Study on the Physical and Mechanical Properties of Organic Ginger (Zingiber Officinale) Collected from North-East India

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Abstracts
This study investigates the physical, mechanical, and thermal properties of organic ginger (*Zingiber officinale*) varieties collected from North-East India, a region known for its rich agro-biodiversity and significant contribution to organic ginger production. Five landraces—Nadia, Jatiyo Ada, Naga Ada, Naga Moran, and Sawhthing—were analyzed to generate engineering data essential for the design of mechanized post-harvest systems. Physical properties such as axial dimensions, geometric mean diameter, sphericity, surface area, bulk density, and frictional characteristics were determined using standard measurement techniques. Mechanical properties including penetration force, shear force, and compressive strength were evaluated using a texture analyzer, while thermal properties such as specific heat, thermal conductivity, and diffusivity were also assessed.
Results revealed substantial variability among the varieties. The GI-tagged Nadia exhibited relatively lower mechanical resistance (~2.6 kgf), indicating a softer and more brittle structure, whereas Naga Ada showed the highest shear strength (~10 kgf), reflecting a highly fibrous and tough internal structure. Jatiyo Ada and Sawhthing demonstrated intermediate characteristics with notable heterogeneity and elastic recovery. Significant differences were also observed in geometric and frictional properties, influencing handling, storage, and processing behavior. The findings highlight that a uniform mechanization approach is unsuitable for ginger due to its morphological and structural diversity. The study provides a critical engineering database that can support the development of variety-specific machinery, thereby enhancing processing efficiency, reducing labor drudgery, and promoting sustainable mechanization in the ginger sector of North-East India.

Keywords: Zingiber officinale; Physical properties; Mechanical properties; Texture analysis; Shear force; Engineering properties; Variety-specific machinery.

1. Introduction

1.1 The Regional Significance of North-East India

North-East India, comprising eight states, is globally recognized as a premier biodiversity hotspot. Its unique topography—ranging from the Himalayan foothills to the floodplains of the Brahmaputra—creates diverse agro-climatic niches. These conditions are exceptionally conducive to the cultivation of high-value organic crops. Among these, ginger (*Zingiber officinale*) stands as a cornerstone of the regional agrarian economy. The region is one of the largest producers of ginger in the world, characterized by traditional farming systems that maintain the organic integrity of the crop.

1.2 Varietal Diversity and Chemical Composition

The environmental stressors and soil compositions of the NE region have led to the evolution of distinct ginger landraces. Varieties such as the G.I. tagged *Nadia*, Aizol of Assam or the *Sawhthing* of Mizoram are sought after not only for their culinary use but for their industrial value. These varieties exhibit significant variations in: a) Fiber Content: Crucial for determining the mechanical resistance during slicing and grinding b) Moisture Levels: A primary factor in post-harvest shelf life and bulk density c) Oleoresin and Essential Oils: The bioactive compounds that determine the "pungency" and pharmaceutical value of the rhizome.

1.3 The Problem of Post-Harvest Mechanization

Despite being a leading producer, the ginger industry in North-East India suffers from low levels of mechanization. Harvesting, cleaning, and processing are largely performed manually, leading to high labor costs and significant post-harvest losses (estimated between 15% to 30%). The primary obstacle to mechanization is the complex, irregular, and branched morphology of the ginger rhizome. Unlike uniform crops like potatoes or grains, ginger requires highly specialized machinery that can handle its varied "finger" shapes without causing mechanical fractures or skin bruising, which lead to rapid microbial spoilage.

1.4 Rationale for the Study

To transition from manual labor to precision engineering, a "technical foundation" of the crop's physical and mechanical behavior is mandatory. Engineers cannot design efficient planters or harvesters without knowing the exact force required to penetrate the skin, the coefficient of friction of the rhizome against stainless steel, or the bulk density for storage bin design. This research was meticulously conducted during an intensive 30-day academic residency from April 1 to June 1, 2025, at the AICRP-FIM and AICRP-PHET laboratories. By focusing on five distinct regional varieties, this study aims to fill the data gap in the "Engineering Properties of Ginger," providing the empirical data necessary to develop the next generation of agricultural implements tailored specifically for the North-Eastern terrain.

