Indian Journal of Natural Products and Resources
Vol. 17(1), March 2026, pp. 187-198
DOI: 10.56042/ijnpr.v17i1.17683

Preparation of low-sugar fruit jams with microcrystalline cellulose and a multicomponent fluid matrix containing leaf-based pectic substances

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Received 06 March 2025; revised received 05 February 2026; accepted 11 February 2026

Pectic substances were extracted from the leaves of *Holarrhena pubescens*. Various factors affecting yield were studied. The liquid-to-solid ratio, pH, oxalate concentration, and treatment time were found to affect the yield. A multicomponent fluid matrix was produced using the pectic substances, sucrose, calcium chloride, histidine, and ascorbic acid. The optimum concentration of each component required to form the matrix with the highest average apparent viscosity was estimated. The multicomponent fluid matrix was then used to produce a pineapple jam with microcrystalline cellulose as a filler. FTIR–ATR spectroscopy was used to study the mechanism of gel and jam formation and was found to include the formation of hydrogen bonds between the components. Both the multicomponent fluid matrix and the microcrystalline cellulose affected the textural properties of the jam, making it possible to produce jams with a predetermined textural property. The low-sugar jam contained only 0.1% of sucrose in the finished product, making it useful for diabetic patients. The leaf-based pectic substances, with a low concentration of galacturonic acid, can be used as an effective gelling agent after transforming into a composite multicomponent fluid matrix. Thus, the flow and textural properties of pectic substances may be modified by mixing with suitable ingredients to suit various applications in food and other industries. Future projects should aim to utilise pectin from other sources as well for the production of similar low-sugar food products for the welfare of the diabetic community.

Keywords: Average apparent viscosity, Fruit jam, Microcrystalline cellulose, Multicomponent fluid matrix, Pectic substances, Texture profile analysis

IPC code; Int. cl. (2021.01)– A23L 19/00

Introduction

Pectin is a plant-derived heteropolysaccharide containing at least 65% galacturonic acid with many industrial applications. It is a natural component of the plant cell wall, where it performs many vital physiological functions[1]. Traditionally, pectin is obtained from fruit waste[2,3] and is considered a value-added product. Pectin is used in various applications, ranging from modifying gelling properties to increasing agricultural productivity[4]. Since new applications are being developed for pectin-based materials worldwide[5-7], it is essential to identify new sources of pectic substances and develop methods to increase the functional efficiency of pectic substances extracted from different non-traditional sources. This author reports preparing a multicomponent fluid matrix using pectic substances and non-pectic molecules, which is then used to prepare low-sugar pineapple jam with microcrystalline cellulose. Augmentation of pectin's properties by adding other molecules is not a new idea[8]. The presence of different types of molecules results in diverse microenvironments, which result in new interactions such as hydrogen bonding, hydrophobic interactions, and ionic interactions, thereby increasing the functional applicability of the product[9].

Holarrhena pubescens Wall. ex G.Don is a plant of the Apocynaceae family, order Gentianales, Kingdom Plantae, distributed widely in tropical regions. The plant is well known in connection with traditional Indian medicine[10] and has been studied for its metabolite contents[11]. Alkaloids extracted from different parts of the plant are known to have antimicrobial properties[12]. Although many clinical applications have been developed using extracts from various parts of the plant[13], applications in the food industry have not yet been reported in the published literature. Earlier literature indicates that this plant is widely used in traditional medicinal systems without adverse effects[14].

Pectin in the leaves of plants has been attracting attention from scientific communities in the recent

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past[15]. Extracting pectic substances from the leaves of plants has gained momentum in recent years[16]. This author is reporting, for the first time, the extraction of pectic substances from the leaves of *H. pubescens*. Dried and powdered leaves were mixed with oxalic acid-ammonium oxalate solutions at a range of oxalate concentrations and pH values, and heated in a pressure cooker for predetermined periods. The optimum yield was calculated and tested by optimising the conditions using response surface methodology in Minitab. The pectic substances obtained were then tested for the degree of methylation and galacturonic acid content. Functional groups were studied using FTIR–ATR.

Pectic substances obtained from some non-traditional sources often do not have 65% galacturonic acid content, and therefore, have fewer gelling capabilities. In such situations, the development of composites, containing many functional groups and structural diversities, is an efficient method for increasing the functional efficiency of the final product[17]. Some authors have recently reported that weak molecular-level interactions between pectin and other components result in a supramolecular network with highly amplified properties compared with those of the individual components[18]. This author produced a multicomponent fluid matrix using the extracted pectic substances and a few other small molecules. A series of small molecules was analysed in a preliminary study (data not shown) to identify the molecule that can potentially contribute to the viscosity of suspensions of pectic substances. Thus, in addition to the leaf-based pectic substances, sucrose, calcium chloride, histidine, and ascorbic acid were identified as potential components of the multicomponent fluid matrix to be formed. The optimum concentration of each of these molecules required to form a gel with the highest average apparent viscosity in water as the solvent was identified in independent experiments. Then, all components were mixed at their respective optimal concentrations to produce a multicomponent fluid matrix with the highest average apparent viscosity. The mechanism of formation of this multicomponent fluid matrix was studied using FTIR-ATR spectra of the individual components and the multicomponent fluid matrix.

