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Evaluation of textural and mechanical properties of tamarind

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Abstract

This study investigated the textural and mechanical properties of tamarind (*Tamarindus indica*), including all parts such as shell, pods and pulp. The tamarind underwent various tests, including the compression test, cutting test, and textural profile analysis (TPA). Textural attributes including hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience were analyzed which provides a detailed understanding of the sensory characteristics of tamarind. Standardized testing methods were used to assess the mechanical properties and illustrate significant insights into the structural integrity of tamarind. The findings indicated the variability in texture and mechanical behaviour between different parts of tamarind. This data is valuable because of its application in designing food processing machinery and product development. The highest peak force required to break the shell was 2383.809 N and the force required to cut through the pulp was 14765.195 g indicating significant resistance to deformation. The mechanical properties of the shell of tamarind help in designing suitable packaging that protects the tamarind during transportation and handling, preventing damage and spoilage. The tamarind pod demonstrated a tough texture due to the presence of seed inside the pulp and moderate adhesiveness, good springiness, and cohesiveness, contributing to chewiness and resilience. The pulp exhibited firmness, moderate adhesiveness, elasticity, and chewiness, ensuring solid texture and mouthfeel quality.

Key words: Textural analysis, compression test, cutting test, tamarind, texture profile analysis

Introduction

Tamarind (*Tamarindus indica* L.) is a tropical fruit tree which is native to Africa and widely grown and cultivated in Asia (Caluwe *et al.*, 2009). The pulp of the fruit had a sweet-acidic taste due to the presence of high tartaric acid content and is widely used in various food items including seasoning, confectionaries, and beverages (Caluwe *et al.*, 2009). India produces about 300,000 tonnes of tamarind and also exports its various products annually, which shows the economic importance of tamarind (Shankaracharya, 1998; Yahia & Salih, 2011). Textural and mechanical properties of fruits and vegetables are important in determining the quality, usability and designing processing equipment (Blahovec, 2001; Abbott, 2004; Mahiuddin *et al.*, 2020). It encompasses various mechanical properties like firmness and crispness, which are primarily determined by the fruit's structural elements (Abbott, 2004; Bourne, 1979). These textural attributes are closely linked to the cellular structure, intercellular spaces, and cell wall composition of fruit (Vanoli *et al.*, 2015; Reeve, 1970). Fruit texture measurement techniques evolved from manual assessments to sophisticated instrumental methods which include puncture tests, compression tests and non-destructive optical approaches (Abbott, 2004; Vanoli *et al.*, 2015).

Measuring the textural properties of tamarind is crucial for designing processing equipment, storage material and methods, and transportation (Sinha *et al.*, 2015). Rheological properties include viscoelastic characteristics which are important for predicting the stability of products and designing food products (Tirado *et al.*, 2014). The elastic modulus is a measure of material hardness, which can increase in pulps with increased sugar content (Tirado *et al.*, 2014). These properties is vital for developing post-harvest machinery and processing technologies (Bidyalakshmi *et al.*, 2023). Tamarind processing involves various unit operations which include drying, dehulling, deseeding, and pressing, which can be performed using traditional or mechanical methods (Bidyalakshmi *et al.*, 2023). Mechanical failure that occurs in fruits and vegetables can be classified as cleavage, slip or bruising which depends on the applied stress and the strength of the material holding the fruit and vegetable (Holt & Schoorl, 1982). Understanding mechanical properties is essential for reducing damage during handling and processing it also helps in evaluating textural characteristics (Holt & Schoorl, 1982; Abbott, 2004). Proper assessment of the textural properties of tamarind enables the development of value-added products, such as pulp powder, juice concentrate, and candies, potentially increasing its commercial value and shelf life (Bidyalakshmi *et al.*, 2023).