1.5 Objectives

The overarching goal of this study is to quantify the physical, mechanical, and thermal properties of organic ginger collected from the "nooks and corners" of the North-East. Specifically, the paper seeks to:

1. Establish a database of axial dimensions (Length, Width, Thickness) for regional varieties.
2. Determine the mechanical resistance—specifically penetration and cutting force—to inform the design of processing blades.
3. Analyze the frictional characteristics to optimize the flow of rhizomes in mechanized hoppers.

2. Materials and Methods

2.1 Sample Selection, Integrity, and Preparation

The experimental phase focused on a comparative analysis of five distinct ginger landraces. To mitigate the high biological variability inherent in rhizomes, a stringent selection protocol was established. Ten varieties were initially screened, with five primary varieties selected based on their economic dominance in the North-East: Nadia, Jatiyo Ada, Naga Ada, Naga Moran, and Sawhthing.

- Sampling Strategy: For each variety, a sample size of n=24 units was maintained. To achieve high statistical confidence ($p < 0.05$), each individual unit underwent three replications for every physical and mechanical measurement, totaling 72 data points per parameter per variety.
- Quality Assurance: Only "A-grade" rhizomes were selected. Samples showing signs of "rhizome rot" (*Pythium aphanidermatum*), mechanical skinning during harvest, or desiccation from fluctuating weather conditions were excluded.
- Cleaning: Samples were manually cleaned using a soft brush to remove adhering soil and debris, ensuring that measurements reflected the true biological dimensions of the ginger rather than external contaminants.

Plate 1: Displays the "Jatiyo Ada" samples prepared for trial.

Plates 2: Represent the experimental setup and sample variety.

2.2 Geographic and Agro-Climatic Context of Varieties

The sourcing of these varieties covers a diverse range of the North-Eastern topography, which significantly influences their structural density:

1. Nadia (Assam): Sourced from the hilly terrain of Karbi Anglong. This G.I. Tagged variety is known for high dry matter and low fiber content.
2. Jatiyo Ada (Upper Assam): Collected from the alluvial plains of Jorhat and Moran. This variety typically exhibits high moisture and large, succulent fingers.
3. Naga Ada & Naga Moran: Sourced from the humid, high-altitude regions of Nagaland and the border districts. These varieties are characterized by intense pungency and high oleoresin concentrations.
4. Sawhthing (Mizoram): Originating from the steep slopes of Mizoram, this variety is structurally distinct, often featuring more elongated and slender rhizome fingers.

2.3 Determination of Physical and Gravimetric Properties

The physical characterization followed standard procedures for irregularly shaped agricultural products.

- Axial Dimensions: The three principal axes—Length (major diameter, x), Width (intermediate diameter, y), and Thickness (minor diameter, z)—were measured using a digital Vernier caliper with an accuracy of ±0.05mm.
- Geometric Mean Diameter (D_g): Calculated to represent the overall size of the rhizome:

$$D_g = (abc)^{\frac{1}{3}}$$

- Sphericity (Φ): This dimensionless parameter indicates how closely the ginger shape resembles a sphere, which is critical for designing hopper openings:

$$\Phi = \frac{(abc)^{\frac{1}{3}}}{a}$$

- Surface Area (S): Calculated based on the Dg to estimate the heat and mass transfer area during drying: $S = \pi D^2 g$
- Frictional Behavior: The static coefficient of friction (μ) was determined against four structural surfaces: Stainless Steel, Galvanized Iron, Plywood, and Glass. The Angle of Repose (Θ) was measured using the "emptying method" to determine the natural slope ginger forms when piled, crucial for storage bin design.

Plate 2: Shows the use of a digital Vernier caliper to measure axial dimensions in Jorhat, Assam.

Plate 3: Illustrate the measurement of weight and bulk volume using the displacement method.

2.4 Mechanical Characterization via Texture Analysis

Mechanical strength was evaluated using a Stable Microsystems TA.XTplus (TA XT2i) Texture Analyser. Given the non-uniformity of ginger, tests were standardized by categorizing the rhizome into primary, secondary, and tertiary fingers.

1. **Penetration Test (Firmness):** A 2 mm stainless steel needle probe (P/2N) was utilized to measure the force-deformation profile. This test quantifies the resistance of the skin and the sub-epidermal tissue, serving as an indicator of harvest maturity.
2. **Cutting/Shear Test:** Using a Warner-Bratzler shear blade, the maximum force required to slice through the rhizome core was measured. This data informs the power requirements for industrial slicers and shredders.
3. **Compression Test:** To simulate the static loading ginger faces in deep-bed storage or transport, samples were compressed between two 65 mm flat plates. A 50 kg load cell was applied at a constant cross-head speed of 5 mms^{-1} to a deformation distance of 5 mm.