Usually, fruit jams are produced with a higher sugar content, which provides the product with textural and rheological properties, but, at the same time, makes it unpalatable for diabetic patients. This author produced a low-sugar pineapple jam by boiling a multicomponent fluid matrix containing finely pulverised ripe pineapple and microcrystalline cellulose as a filler. Microcrystalline cellulose, a byproduct from agriculture-based industries, had been used earlier for the production of biocomposites[19]. The effect of varying concentrations of the microcrystalline cellulose on the textural and rheological properties of the jam was studied. The highest concentration of microcrystalline cellulose that could be supported by a given amount of the multicomponent fluid matrix without compromising the apparent viscosity was identified. Both the multicomponent fluid matrix and a particular concentration of the microcrystalline cellulose were found to increase the viscosity of the jam, while both these were found to affect the textural properties of the jam. Fruit jams of any particular hardness could be designed by altering the concentration of the multicomponent fluid matrix and the microcrystalline cellulose in them. This offers the potential to produce food materials for people with chewing problems. The lower sucrose content of the final product makes it suitable for patients with diabetes. The FTIR-ATR spectrum of the final product was studied and compared with the spectra obtained from the components to elucidate the mechanism behind the formation of the final product.

Materials and Methods

Plant sample collection and identification

Leaves of *H. pubescens* were collected from Thennilapuram in Kavassery village, Alathur taluk, Palakkad district, Kerala state, India, during November 2023. The plant was identified by the experts of the Department of Botany of the author's institution. A herbarium specimen of this plant with the scientific name *H.pubescens* Wall. ex G.Don is kept as specimen number 40414 in the Digital Flora of Peninsular India, Herbarium JCB, Indian Institute of Science, Bangalore, India. The leaves were then dried in the sun to constant weight, powdered and sieved, and stored in air-tight vessels until further use.

All reagents were purchased from Research Lab Fine Chem Industries, India. Deionised water was used throughout the work to prepare samples.

Extraction of pectic substances

Leaf dust was weighed and soaked in ammonium oxalate solution to get different predetermined liquid-

to-solid ratios, pH adjusted with oxalic acid to predetermined values, kept for one hour at room temperature, boiled in a pressure cooker at 121°C and 30 Psi pressure, for a predetermined duration (Table 1), removed from the flame and allowed to cool to room temperature spontaneously. The liquid lost by evaporation was replaced, mixed well using a cyclomixer, centrifuged to remove the dust, and an equal volume of isopropyl alcohol was added to the clear liquid, which was then mixed well and kept overnight at room temperature. The solution was then filtered using Whatman No. 1 filter paper. The residue was resuspended in water, precipitated with an equal volume of isopropyl alcohol, and the process was repeated five times. Finally, the aqueous suspension was slightly evaporated at 70°C to remove the alcohol and increase the concentration of the pectic substances, and was then kept refrigerated for analysis and further work.

To identify the optimum yield, the extraction was performed in triplicate using a central composite design (Table 1), and the results were analysed using response surface methodology in Minitab.

Percentage of galacturonic acid

Enough volume of the suspension of pectic substance was dried under vacuum to a constant weight. 50 mg of it was heated with 20 mL of 2 M trifluoroacetic acid at 106°C for 3.5 hours, and the acid was evaporated using a stream of air. 3 mL of isopropyl alcohol was added, mixed using a cyclomixer, and evaporated. Then 1 mL of water and 1 mL of buffered copper solution (prepared by dissolving 6.4 g of sodium acetate, 46.4 g of sodium chloride, and 2 mL of glacial acetic acid in 160 mL of water. Then 1.0 g of copper(II) sulfate pentahydrate was added, the mixture was made up to 200 mL with water was added, heated at 101°C for 40 minutes, and then cooled to room temperature. 16 mL of Folin Ciocalteau reagent (prepared by mixing 2 mL of 2N Folin Ciocalteau reagent and 78 mL of water) was added, mixed using a cyclomixer, and then the optical density was measured at 750 nm using a UV-VIS Spectrophotometer (Perkin Elmer Model: Lambda 650). Citrus pectin containing 74% galacturonic acid, and a solution without pectin, both treated in the same way, were used as the standard and control, respectively[20].

Table 1 — Conditions used for the extraction of pectic substances from the leaves of *H. pubescens*

Independent variable	Range		
Liquid (mL) to solid (g) ratio	30	40	50
pH	4.0	4.5	5.0
Concentration of ammonium oxalate solution (%)	0.6	0.8	1.0
Duration of heating (min)	12	14	16

Note: These values were finalised after a series of preliminary experiments, not mentioned here

Degree of esterification

The FTIR-ATR spectrum of the above pectin suspension was obtained in the range of 4100-400 cm^{-1} in the transmission mode using a PerkinElmer machine. The ratio of the number of methylated carboxyl groups (peak at 1745 cm^{-1}) to the total number of carboxyl groups (peaks at 1745 and 1630 cm^{-1}) was used for the calculation of the degree of methyl esterification[21].

