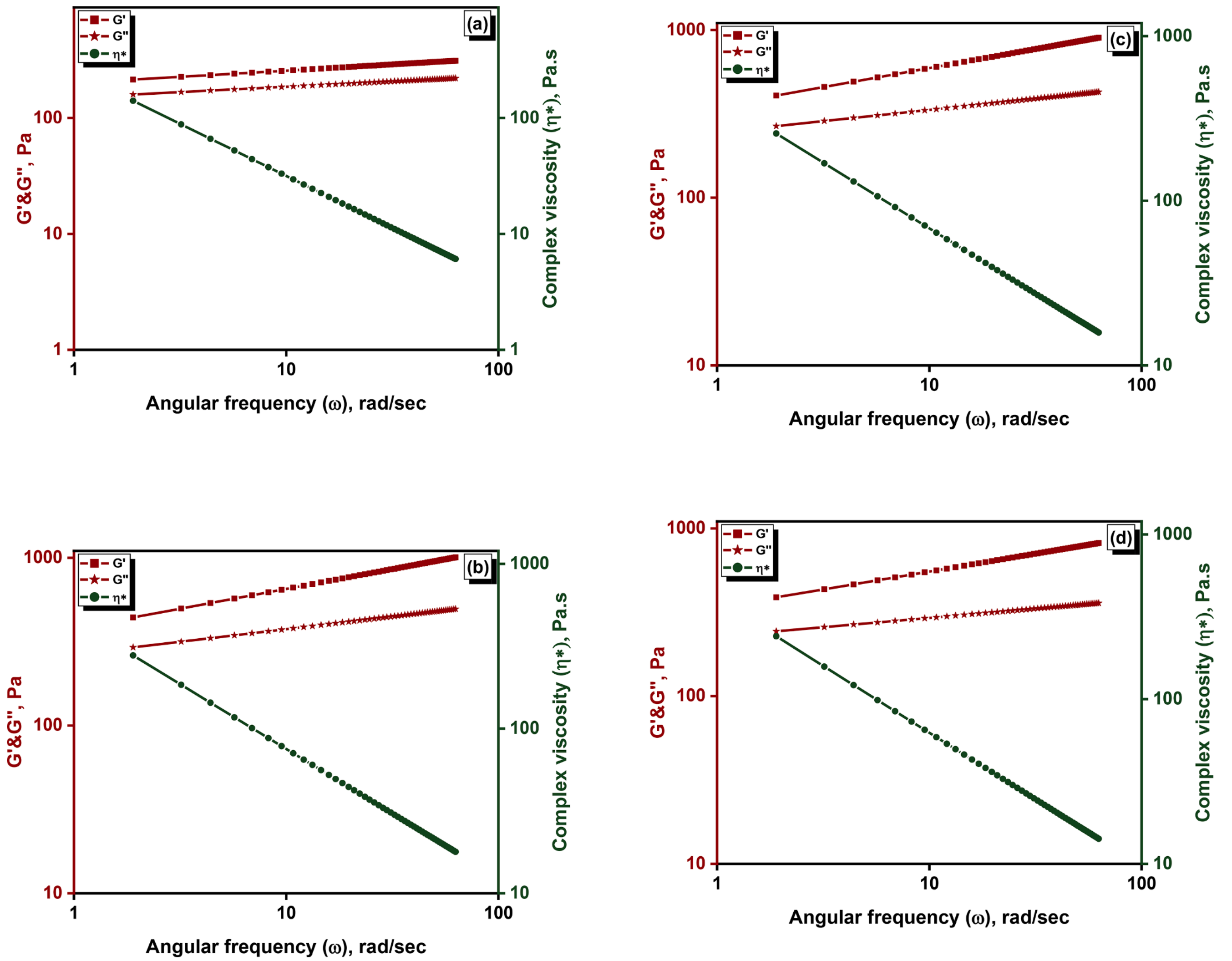

Fig 2. Storage modulus (G′), loss modulus (G″) and complex viscosity (η^*) at temperature 40 °C for the betacyanin incorporated kiwi fruit purees (a) without hydrocolloid; (b) guar gum; (c) gellan gum; and (d) xanthan gum.

Table 4
Estimated power law parameters for viscoelastic properties of kiwi fruit puree.