Materials and method

The textural and mechanical properties of unshelled tamarind, shelled tamarind, and tamarind seeds were investigated completely in this study. The tamarind samples required for the experiments were procured from the Department of Horticulture at Dr Panjabrao Deshmukh Krishi Vidyapeeth, located in Akola, Maharashtra, India. Different test were conducted to evaluate the textural and mechanical properties of tamarind such as the compression test, the cutting test, and the texture profile analysis (TPA) test. The compression test was utilized to measure the force required to compress the tamarind samples which provided insights about their firmness and resistance to deformation. The cutting test determines the force required to cut through the tamarind samples, which indicates their toughness and structural integrity. The TPA test is a widely used method in food texture analysis which was performed to obtain a detailed profile analysis of the textural characteristics which include parameters such as hardness, cohesiveness, springiness, and chewiness. These tests were essential in understanding the mechanical behaviour and textural attributes of tamarind.

Compression Test- The compression test of tamarind was conducted using the Stable Micro Systems, U.K, Model TA-XT2. This sophisticated texture analyzer is widely recognized for its precision and reliability in evaluating the mechanical properties of food products (Letaief *et al.,* 2008). The test involved placing tamarind with a shell under compression to measure their resistance to deformation and the force required to break the shell of tamarind. Five unshelled tamarind samples were randomly selected for this purpose.

The primary objective of the compression test was to determine the firmness and textural integrity of the unshelled tamarind. A controlled compressive force was applied to the tamarind and then the force required to compress each sample was recorded by Model TA-XT2 texture analyzer exponent connect software (Hong *et al.*, 2018; Lupu *et al.*, 2024).

Table 1. Specification for compression test in texture analyser

S.N.	Parameters	Unshelled tamarind
1.	Probe type	P/75
2.	Load cell	250 kg
3.	Pre-test speed	5 mm/sec
4.	Test speed	2 mm/sec
5.	Post-test speed	5 mm/sec
6.	Distance	8 mm
7.	Trigger force	5g

Cutting test: The Stable Micro Systems, UK, Model TA-XT2 texture analyzer was used to determine the cutting force of tamarind. This advanced equipment measured the total force required to cut through tamarind samples which provides insights of its toughness and structural integrity. A total of five shelled tamarind samples were randomly selected for testing. Each sample was subjected to the cutting test one by one and the analyzer recorded the peak force exerted on the blade to cut through the tamarind. This data was then analyzed to calculate the average effective cutting force which represents the cutting force required to cut the tamarind pod and pulp. The analyzer precisely recorded the peak force exerted as the blade penetrated and cut through the tamarind and also recorded the resistance encountered during the cutting process (Yadav & Mate 2023).

Table 2. Specification for cutting test of shelled tamarind/tamarind pulp in texture analyzer

S.N.	Parameters	Pod / Pulp
1.	Probe type	Warner Bratzler (rectangular)
2.	Load cell	50kg
3.	Pre-test speed	1mm/sec
4.	Test speed	5mm/sec
5.	Post-test speed	10mm/sec
6.	Distance	10mm

Texture Profile Analysis (TPA) test: The TPA test is a widely used method for evaluating fruit texture (Nadulski and Grochowicz, 2001). This test measures parameters such as hardness, cohesiveness, and elasticity (Nadulski and Grochowicz, 2001; Madieta *et al.*, 2011). However, due to experimental conditions, TPA results can significantly influence. Sample size and degree of deformation significantly affect hardness and elasticity measurements (Nadulski and Grochowicz, 2001), The degree of deformation and the speed at which the crosshead moves play significant roles in influencing the cohesiveness and gumminess of a material (Madieta *et al.*, 2011). The TPA test performed by using texture analyzers provides both sensitive and objective results for assessing fruit and vegetable texture (Hong-bo, 2010). The Texture Profile Analysis test process involves exposing samples of shelled tamarind (tamarind pod) and 10g of compressed tamarind pulp to a double compression cycle. This test is designed to mimic the physical action of biting and chewing in the mouth. The test provides a detailed profile of the food's texture by measuring several key parameters:

Hardness: The peak force at P1 during the compression cycle, indicating the sample's firmness.