Preparation of multicomponent fluid matrix

Aqueous solutions of sucrose, calcium chloride, histidine, and ascorbic acid were prepared. These components were selected after screening many food-grade molecules; the details are not provided here. Measured volumes of these components and pectic substances were mixed to obtain a mixture with a predetermined concentration of each component, heated in a beaker over a flame until the gel reached a predetermined weight (5 g), removed from the flame, and packed for analysis. The range of concentration of all components, as percentage by weight of the finished product, is given in Table 2a. Every experiment was done in triplicate. The apparent viscosity of the gels was measured using a Rotational Rheometer Model RheolabQC from Anton Paar, Austria, with a 1 mL cylinder measuring cup. The average of this apparent viscosity was calculated and compared. FTIR–ATR spectra, in the range of 4100-400 cm^{-1} in transmission mode, of the above solutions and that of the multicomponent fluid matrix were obtained with a PerkinElmer machine. The conditions for forming the multicomponent fluid matrix with the highest average apparent viscosity were optimised using response surface methodology in Minitab.

Preparation of fruit jam

Ripe pineapple was chopped into small pieces and finely pulverised in a mixer. A fixed quantity was added to a series of weighed beakers, followed by a fixed volume of the multicomponent fluid matrix, and predetermined, increasing concentrations of microcrystalline cellulose. The concentration ranges for all components are given in Table 2b. All beakers

Table 2 — a. Range of concentration of different components of multicomponent fluid matrix (MCFM) - values as % weight of final product

Components	T1	T2	T3	T4
Pectic substances	0.2	0.4	0.6	0.8
Sucrose	1	2	3	4
Calcium chloride	0.02	0.04	0.06	0.08
Histidine	0.2	0.4	0.6	0.8
Ascorbic acid	0.10	0.20	0.30	0.40

b. The concentration of components and the resulting average apparent viscosity (AAV) of Pineapple jams prepared using pectic substances from the leaves of *H. pubescens*. The pectic substances were first used to prepare the MCFM, and then microcrystalline cellulose (MCC) and pineapple fruit were added to prepare the pineapple fruit jam.

Test No.	MCFM(g)	MCC(g)	% of MCC	Water (ml)	Fruit (g)	AAV(Pa.s)
1	4	0	0	0	10	13169
2	0	0.5	2.5	20	10	11238
3	4	0.5	2.5	0	10	18153
4	4	1	5	0	10	821
5	4	1.5	7.5	0	10	7674
6	4	2	10	0	10	2425
7	4	2.5	12.5	0	10	7344

were heated on a flame until a net weight of 40 g was reached, removed from the flame, and the formed jams were packed for analysis. The apparent viscosity of the jams was measured as mentioned above. Texture profile analysis of these jams was carried out using a CT 3 Texture Analyser (make CT 3 Brookfield Engineering) from Brookfield AMETEK, at a speed of 1 mm/s, using Texture Pro CT V1.7 Build 29 software. FTIR–ATR spectra of the microcrystalline cellulose, the finely pulverised fruit, and the finished product were measured as mentioned above.

Statistical analysis

All extraction experiments were performed in triplicate, and the conditions were optimised using response surface methodology in Minitab. All multicomponent fluid matrices and fruit jams were prepared in triplicate, and the average value was used to calculate apparent viscosity. The concentration of the components of the multicomponent fluid matrix was optimised using response surface methodology in Minitab.

Results and Discussion

Yield and optimum conditions for extraction

The highest yield was 6.4%. The values of LSR – 42, pH – 4.5, concentration of ammonium oxalate – 0.8, and duration – 14 minutes were found to be the optimum conditions. Fig. 1 shows the contour plots of the yield of pectic substances from the leaves of *H. pubescens*. The yield reported is less compared to the yield from traditional citrus sources using mineral acids[22]. But using mineral acids often results in reduced product quality, such as the degree of esterification and solubility.

Galacturonic acid content and degree of esterification

The galacturonic acid content of the extracted pectic substances was 52.3%. while the DE calculated from FTIR–ATR data was 45.5%. Thus, the extracted pectic substances are of the low methoxyl type. The content of galacturonic acid is less compared with pectin extracted from other sources. Therefore, other molecules are added to it, making a composite material[23] to augment the functional properties of the pectic substances. Some workers have reported pectins with a similar degree of esterification from other traditional sources[24].

Optimum composition and apparent viscosity of multicomponent fluid matrix

Fig. 2 shows contour plots of the average apparent viscosity of the multicomponent fluid matrix prepared with different compositions of the components. From these plots, 0.8% of pectic substances, 1% of sucrose, 0.06% of calcium chloride, 0.3% of ascorbic acid, and 0.4% of histidine (all about the final weight of the finished product) were found to be the optimum concentration required for the formation of the multicomponent fluid matrix with the highest average apparent viscosity. Of these components, calcium is already known to play a vital role in the composite cell wall in plants[25] while sucrose is known to influence the rheological properties of pectin-based