Sample		*K′* or *K″*	*n′* or *n″*	R^2	$\chi^2 \times 10^{-4}$	*RMSE* $\times 10^{-2}$
Control	G’	200.380 ± 1.213	0.107 ± 0.018	0.981	6.698	2.586
	G"	150.720 ± 1.500	0.092 ± 0.029	0.978	9.625	3.070
Guar gum	G’	378.750 ± 2.031	0.236 ± 0.015	0.983	32.676	5.656
	G’’	265.490 ± 1.439	0.150 ± 0.016	0.987	11.295	3.325
Gellan gum	G’	351.340 ± 1.177	0.227 ± 0.009	0.968	10.553	3.215
	G’’	245.230 ± 1.372	0.134 ± 0.016	0.974	9.577	3.062
Xanthan gum	G’	338.370 ± 1.088	0.213 ± 0.009	0.971	8.470	2.880
	G’’	226.720 ± 1.432	0.111 ± 0.018	0.985	9.467	2.966

so as a result the ability of binding and holding of water molecule was less when compared with the other puree samples. Similar results were reported where the T_g value of orange sample without biopolymers is lower compared with orange juice containing biopolymers (Silva-Espinoza, Camacho & Martínez-Navarrete, 2020). The T_g (°C) values 62, 64 and 61 was observed for the other leather L_X, L_E and L_U samples respectively. The T_g for all the samples was near to 60 °C due to the addition of 10% sugar in the preparation of puree which might have developed the stickiness. Similar outcomes were reported for the leather prepared using *Syzygium cumini L* (Pegu & Arya, 2021). Furthermore, the addition of sugar and the combination of hydrocolloid provided the chewing effect of the leather samples prepared.

3.4. Release kinetics of betacyanin

The mechanism and behaviour of the core material entrapped in microcapsule can be studied by means of release of active ingredient in simulated gastrointestinal solution. The results demonstrated that the leather formed without hydrocolloid found to have a higher release of betacyanin when compared with the other leathers formed using hydrocolloid (L_X, L_E and L_U) as thickening agent. The burst release of betacyanin at the initial stages was observed, and this can be due to presence of core material near the surface of microcapsules used in the preparation of leather. A similar trend of the higher release of spearmint essential oil was reported at the initial stage of 7 mins during the study of release profile of spray dried Mentha spicata encapsulated product in aqueous (water), oily (50% ethanol), alcoholic (10% ethanol), and acidic (3% acetic acid) medium (Mehran, Masoum & Memarzadeh, 2020). The approximate time taken for the leather samples L_C, L_X, L_E and L_U to release 50% of the betacyanin was found to be 10, 15, 25, and 35 mins, respectively. The time taken to release 98% of the betacyanin from the leather samples in the simulated gastrointestinal solution was 95 mins for L_C, 135 mins for L_X, 165 for L_E and 180 for L_U. Betacyanin release from leather samples in a simulated gastrointestinal digesting media was observed, and the cumulative betacyanin release from encapsulated products was plotted versus release time (Fig. 3). The mechanism of release was assessed by fitting with four kinetic models such as Higuchi, Korsmeyer, Weibull, and Peppas-Sahlin Eq. (7)-(10). The parameters of the four models, as well as the statistical characteristics (R^2, χ^2 and RMSE) were presented in Table 5–8.

