Back-Extrusion Characterization of Fresh *Kesar* Mango Pulp for Thermal Processing and Equipment Design

Abstract

The present study evaluated the rheo-textural characteristics of fresh *Kesar* mango pulp using back-extrusion test to establish baseline structural data for process and equipment design applications. Texture measurements were performed using a TA-XT Plus texture analyser equipped with back-extrusion rig probe under controlled compression-withdrawal conditions. The back-extrusion parameters obtained were firmness, consistency, cohesiveness and work of cohesion. Fresh *Kesar* mango pulp showed firmness of 775.59 ± 5.93 g, consistency of 784.95 ± 231.23 g·s, cohesiveness of −359.80 ± 23.67 g and work of cohesion of −173.48 ± 11.09 g·s. The results indicated that the pulp had moderate firmness, appreciable internal structural bonding and balanced adhesive and flow related characteristics due to the combined effects of pectin network, soluble solids and suspended fibrous particles. These findings provide useful baseline rheo-textural information for optimization of agitation, pumping and thermal processing operations involving mango pulp, particularly in agitation-assisted ohmic heating and related unit operations.

Keywords: *Kesar* mango pulp, Back-extrusion test, Texture analyser, Thermal processing operations

Introduction

Mango (*Mangifera indica* L.) is one of the most widely consumed tropical fruits and is extensively used for the preparation of pulp, puree, beverages, concentrates and other processed products due to its characteristic flavour, attractive colour and nutritional value (Ribeiro *et al.,* 2024; Sharma *et al.,* 2026). Among the Indian mango cultivars, *Kesar* is highly preferred for processing because of its rich aroma, bright saffron-coloured pulp and good pulp recovery (Yadav *et al.,* 2025).

Texture and firmness are also considered important quality characteristics in mango-based products because they influence processing behaviour, handling properties and overall product acceptability. In semi-solid fruit systems, the resistance offered by the pulp during deformation depends on the interaction among suspended particles, pectic substances and soluble solids present within the pulp matrix. These structural properties become highly important during pumping, mixing and thermal processing operations where the pulp is continuously subjected to mechanical stress (Jha *et al.,* 2010).

The flow behaviour of mango pulp is an important consideration during industrial processing, as it directly affects pumping, agitation, heat transfer and product handling operations (Manohar *et al.,* 1990; Hoshino, 2020). Since mango pulp behaves as a semi-solid and non-Newtonian material, its movement inside processing equipment depends largely on its resistance to deformation and flow under applied mechanical force. These characteristics are mainly influenced by the presence of suspended fibrous particles, soluble solids, pectic substances and other colloidal components in the pulp matrix (Chandel *et al.,* 2022; Sharma *et al.,* 2026). Variations in these components may alter the consistency, cohesiveness and resistance to flow of mango pulp during thermal and ohmic heating operations (Makroo *et al.,* 2019).

The structural behaviour of fruit pulp during processing is closely related to its firmness, consistency and internal bonding characteristics. Variations in these properties may affect the circulation pattern of pulp inside processing equipment and can influence heat transfer efficiency during thermal operations. Therefore, understanding the mechanical response of mango pulp under compression and flow conditions is useful for improving process design and operational control (Jarimopas & Kitthawee, 2007).

Knowledge of the structural and flow-related properties of mango pulp is therefore essential for designing thermal processing unit such as agitation-assisted ohmic heating systems in which controlled laminar movement and uniform mixing of pulp are required. Such information helps in selecting suitable agitator speed, vessel geometry and operational conditions for efficient pulp handling while minimizing flow stagnation and uneven heating during processing (Hoshino, 2020; Lee *et al.,* 2025). Changes in the structural behaviour of mango pulp may further influence heat transfer pattern, heating uniformity and energy utilization efficiency during thermal processing operations involving semi-solid food systems (Makroo *et al.,* 2019).

Back-extrusion test is widely used for evaluating the texture and flow-related behaviour of semi-solid food materials because it can effectively characterize heterogeneous and particulate-containing samples such as fruit pulp (Bourne, 2002; Hoshino, 2020). The force-time curve generated during back-extrusion provides useful parameters including firmness, consistency, cohesiveness and work of cohesion, which describe the resistance of the pulp to deformation, flow, internal structural bonding and adhesive behaviour, respectively (Bourne, 2002; Hoshino, 2020). Such parameters are useful for better interpreting the mechanical behaviour of pulp during agitation and bulk movement inside processing systems (Sahin & Sumnu, 2006; Lee *et al.,* 2025).

Back-extrusion analysis has also been successfully applied for characterizing highly viscous and semi-solid food products because the method provides rapid and reproducible information regarding flow resistance, consistency and structural stability under confined deformation conditions. The technique is particularly suitable for particulate-containing systems in which conventional flow measurements may become difficult (Nasaruddin *et al.,* 2012; Chen *et al.,* 2021).