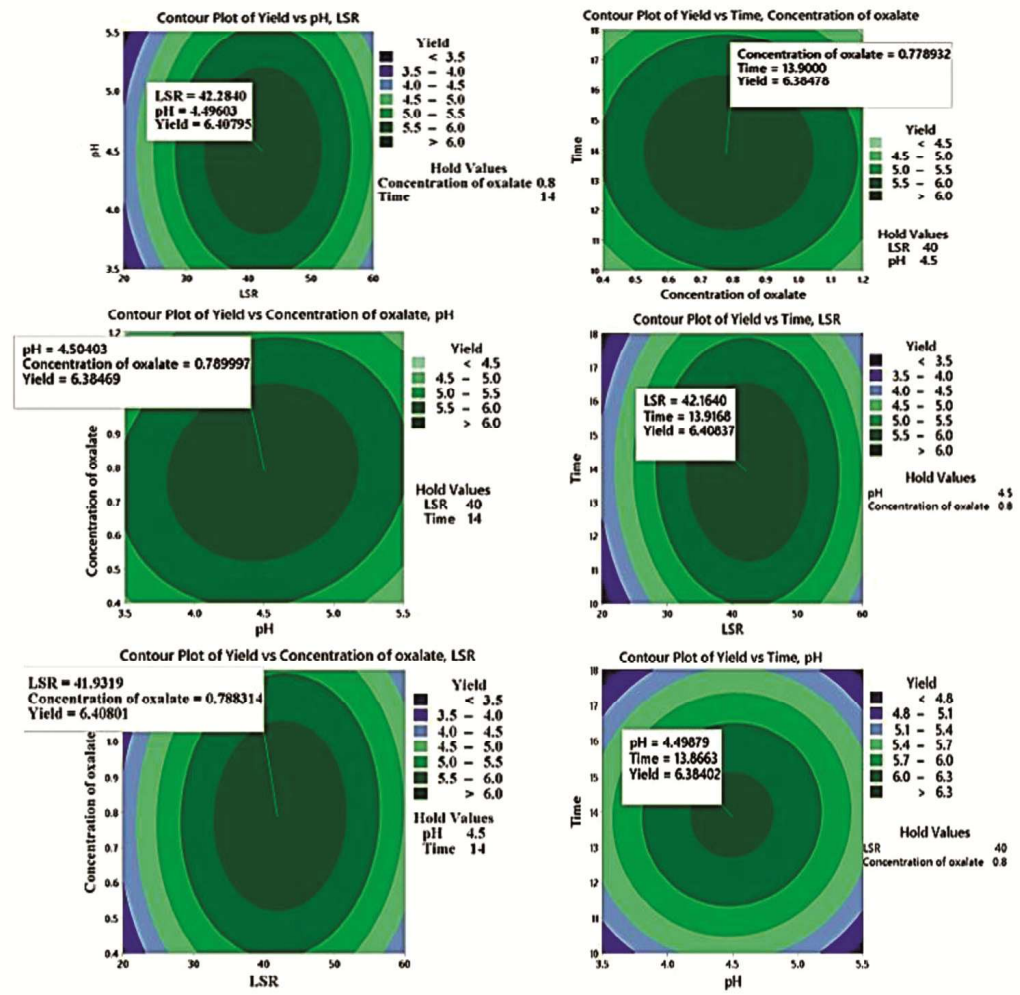

Fig. 1 — Contour plots of the yield of pectic substances from the leaves of H. pubescens as a function of liquid-to-solid ratio (LSR), pH, concentration of ammonium oxalate, and duration of heating.

gels[26]. Other workers have shown that added materials can influence the rheological properties of pectin-based matrices[27]. Earlier studies indicate that particular concentrations of components provide a suitable microenvironment for the formation of a strong network of molecules through hydrogen bonding, ionic interactions, etc.,[28]. Therefore, in this work, it may be assumed that at the concentration mentioned above, the components formed the best possible network in the composite matrix, involving different types of weak interactions, thereby increasing the apparent viscosity.

FTIR–ATR of Multicomponent Fluid Matrix

Fig. 3 compares the spectra of all components of the multicomponent fluid matrix. Many peaks of the spectra of the components disappeared, while the wave numbers of many others shifted during the formation of the multicomponent fluid matrix, indicating that the multicomponent fluid matrix is not merely a mixture of many substances, but is a product of chemical interaction among the components. The formation of the multicomponent fluid matrix is associated with interactions among the functional groups of the different components. This includes O-H stretching vibrations[29], C-H stretching vibrations[30], and aliphatic C-H stretching vibrations[31]. Table 3 shows the changes in the FTIR–ATR spectra of the components upon the formation of the multicomponent fluid matrix. It is clear from the spectral analysis that some chemical groups of the individual components interacted to form new groups in the multicomponent fluid matrix. For example, the peaks at wave numbers 3304.31 cm^{-1} of the sucrose, 3306.8 cm^{-1} of histidine, 3309.51 cm^{-1} of $CaCl_2$, and 3309.74 cm^{-1} of ascorbic acid, all of which indicate O-H stretching[32], interacted together to form