Springiness: The extent to which the sample returns to its original shape after the first compression indicated by d2.

Cohesiveness: The ratio of the work done during the second compression to the work done during the first compression, indicating the internal bonding of the sample measured by A2/A1.

Adhesiveness: The negative force area for the first bite, reflects how much force is required to overcome the attractive forces between the food and the probe measured by A3.

Gumminess: It was calculated as hardness multiplied by cohesiveness, it describes the energy required to disintegrate a semi-solid food to a state ready for swallowing.

Chewiness: Calculated as gumminess multiplied by springiness, it represents the energy required to chew a solid food to a state ready for swallowing (Trịnh and Glasgow 2012; Bourne, 1979).

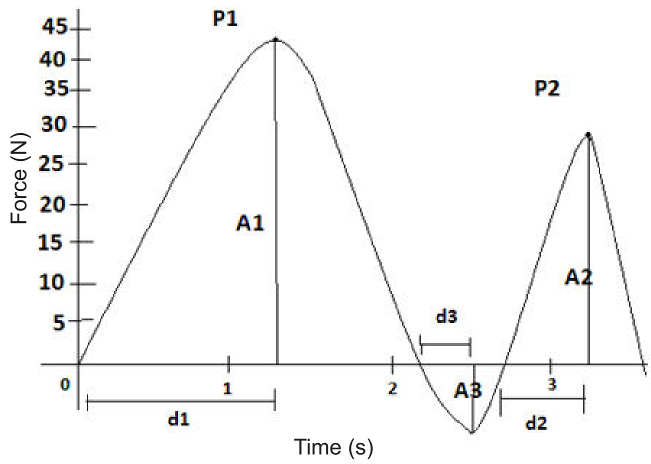

Fig. 1. TPA Curve made by texture analyzer and their specification

During the TPA test, a probe comes downward to make contact with the sample. Once a minimum trigger force was achieved the probe descended further for a preset distance at a specified speed which then starts compressing the sample. The probe then moves back to its original position and descends again for the second compression which resembles the double-bite action (Jauharah *et al.,* 2017). Texture Profile Analysis of tamarind helps in product design by measuring and optimizing texture attributes like hardness and chewiness. TPA test is crucial for enhancing product quality and meeting consumer expectations effectively. It also helps in understanding the behaviour of tamarind during its processing in machinery.

Table 3. Specification for texture profile analysis (TPA) test in texture analyzer

S.N.	Parameters	Pod	Pulp
1.	Probe type	P/75	P/75
2.	Load cell	250 kg	250 kg
3.	Pre-test speed	0.50 mm/sec	0.50 mm/sec
4.	Test speed	0.50 mm/sec	0.50 mm/sec
5.	Post-test speed	1 mm/sec	1 mm/sec
6.	Distance	2.5 mm	3.5 mm
7.	Time	5.00 sec	5.00 sec
8.	Trigger force	5.00 g	10.00 g

Result and discussion

The textural and mechanical properties of tamarind were expressed in terms of the maximum force required to rupture the shell and to deform the shape of unshelled tamarind. The mean value of the test results for each tamarind was taken as the final results, and the corresponding parameters of force and deformation were plotted as the force-deformation curves using exponent connect software.

Compression test: The compression test of unshelled tamarind was conducted using the Texture analyzer (Stable Micro Systems, UK, Model TA-XT2) which gives the maximum peak force which is required to break the shell of the tamarind. Fig. 2 showing graph of compression test obtained by exponent connect software of stable micro system texture analyzer. Five unshelled tamarind samples were randomly selected for compression test. During the compression test on tamarind, several key forces were measured to determine its mechanical properties. The maximum Peak Positive Force among all sample recorded was 2383.809 N indicating the maximum force required for compressing the tamarind. At a deformation of 5 mm, the force recorded was 113.641 N demonstrating the initial resistance to compression. As the compression continued, the force measured to a specific target point was 2372.611 N which is very close to the maximum force observed. These results suggest that the seeds present in tamarind exhibits a significant increase in resistance to deformation as the compression progresses it is reflecting tamarinds strong structural integrity under compressive forces. The force recorded at deformation of 5mm is the minimum force required to break the shell of the tamarind. Knowing the force needed to break the shell helps in designing dehullers for de-shelling tamarinds and also helps in designing appropriate packaging that can protect the tamarind during transportation and handling which prevents damage and spoilage. Processing machineries can be optimized by applying the precise amount of force required for particular operation.