During back-extrusion testing, the sample experiences simultaneous compression, shear and upward flow around the probe surface. Because of this combined deformation behaviour, the technique is considered suitable for evaluating semi-solid food materials containing fibrous and particulate matter. The generated force-time curve provides useful information regarding structural resistance, adhesive nature and flow-related behaviour of fruit pulp systems under confined deformation conditions (Jarimopas & Kitthawee, 2007).

Although several studies have reported rheological and firmness properties of mango and other fruit pulps, detailed back-extrusion characterization of fresh *Kesar* mango pulp is still limited. Information related to firmness, consistency, cohesiveness and adhesive behaviour is particularly important for understanding pulp movement and structural stability during processing operations. Therefore, the present study was carried out to evaluate the back-extrusion texture properties of fresh *Kesar* mango pulp in order to establish baseline structural information useful for future thermal processing and equipment design applications.

Material and Methods

Texture Analysis of Fresh *Kesar* Mango Pulp

The texture properties of fresh *Kesar* mango pulp were measured using a texture analyzer (TA-XT plus model, Microsystems, US). The back-extrusion rig with 35 mm disc probe (A/BE-d35) was used for analysed the sample. Fresh pulp was obtained from ripe *Kesar* mangoes as method suggested by Yadav *et al.,* (2025). The sample was filled into the back-extrusion rig carefully to avoid air incorporation.

During testing, the disc probe moved downward into the pulp sample and forced the material to flow upward through the narrow gap between the probe and container wall. This created a combined compression and extrusion effect which simulated the type of mechanical deformation generally experienced by semi-solid food materials during industrial handling and agitation processes. The confined annular flow generated between the probe and container wall allowed the pulp to undergo controlled deformation during testing, which helped in obtaining reproducible force-time responses for evaluating texture-related parameters (Chen *et al.,* 2021).

The test was conducted in compression mode at a pre-test speed of 1.0 mm/s, test speed of 2.0 mm/s and post-test speed of 10.0 mm/s. The trigger force was maintained at 5 g under auto-force detection and data were collected at 500 peaks per second. The texture parameter was obtained directly by Exponent Connect software associated with texture analyser. All measurements were carried out in triplicate and reported as mean ± standard deviation.

The force-time curve generated during the test consisted of a positive compression region and a negative withdrawal region. The positive region represented the resistance offered by the pulp against probe movement, whereas the negative region reflected the adhesive and cohesive behaviour of the sample during probe withdrawal.

Firmness (g): Maximum positive force recorded during compression, representing the resistance of pulp to probe penetration.

Consistency (g·s): Positive area under the force–time curve during compression, indicating resistance to flow.

Cohesiveness (g): Maximum negative force during probe withdrawal, representing internal structural bonding of the pulp matrix.

Work of Cohesion (g·s): Negative area under the withdrawal curve, indicating adhesive energy required to separate the probe from the sample.

Results and Discussion

The back-extrusion texture parameters of fresh *Kesar* mango pulp are presented in Table 1. The back-extrusion test provided detailed information related to the resistance, adhesive nature, internal bonding and flow characteristics of mango pulp, which collectively reflected the overall structure of fresh *Kesar* mango pulp.

The obtained texture profile indicated that fresh *Kesar* mango pulp behaved as a structured semi-solid system with noticeable resistance against deformation and flow (Jarimopas & Kitthawee, 2007). The observed behaviour might be possible due to the combined effect of pectin substances, suspended fibrous particles, soluble sugars and colloidal interactions within the pulp matrix (Schouten *et al.,* 2018). Similar structural characteristics have been reported in fruit-based semi-solid food systems where the internal network contributes significantly toward texture and flow behaviour (Bourne, 2002; Hoshino, 2020).

Table 1. Back-extrusion texture parameters of fresh *Kesar* mango pulp

Parameter	Unit	R1	R2	R3	Mean	SD
Firmness	g	781.41	769.55	775.82	775.59	5.93
Consistency	g·s	1016.17	553.72	784.95	784.95	231.23
Cohesiveness	g	-383.66	-336.34	-359.40	-359.80	23.67
Work of Cohesion	g·s	-162.23	-184.37	-173.85	-173.48	11.09

The firmness of fresh *Kesar* mango pulp was recorded as 775.59 ± 5.93 g. It indicates the maximum force required for probe penetration during compression. This parameter reflects the resistance of the pulp matrix to deformation and is governed by the structural integrity of suspended insoluble solids, cell wall fragments and pectic substances dispersed throughout the pulp. The observed moderate firmness suggests that fresh *Kesar* mango pulp possessed a sufficiently structured semi-solid matrix with appreciable resistance to compressive deformation. Similar findings have shown that firmness in fruit-based semi-solid systems is strongly associated with the integrity of suspended particulates and hydrocolloidal interactions within the matrix (Bourne, 2002; Hoshino, 2020).