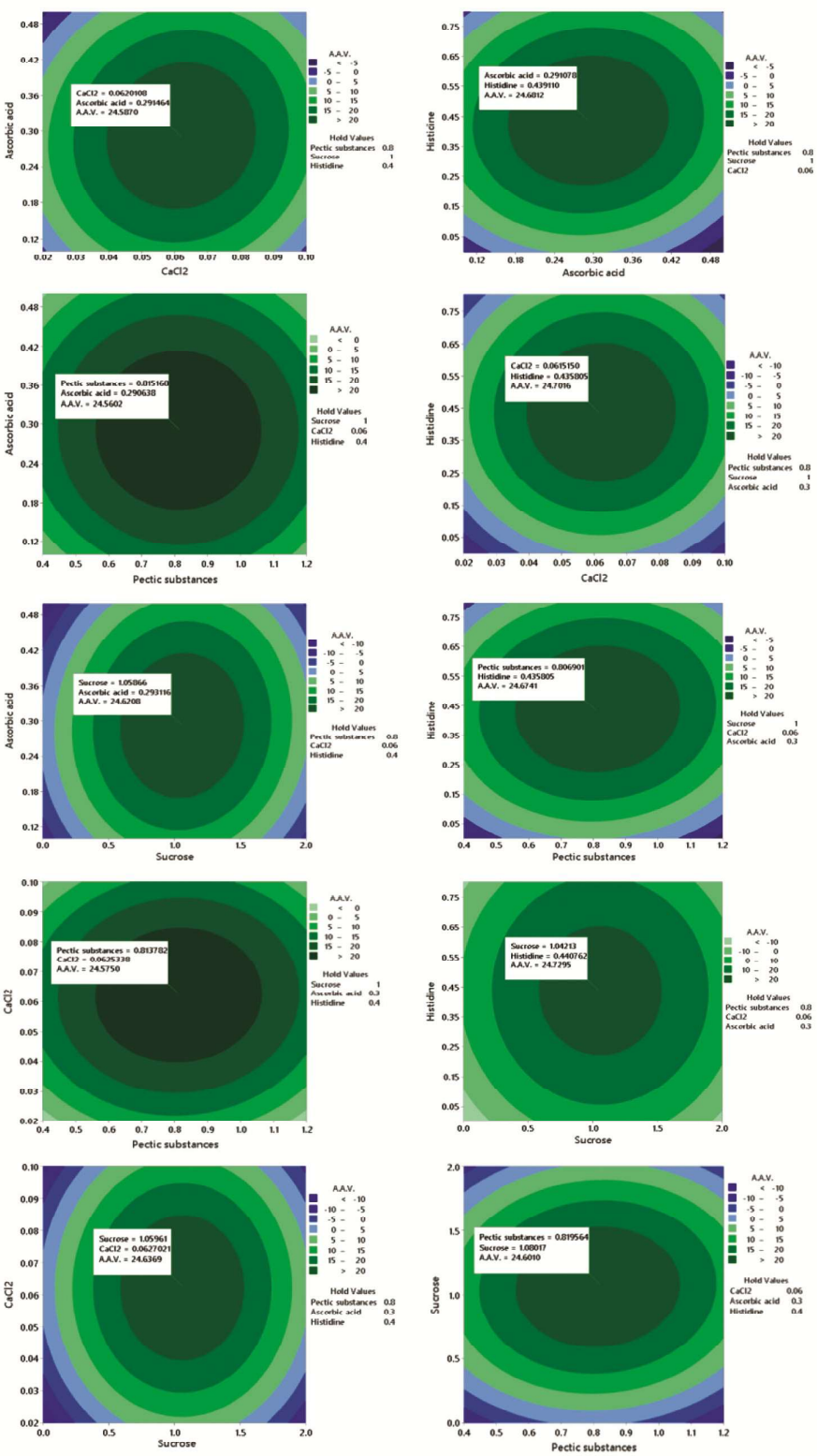

Fig. 2 — Contour plots of the average apparent viscosity of the multicomponent fluid matrix prepared with different concentrations of components. The values of components shown here are percentages by weight of the finished product. A.A.V. is measured in Pa.s.