The Peppas-Sahlin model was found to be the best model to determine betacyanin release kinetics, and it described the release profile of four leather products with a higher mean R^2 of 0.989 and a lower mean error value of 0.002 and 0.050 for χ^2 and RMSE, respectively illustrated in Fig. 3. The mean R^2 value for Higuchi, Korsmeyer-Peppas, and Weibull was found to be 0.978, 0.988 and 0.989, respectively. The mean χ^2 value was found to be 0.261, 0.039 and 0.005 and the mean RMSE values were 0.679, 0.258 and 0.081 for Higuchi, Korsmeyer-Peppas, and Weibull models, respectively. The Higuchi model constant $k_h$was found to be 1.011, 0.842, 0.761, and 0.693 for the leather samples L_C, L_X, L_E and L_U, respectively (Table 5). The higher value of the Higuchi model constant depicts the faster release betacyanin from the encapsulated product, and lower values indicate the slow release of betacyanin. The constants of Korsmeyer–Peppas model were kinetic constant (k_k) and release exponent (n). The k_k value signifies the kinetic constant related to the properties of the delivery system and encapsulated substance ranging from 0.84 – 0.123 (Table 6). The n value depends on the geometry, transport type, and polydispersity solute and shows the transport mechanism of solute. If n is less than 0.43, Fickian Diffusion takes place (Case I transportation); if n varies from 0.43 to 0.85, anomalous transport is main transport mechanism resulting from combination of diffusion mechanisms and swelling releases; if n is greater than or equal to 0.85, the transport is the consequence of matrix swelling ($n = 0.85$ – Case II Transp ort; $n > 0.85$ – Super Case II Transport) (Lucas, Ralaivao, Estevinho & Rocha, 2020; Ribeiro, Estevinho & Rocha, 2019). For betacyanin release from leather samples prepared with different hydrocolloids, the fitted values of release exponent in Korsmeyer–Peppas model was varied from 0.263 – 0.414 ($n < 0.43$), indicating Fician diffusion mechanism. The Weibull model constants α and β for betacyanin release from the encapsulate product were found to be in the range of 17.614 – 48.768 and 0.656 – 0.937, respectively (Table 7). The parameter β signifies the shape parameter of curve; if the curve is the

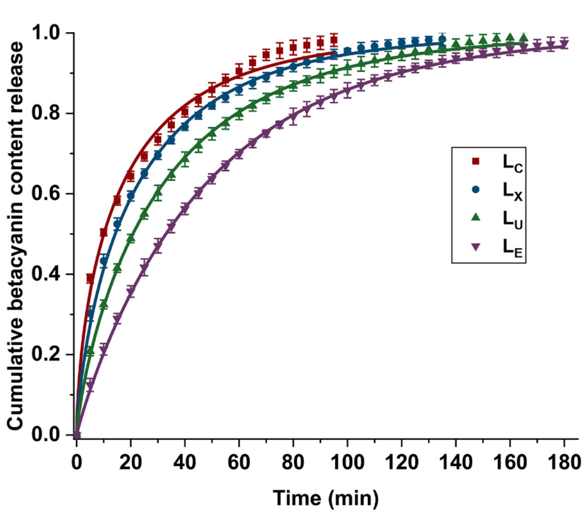

Fig. 3. Peppas-Sahalin model fit for release kinetics of betacyanin from kiwi fruit leather incorporated with betacyanin microcapsule.

Table 5
Higuchi model parameters for release kinetics of betacyanin content from kiwi fruit leather.

Sample	k_h	R^2	χ^2	RMSE
L_C	1.011 ± 0.031	0.972	0.270	0.717
L_X	0.842 ± 0.020	0.975	0.496	0.978
L_E	0.761 ± 0.015	0.978	0.193	0.612
L_U	0.693 ± 0.008	0.985	0.086	0.409

Table 6
Korsmeyer-Peppas model parameters for release kinetics of betacyanin content from kiwi fruit leather.

Sample	k_k	n	R^2	χ^2	RMSE
L_C	0.254 ± 0.007	0.306 ± 0.008	0.989	0.009	0.125
L_X	0.284 ± 0.015	0.263 ± 0.012	0.989	0.036	0.259
L_E	0.176 ± 0.013	0.353 ± 0.016	0.986	0.058	0.330
L_U	0.123 ± 0.010	0.414 ± 0.018	0.987	0.053	0.317

Table 7
Weibull model parameters for release kinetics of betacyanin content from kiwi fruit leather.