Table 4. Results of compression test

S.N.	Peak Positive Force	Force at 5 mm	Force at target point
Sample 1	2263.544 N	111.878 N	2199.367 N
Sample 2	2175.465 N	99.221 N	2123.479 N
Sample 3	1989.876 N	107.954 N	2032.126 N
Sample 4	2383.809 N	113.641 N	2372.611 N
Sample 5	2098.418 N	102.567 N	2176.543 N
Average	2182.2224 N	107.0522 N	2180.825 N
SD	151.092966 N	6.102429 N	125.044 N
CV	22829.0844 N	37.23964 N	15635.99 N

Cutting test: The cutting test for tamarind pulp using a Texture Analyzer helps to determine the maximum amount of force required to cut the tamarind pulp and pod. Fig. 3 shows a graph of cutting tests obtained by exponent connect software of stable micro system texture analyzer. The test was conducted by using a Warner Bratzler rectangular probe and a 50 kg load cell, with pre-test, test, and post-test speeds of 1 mm/sec, 5 mm/sec, and 10 mm/sec, respectively, over a distance of 10 mm. The results obtained that the maximum Peak Positive Force was 14765.195 g which indicated the maximum force required to cut through the tamarind pulp. At a depth of 5 mm, the force measured was 14466.253 g, showing significant resistance even at a shallow depth. The Force recorded at Target was 5966.765 g which was lower than the peak force. The relatively low force at the target distance of 10 mm suggests that tamarind pulp cuts or separates before fully compressing. The observed separation distance was 6.139 mm which is the distance traveled by the probe before the sample separated. These findings suggest that the tamarind pulp in the pod has a tough texture which required substantial force to cut through initially because tamarind pulp was tightly covered over tamarind seed with the help of tamarind thread but later it becomes easier to slice as the cut deepens. Understanding the cutting force required to cut the tamarind pulp helps to design machinery for tamarind deseeding and also helps in developing the tamarind product of desired texture.