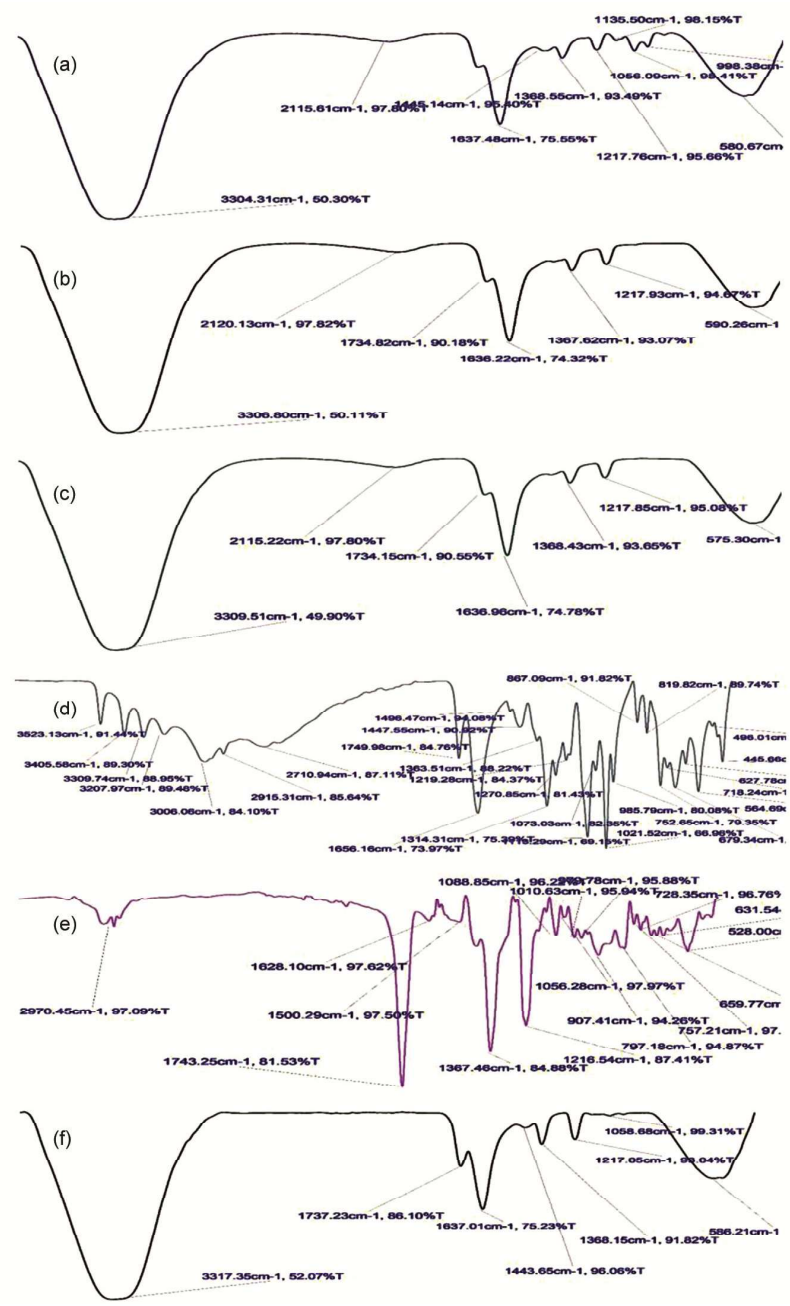

Fig. 3 — FTIR-ATR spectra (a) sucrose solution, (b) histidine solution (c) calcium chloride solution, (d) ascorbic acid powder, (e) pectic substances powder extracted from the leaves of *H. pubescens*, and (f) MCFM.

Table 3 — Changes in the wave numbers of the components upon the formation of the multicomponent fluid matrix, as is evident from their FTIR–ATR spectra

Component	Change in Wave number (cm^{-1}) during the formation of a multicomponent fluid matrix
Sucrose solution	2115.61, 1135.5, and 998.38 disappeared
	3304.31 (OH stretching vibration), 1637.48 (C=O stretching vibration),1445.14, 1368.55, 1217.76, 1056.09, and 580.67 shifted to 3317.35, 1637.01,1443.65, 1368.15, 1217.05, 1058.68, and 586.21, respectively
Histidine solution	3306.8 (OH stretching vibration), 1734.82, 1636.22 (C=O stretching vibration), 1367.62, 1217.93, and 590.26 shifted to 3317.35, 1737.23, 1637.01, 1368.15, 1217.05, and 586.21, respectively
	2120.13 disappeared

(*Contd*.)

Table 3 — Changes in the wave numbers of the components upon the formation of the multicomponent fluid matrix, as is evident from their FTIR–ATR spectra (*Contd*.)

Component	Change in Wave number (cm^{-1}) during the formation of a multicomponent fluid matrix
Calcium chloride solution	3309.51 (OH stretching vibration), 1734.15, 1636.96, 1368.43, 1217.85, and 575.3 shifted to 3317.35, 1737.23, 1637.01, 1368.15, 1217.05, and 586.21, respectively
	2115.22 disappeared
Ascorbic acid powder	3523.13 (OH stretching vibration), 3405.58 (OH stretching vibration), 3207.97, 3006.06, 2915. 31 (C-H stretching), 2710.94, 1749.98, 1656.16 (C=O stretching vibration), 1496.47, 1447.55, 1363.51, 1314.31, 1270.85, 1219.28, 1113.29, 1073.03, 1021.52, 985.79, 867.09, 819.82, 752.65, 718.24, 679.34, 627.78, 564.69, 496.01, and 445.66 disappeared
	3309.74 shifted to 3317.35(OH stretching vibration)
Pectic substances powder	2970.45 (aliphatic C-H stretching vibrational peaks), 1743.25, 1628.1(C=O stretching vibration), 1500, 1088.85, 1056.28, 1010.63, 979.78, 907.41, 797.18, 757.21, 728.35, 659.77, 631.54, and 528 disappeared
	1367.46 and 1216.54 shifted to 1368.15 and 1217.05, respectively

3317.35 cm^{-1} of the resultant multicomponent fluid matrix during H bonding. Peaks at 1637.48 cm^{-1} of sucrose, 1636.22 cm^{-1} of histidine, and 1636.96 cm^{-1} of $CaCl_2$ interacted together to form 1637.01 cm^{-1} of the multicomponent fluid matrix. These peaks probably indicate the vibrations – both stretching and bending- of the H-O-H bonds in the aqueous solutions during the transient interactions[32]. The peaks at 1368.55 cm^{-1} of sucrose, 1367.62 cm^{-1} of histidine, 1368.43 cm^{-1} of $CaCl_2$, and 1367.46 cm^{-1} of pectic substances interacted together to form 1368.15 cm^{-1} of the multicomponent fluid matrix. Similarly, the peaks at 1217.76 cm^{-1} for sucrose, 1217.93 cm^{-1} for histidine, 1217.85 cm^{-1} for $CaCl_2$, and 1216.54 cm^{-1} for pectic substances interacted to form a 1217.05 cm^{-1} multicomponent fluid matrix. Likewise, the peaks at 1734.82 cm^{-1} of histidine interacted with 1734.15 cm^{-1} of $CaCl_2$ to form 1737.23 cm^{-1} of the multicomponent fluid matrix, and 590.26 cm^{-1} of histidine interacted with 575.3 cm^{-1} of $CaCl_2$ to form 586.21 cm^{-1} of the multicomponent fluid matrix. All wavenumbers of the multicomponent fluid matrix are accounted for, and none are newly formed. Thus, different chemical groups of all components interacted together to form the functional multicomponent fluid matrix.