Sample	a	b	R^2	χ^2	RMSE
L_C	17.614 ± 0.484	0.656 ± 0.022	0.989	0.013	0.153
L_X	23.392 ± 0.311	0.741 ± 0.012	0.988	0.004	0.081
L_E	32.772 ± 0.207	0.805 ± 0.006	0.989	0.001	0.050
L_U	48.768 ± 0.191	0.937 ± 0.006	0.988	0.002	0.040

shape of dissolution/release curve that corresponds precisely to the exponential profile shape, then $\beta = 1$. For β<1, the shape of curve (parabolic) would show a steeper increase than an exponential profile, which was observed for all of the results attained for betacyanin release profiles studied for various leather samples. For $\beta > 1$, the shape of the curve gets sigmoidal with turning point (Estevinho, Horciu, Blaga & Rocha, 2021). The Peppas-Sahlin model constants k_d, k_r, and m were in the range of 0.047 to 0.209, −0.010 to −0.001, and 0.447 to 0.720, respectively (Table 8). The Peppas–Sahlin model is more accurate to measure the attrition and diffusion release process by the ratio of k_d/k_r. In this study, the k_d/k_r is greater than 1, which depicts that diffusion mainly controlled the betacyanin release in simulated gastrointestinal digestion medium. Similar trend was reported where the k_d/k_r ratio was higher than 1, and diffusion was the major factor in vanillin release from almond gum and poly vinyl alcohol composite nanofibers made by electrospinning method into aqueous food simulants and simulated saliva (distilled water, 10% ethanol 3% acetic acid, and 50% ethanol) (Rezaei, Nasirpour, Tavanai & Fathi, 2016).

4. Conclusion

Four different kiwi fruit purees incorporated with betacyanin microcapsule were used for rheological study at different temperatures and for kiwi fruit leather preparation by convective hydro drying. Out of four kiwi fruit purees, three were prepared by using three hydrocolloids (xanthan gum, gellan gum, and guar gum) and one was prepared without hydrocolloid. For the rheological study, the shear rate was plotted against apparent viscosity and fitted with three models, such as Cross, Carreau, and modified Powell model. All three models fitted the data with higher R^2 (>0.987) and lower χ^2 and RMSE values. Out of all the three models, the Cross model fitted the flow curves of apparent viscosity vs. shear stress with a good fit. The flow behaviour index value for all the models was found to be less than one, which showed that the kiwi fruit puree exhibited non-Newtonian behaviour with pseudoplastic properties. The viscoelastic properties (G′ and G″) was found to increase with increase of angular frequency and G′ values are higher than G″ at

Table 8
Peppas-Sahalin model parameters for release kinetics of betacyanin content from kiwi fruit leather.

Sample	k_d	$k_r \times 10^{-2}$	m	R^2	χ^2	RMSE
L_C	0.209 ± 0.004	− 1.031 ± 0.028	0.447 ± 0.007	0.989	0.001	0.036
L_X	0.157 ± 0.003	− 0.631 ± 0.024	0.511 ± 0.005	0.989	0.003	0.039
L_E	0.092 ± 0.003	− 0.219 ± 0.012	0.606 ± 0.007	0.988	0.004	0.067
L_U	0.047 ± 0.002	− 0.058 ± 0.004	0.720 ± 0.008	0.989	0.001	0.060

specific frequency revealed the weak gel behaviour of the purees formed. The glass transition temperature ranged from 59 – 64 °C for the formed four leather samples. The in vitro release of betacyanin from fruit leather showed that the control sample released the betacyanin faster whereas the leather formed with guar gum found to release the betacyanin slowly. The Peppas-Sahlin model was found to fit the release of betacyanin with respect to the time with more accuracy and less error when compared with the other three models. Future research is required to optimize the process parameters and ingradients for the production of hydrocolloid-incorporated kiwi fruit leather based on a variety of physicochemical attributes.By emphasizing on physicochemical characteristics like water activity, thermal stability, color retention and pigment stability, tensile strength and elasticity, microstructural analysis, shelf-life and degradation kinetics, hydration and rehydration properties, and so on, the quality, stability, and functionality of kiwi fruit leather can be stabilized. Although hydrocolloids provide a variety of beneficial characteristics in the development of kiwi fruit leather, careful formulation, consumer testing, and regulatory compliance are essential.

Ethical statement - Studies in humans and animals

■ This study does not involve any animals or human subjects.

Declarations

Human and animal rights and informed consent

This article does not include any experiments with human or animal subjects done by the authors.

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CRediT authorship contribution statement

G.V.S. Bhagya Raj: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kshirod Kumar Dash:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rafeeya Shams:** Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Shaikh Ayaz Mukarram:** Visualization, Validation, Resources, Funding acquisition. **Bela Kovács:** Visualization, Validation, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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