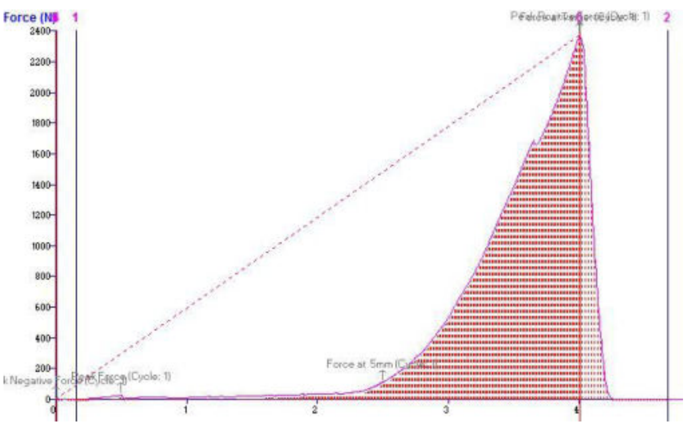

Fig. 2. Force-time graph for compression test from exponent connect software

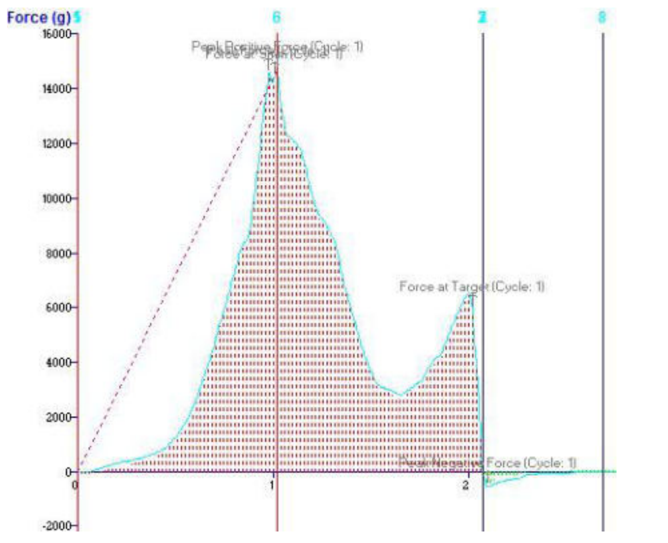

Fig. 3. Force-Time graph for cutting test from exponent connect software

Table 5. Showing results of cutting test for tamarind pulp

S.N.	Peak Positive Force (g)	Force at 5 mm (g)	Force at target point (g)	Separation distance (mm)
Sample 1	13999.877	13792.329	4576.845	7.678
Sample 2	14765.195	14466.253	5966.765	6.139
Sample 3	14257.983	14175.732	5734.193	6.023
Sample 4	13587.374	13287.983	5654.543	7.022
Sample 5	14563.231	14128.723	4327.956	5.981
Average	14234.732	13970.204	5252.0604	6.568
SD	464.777	450.138	744.165	0.752
CV	216018.111	202624.912	553782.882	0.565

Texture Profile Analysis (TPA) test: The texture analysis of the tamarind pod and pulp using a texture analyzer helped to determine its mechanical properties. Fig. 4 and 5 show a graph of TPA test of pod and pulp obtained by exponent connect software of stable micro system texture analyzer. The mean peak force required for compression of pod was recorded as 2549.297 g which indicates the pod's maximum resistance to deformation and reflecting its hardness was 2813.299 g. The pod demonstrated no fracturing under compression which indicates excellent structural integrity due to the presence of seed. Adhesiveness was -66.369 g-sec indicating its stickiness and ability to adhere to surfaces. Springiness was recorded at 0.814 mm showing the pod's elasticity and capacity to regain its original shape post-deformation. Cohesiveness was 0.653 indicating its internal bonding strength and structural integrity during chewing. Gumminess was 1837.136 g showcasing its chewy and resilient nature. Chewiness was 1495.770 g-sec, which quantifies that more energy is required to masticate the pod into a state that is ready to swallow. And resilience was 0.235 indicating the ability of the tamarind pod to recover its shape after the compressive force was removed. These findings suggest that tamarind pod contains seeds and fibrous threads which provide it extra support and strong structure, keeping the pod intact and making it more resilient. Results conclude moderate adhesiveness, good springiness, and a cohesive structure which collectively enhance the chewiness and resilience of the pod.

Table 6. Showing results of TPA test for pod and pulp

Parameter	Pod	Pulp
Peak Force	2549.297 g	6475.227 g
Hardness	2813.299 g	7559.207 g
Adhesiveness	-66.369 g-sec	-1666.119 g-sec
Springiness	0.814	0.697
Cohesiveness	0.653	0.535
Chewiness	1495.770 g-sec	2820.351 g-sec
Gumminess	1837.136 g	4044.331 g
Resilience	0.235	0.119
Force at Target	27.502 N	74.130 N

The mean peak force recorded to compress the pulp was 6475.227 g indicating its overall firmness and resistance to deformation. The hardness value recorded was 7559.207 g. The absence of fracturability (0 g) implies that the pulp does not exhibit any distinct breaking points under compression indicating a smooth and continuous texture. The adhesiveness value of -1666.119 g-sec suggests that the tamarind pulp has a moderate to high tendency to stick to surfaces, such as the palate or teeth, during consumption. This property may influence the perceived mouth feel and swallowing. The springiness value of 0.697 mm suggests that the tamarind pulp has a moderate ability to regain its original