2.5 Thermal Properties Analysis

Thermal properties were evaluated for both fresh and dehydrated states, as these parameters dictate the efficiency of post-harvest drying and curing.

- **Specific Heat (C_p):** Specific heat is the property needed in the estimation of amount of energy required to change the temperature of the product and was determined by the method of mixtures by equating the heat lost by the hot sample in water to the heat gained by water from the hot sample *(Kaleemullah & Kailappan, 2004).*
- **Thermal Conductivity (k):** Thermal conductivity is the property of a material describing its ability to conduct heat. Thermal conductivity was determined using the transient heat flow method in a line heat source apparatus similar to the one used by Sreenarayanan et al. (1988).
- **Thermal Diffusivity (α):** Thermal diffusivity is obtained as the ratio of thermal conductivity of the material to its volumetric heat capacity. The thermal diffusivity of fresh and dry ginger was calculated using the following equation (Mohsenin 1986).

  Where:

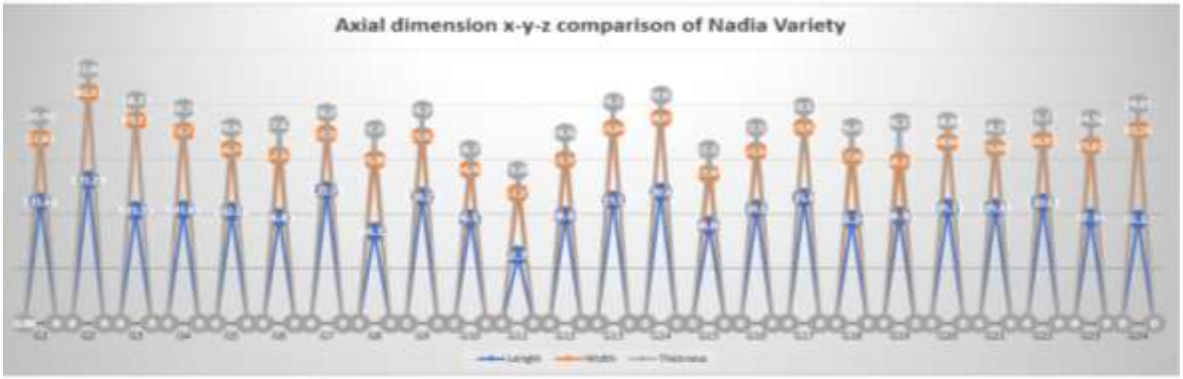
$$\alpha = \frac{k}{\rho C_p}$$

k = Thermal conductivity (W/m·K)
ρ= Bulk density $(kg/m)^3$
C_p = Specific heat (J/kg·K)