The firmness behaviour may also be associated with the maturity stage of mango used for pulp preparation (Jarimopas & Kitthawee, 2007). During ripening, enzymatic degradation of cell wall materials and gradual solubilization of pectin substances reduce tissue rigidity and contribute toward softening of fruit pulp (Schouten *et al.,* 2018). However, the presence of sufficient suspended solids and partially intact structural components may still provide appreciable resistance against compression in fresh mango pulp (Jarimopas & Kitthawee, 2007).

The consistency of the pulp was found to be 784.95 ± 231.23 g·s. It represents the positive area under the force–time curve during compression and indicating resistance to flow under applied stress. Higher consistency values are generally associated with greater viscosity and stronger flow resistance in semi-solid systems. The relatively high consistency observed in the present study confirms the viscous and non-Newtonian behaviour of mango pulp. It may be possible due to the presence of soluble solids, pectin and fibrous suspended particles. Similar relationships between consistency and soluble hydrocolloidal content have been reported in fruit puree systems (Manohar et al. 1990). Similar observations have been reported for mango puree systems in which increase in soluble solids and pectic interactions contributed toward higher consistency and stronger resistance to flow behaviour during processing operations (Makroo *et al.,* 2019).

From a processing point of view, higher consistency generally indicates greater resistance to flow and may influence pumping energy requirement and mixing behaviour during industrial operations. At the same time, moderate consistency can help maintain better suspension stability of pulp particles during storage and thermal processing (Chandel *et al.,* 2022).

Back-extrusion consistency measurements are often considered useful indicators of flowability and bulk movement behaviour in semi-solid food systems. The resistance generated during confined flow may therefore provide indirect information regarding the handling behaviour of mango pulp during pumping and agitation operations (Chen *et al.,* 2021).

The cohesiveness of the pulp was measured as −359.80 ± 23.67 g. The magnitude of cohesiveness indicates the degree of attraction among suspended solids, colloidal particles and hydrocolloidal components. The appreciable cohesiveness observed suggests strong internal structural interactions within the mango pulp. It likely possible due to the natural pectin network and dispersed fibrous matter. Such cohesive behaviour has also been reported in pectin-rich fruit-based semi-solid systems (Chandel *et al.,* 2022). The cohesiveness of mango pulp is generally associated with the interaction among soluble sugars, pectic substances and suspended solids, which collectively contribute toward structural stability and viscoelastic behaviour of the pulp system during processing (Makroo *et al.,* 2019).

The cohesive nature of the pulp may help to maintain uniform distribution of suspended particles during agitation and thermal treatment. Strong internal bonding within the pulp structure may also reduce phase separation during handling and storage operations (Chandel *et al.,* 2022).

The work of cohesion was recorded as −173.48 ± 11.09 g·s. It represents the adhesive energy required to separate the probe from the pulp during withdrawal. This parameter reflects the stickiness and adhesive nature of the pulp and is influenced by soluble sugars, hydrated pectin molecules and serum phase viscosity. The observed value indicates moderate adhesive behaviour of fresh *Kesar* mango pulp. It suggested sufficient tackiness without excessive stickiness. Such balanced adhesive behaviour is desirable in semi-solid food products because it contributes toward better handling properties while avoiding excessive surface sticking during processing (Nasaruddin *et al.,* 2012). Similar adhesive responses in fruit-based colloidal systems have been linked to sugar-pectin interactions and hydration properties (Hoshino, 2020).

The moderate adhesive behaviour observed in the present study may be beneficial during industrial processing because excessively sticky pulp can create operational problems such as wall deposition, sticking and difficulty during product discharge (Bourne, 2002; Hoshino, 2020). Therefore, balanced adhesive properties are important for smooth handling and processing of fruit pulp systems.

Conclusion

The back-extrusion texture profile showed that fresh *Kesar* mango pulp possesses a moderately firm, cohesive and structurally stable semi-solid pulp with balanced adhesive and flow properties. These textural characteristics are primarily governed by the natural pectin network, soluble solids, suspended fibrous particles and colloidal interactions within the pulp. The obtained texture parameters provide baseline structural information for future comparison during thermal processing, concentration, drying, enzymatic treatment, or storage studies. The generated rheo-textural information may also be useful for understanding the flow, heating and handling behaviour of mango pulp during advanced thermal processing techniques such as ohmic heating and related semi-solid food processing operations.

Conflict of Interest

The authors declare no competing interests for this article.

Data Availability Statement

The data supporting the findings of this study are available from corresponding author upon reasonable request.

Clinical Trial Registration

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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