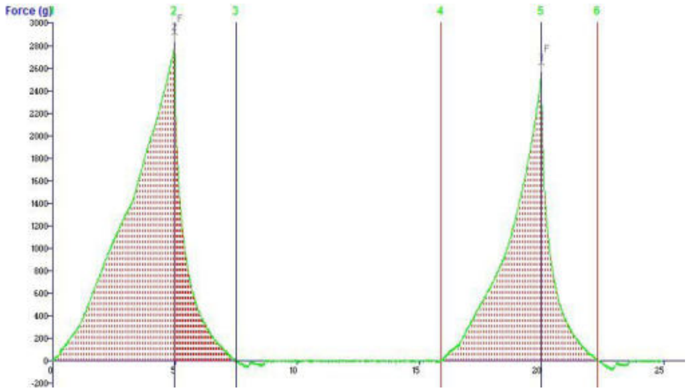

Fig. 4. Force-Time graph for TPA test of pod

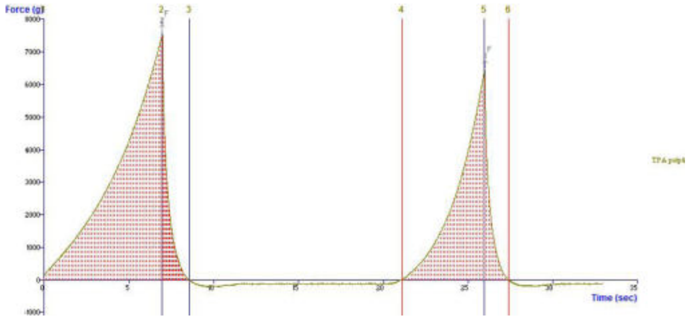

Fig. 5. Force-Time graph for TPA test of pulp

shape after compression which indicates a certain degree of elasticity. The cohesiveness value of 0.535 suggests that the tamarind pulp has a moderate ability to maintain its structure and integrity during chewing. The gumminess value was 4044.331 g suggesting that the tamarind pulp has a moderate level of chewiness and resilience. This property may contribute to the perceived texture and palatability of the pulp. The chewiness value of 2820.351 g-sec suggests that the tamarind pulp requires a significant amount of energy to break down and prepare for swallowing. This property may influence the overall eating experience. The resilience recorded value was 0.119 suggesting that the tamarind pulp has a low ability to recover its original shape after compression. This property may contribute to the perceived texture and mouthfeel of the pulp during consumption. The texture analysis results indicated that the tamarind pulp has high firmness and resistance to deform, high adhesive texture with a low degree of elasticity, high chewiness, and less resilience than the tamarind pod due to the intrinsic cellular structure of the pulp.

The study was conducted using various texture analysis techniques to determine the textural and mechanical properties of tamarind. It provides essential information on structural integrity, sensory characteristics, processing requirements and its handling and processing characteristics. The compression test on unshelled tamarind revealed mean peak force required to break the shell of unshelled tamarind was 2182.222 N which indicates significant resistance to deformation. The cutting test on shelled tamarind pulp showed a mean peak positive force of 14234.732 g which was the mean force required for cutting the pulp. The texture analysis test of tamarind pod and pulp reveals significant differences in their mechanical properties and sensory characteristics. The pod requires less force for compression compared to the pulp due to the presence of seed and the pulp has greater resistance to deformation due to its cellular structure. The pod is moderately adhesive compared to the pulp which is much stickier. The pod shows slightly better elasticity which helps in holding its shape more effectively after compression, stronger cohesiveness, moderate adhesiveness and slightly more resilience due to the presence of seeds and fibrous threads. In contrast, tamarind pulp exhibits higher gumminess, and chewiness due to which it requires more energy to chew.

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