Average apparent viscosity of pineapple jams

The conditions used for the preparation of the pineapple fruit jams and the resultant average apparent viscosity of the jams are given in Table 2b. Both the multicomponent fluid matrix and microcrystalline cellulose contributed to the average apparent viscosity of the pineapple jams. Replacing the multicomponent fluid matrix with an equal volume of water reduced the average apparent viscosity, indicating that the former plays an important role in jam viscosity. The addition of 2.5% microcrystalline cellulose to the jams contributed to the highest average apparent viscosity, while a further increase in its concentration reduced the viscosity of the jams. It is also evident that the microcrystalline cellulose alone, in the absence of a multicomponent fluid matrix, is not effective in increasing the viscosity of the jams. Since 40 g of the jam contained only 40 mg of added sucrose, this is a low-sugar jam and is better for consumption in conditions such as diabetes mellitus, compared with high-sugar jams. Recently, other workers have experimented with different strategies to produce low-calorie fruit jams[33].

Texture profile of pineapple jams

Fig. 4 shows the effect of multicomponent fluid matrix and microcrystalline cellulose on the textural properties of the pineapple jam. Recent experiments have demonstrated that thermal treatment of pectin-based materials can result in structural changes in pectin, thereby affecting the product's textural properties[34]. Modification of the textural properties of pectin in food materials by the addition of non-pectin molecules has been investigated in the past[35]. All textural properties were affected by the presence of both multicomponent fluid matrix and microcrystalline cellulose, and the concentration of the latter. When these components were used separately, the jams had a certain hardness, which was reduced when both were used simultaneously. As is evident from the figure, any change in the concentration of the microcrystalline cellulose resulted in a change in the hardness. These findings support the earlier results that microcrystalline cellulose can affect the textural properties of food materials[36]. Thus, food materials such as jams with any degree of hardness can be prepared by changing the concentration of microcrystalline cellulose in

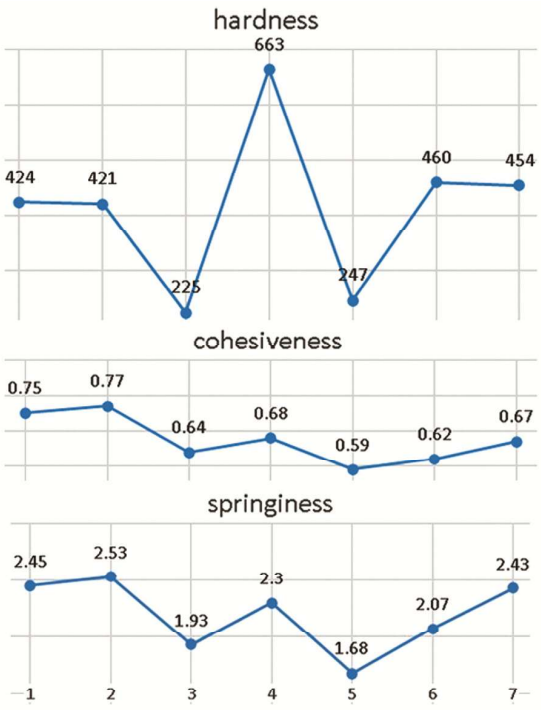

Fig. 4 — Texture profile analysis of pineapple jams. The composition of the tests 1-7 is given in Table 3b. The numbers of the tests are given on the X axis. Units - Hardness (g), cohesiveness - no units as it is a dimensionless ratio, and springiness – mm.

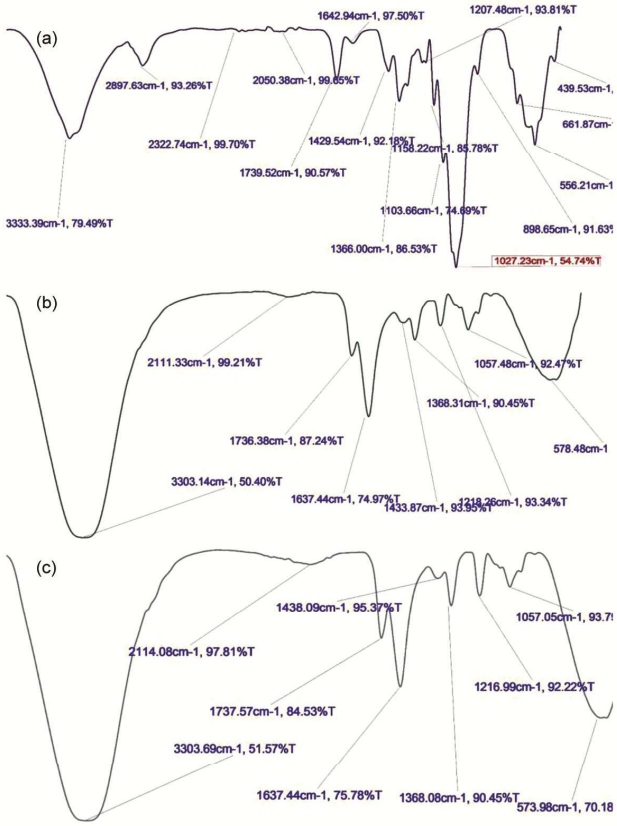

Fig. 5 — FTIR–ATR spectra of (a) microcrystalline cellulose (b) pineapple fruit, and (c) resultant pineapple jam.

them. Cohesiveness and springiness also decreased due to the mixing of microcrystalline cellulose and multicomponent fluid matrix with the fruit, to varying degrees depending upon the concentration of the microcrystalline cellulose. Therefore, the mastication energy required while chewing the product is reduced, and it is useful while designing food for particular clinical situations. All these observations indicate that the formation of the pineapple jam from the multicomponent fluid matrix, microcrystalline cellulose, and the fruit is not just a physical process of mixing but is a chemical process that involves the breaking of internal bonds and the formation of new ones.

FTIR–ATR of pineapple jams

Fig. 5 shows the FTIR–ATR of the spectra of the pineapple jam and its components. A few peaks of the components, such as microcrystalline cellulose (MCC) and multicomponent fluid matrix (MCFM), interacted with those of the pineapple fruit to form new peaks during the formation of the fruit jam. For example, the peak at 1736.38 cm^{-1} of pineapple fruit interacted with that at 1739.52 cm^{-1} of MCC to give rise to the peak at 1737.57 cm^{-1} of the jam. Also, the peaks at 1433.87 cm^{-1} for pineapple fruit, 1443.65 cm^{-1} for MCFM, and 1429.54 cm^{-1} for MCC interacted to give rise to a new peak at 1438.09 cm^{-1} in jam. Similarly, the peaks at 1218.26 cm^{-1} of pineapple fruit, 1217.05 cm^{-1} of MCFM, and 1207.48 cm^{-1} of MCC interacted to give rise to the new peak at 1216.99 cm^{-1} of jam. The peak at 578.48 cm^{-1} of MCFM interacted with the peaks at 898.65 cm^{-1}, 661.87 cm^{-1}, 556.21 cm^{-1}, and 439.53 cm^{-1} of MCC to give rise to the new peak at 573.98 cm^{-1} of jam. The peak at 3317.35 cm^{-1} (O-H stretch of GalA H bonds[37]) of MCFM interacted with the peak at 3333.39 cm^{-1} of MCC to give rise to the new peak at 3303.69 cm^{-1} of jam.

The peaks at 586.21 cm^{-1} of the MCFM, and 2897.63 cm^{-1}, 2322.74 cm^{-1}, 2050.38 cm^{-1}, 1158.22 cm^{-1} (C-O stretch of glycosidic bond[37]), 1103.66 cm^{-1}(β glycosidic bonds[38]), 1027.23 cm^{-1}(β glycosidic bonds[38]), 898.65 cm^{-1} (stretching vibration of β 1, 4 - glycosidic bonds[39]), 661.87 cm^{-1}, 556.21 cm^{-1}, and 439.53 cm^{-1} of the MCC disappeared altogether during the formation of the fruit jam. The peaks at

Table 4 — The wave numbers in the FTIR–ATR spectra of pineapple fruit, multicomponent fluid matrix, and microcrystalline cellulose, which shifted to new values during the formation of the fruit jam

Component	Wave number (cm^{-1}) shifted	
	from	to
Pineapple fruit	2111.33	2114.08
	1736.38	1737.57
	1433.87	1438.09
	1218.26	1216.99
	578.48	573.98
MCFM	3317.35	3303.69
	1443.65 (methyl ester CH_3 bending)	1438.09
	1217.05	1216.99
	1058.68 (glycosidic bond C-O stretching)	1057.05
MCC	3333.39 (O-H stretching)	3303.69
	1739.52	1737.57
	1642.94	1637.44
	1429.54	1438.09
	1366	1368.08
	1207.48	1216.99

571.98 cm^{-1} and 573.98 cm^{-1} were newly formed in the fruit jam. Table 4 shows that a few peaks of the components shifted to new values during the formation of the fruit jam[40].

Thus, it is evident that different chemical groups of all components interact with each other during the formation of the fruit jam.

Conclusion

All components used were found to interact chemically to form the final product. Even though the pectic substances by themselves had less apparent viscosity, this property could be increased noticeably by transforming them into a multicomponent fluid matrix using sucrose, histidine, calcium chloride, and ascorbic acid. The last three components are vital nutrients essential for the normal functioning of the body. All components used in the development of this product are food-grade molecules and do not pose any harm to the body. The microcrystalline cellulose acted as a filler and did not contribute to the glycemic index of the product. It could also influence the textural properties and apparent viscosity of the final product, indicating that it played a critical role in the formation of the jam. Thus, leaf-based pectic substances, having less natural gelling capabilities, can be used effectively to prepare food gels when combined with appropriate concentrations of selected molecules that provide a multitude of reactive chemical groups. In the future, studies may be conducted to identify similar non-traditional sources of pectic substances and to develop functional matrices by combining them with other non-pectin molecules for different applications.

Declaration of interest

The author declares the following competing financial interest(s): A patent application has been filed in the Office of the Controller of Patents, Designs & Trademarks, Government of India, with application number 202441039641, dated 21/05/2024.

Acknowledgments

The following laboratories have contributed to this research work: Central Instrumentation Facility, Punjab University, India - Rheological analyses; CAI−K, KFRI, Peechi, India - UV−Visible spectroscopy; Materials Research Centre, Malavya NIT, Jaipur, India - FTIR–ATR; Instrumentation Centre, Prin. Kundnani College of Pharmacy, Mumbai, India – Texture Profile Analysis.

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