3. Results

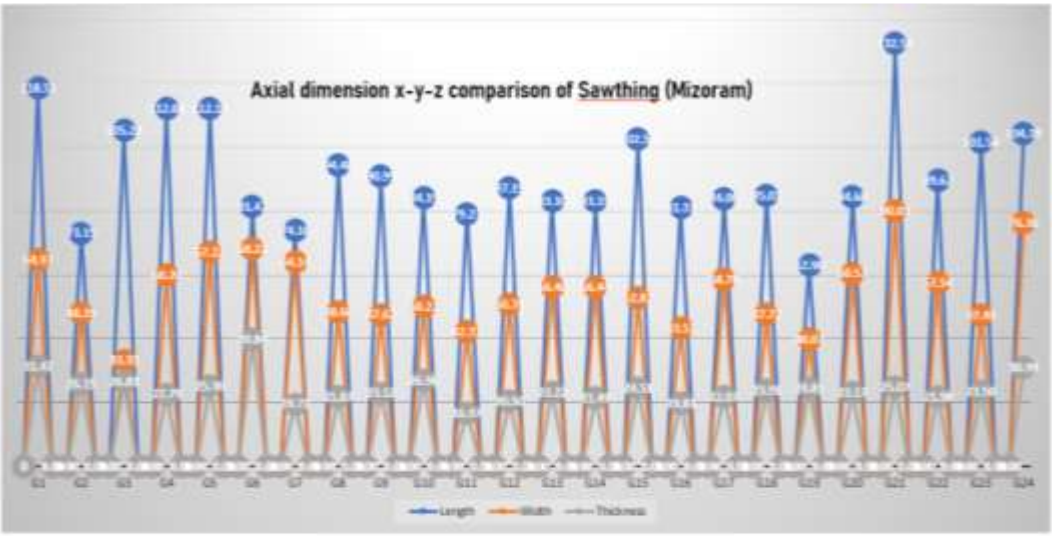
3.1 Graphical Analysis

From these research trials few outcomes were generated such as in terms of the variety number one that is Nadia from Karbi Anglong District which is GI tagged, it was found that length varies between 62 to 131 mm in case of GI tagged variety Nadia, width varies from 44.44- 83.13mm and thickness caries from 18.23 to 36.13. The geometric mean of the ginger ranges from 41.52 to 61.36. The sphericity of the Nadia was found to be in range from 0.41 to 0.55 and the surface area of the ginger was found to be from 55.46 cm to 118.69 cm. Since 24 samples of each variety were taken into consideration hence there was a large variation in terms of weight of the ginger too. The Nadia ginger sample tested exhibits a peak shear force of ~2.6 kgf, indicating a moderately firm texture. The sharp rise and fall of the curve suggest a brittle response, likely with low elasticity. A higher peak = tougher or more resistant sample. The larger the area, the more energy required → indicates harder or denser texture. The steepness of the curve indicates the rate of force increase – useful for assessing brittleness vs. elasticity.



Graph.1: The graph shows how the axial dimensions of the ginger variety Nadia varies in terms Length vs. width and Thickness.

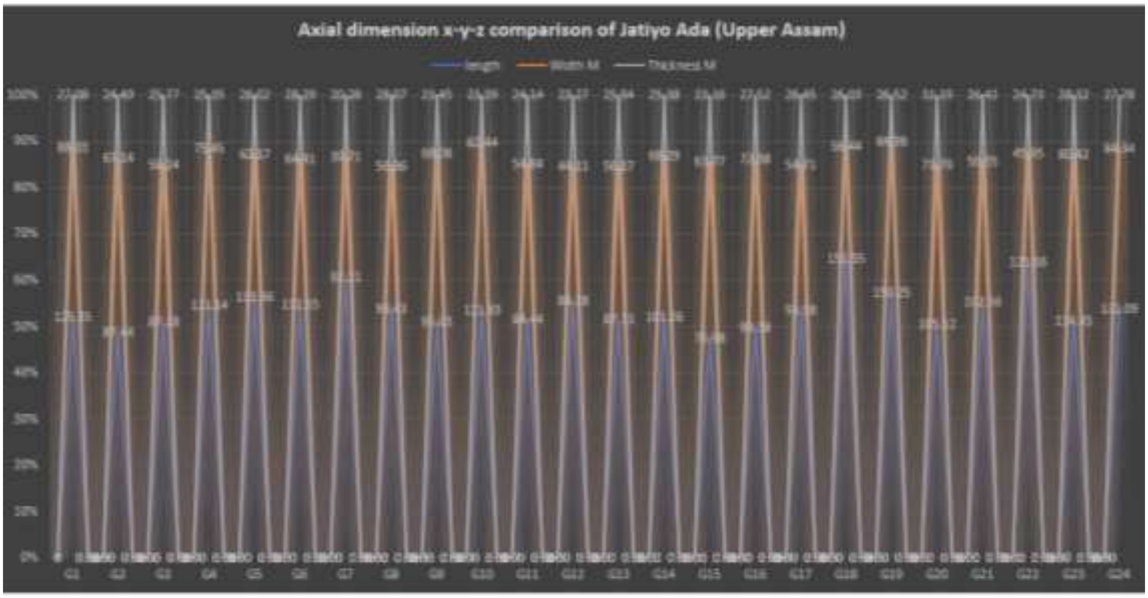
In terms of the variety number one that is Ginger Variety Sawthing (Mizoram), it was found that length varies between 62.98- 118.55mm in case of GI tagged variety Nadia, width varies from 33.33- 68.22 and thickness caries from 16.97- 31.47. The geometric mean of the ginger ranges from 39.71 to 88.03. The sphericity of the Nadia was found to be in range from and the surface area of the ginger was found to be from 0.40 to 0.62 cm. Since 24 samples of each variety were taken into consideration hence there was a large variation in terms of weight of the ginger too.



Graph.2: The graph shows how the axial dimensions of the ginger variety Sawthing varies in terms Length vs. width and Thickness.

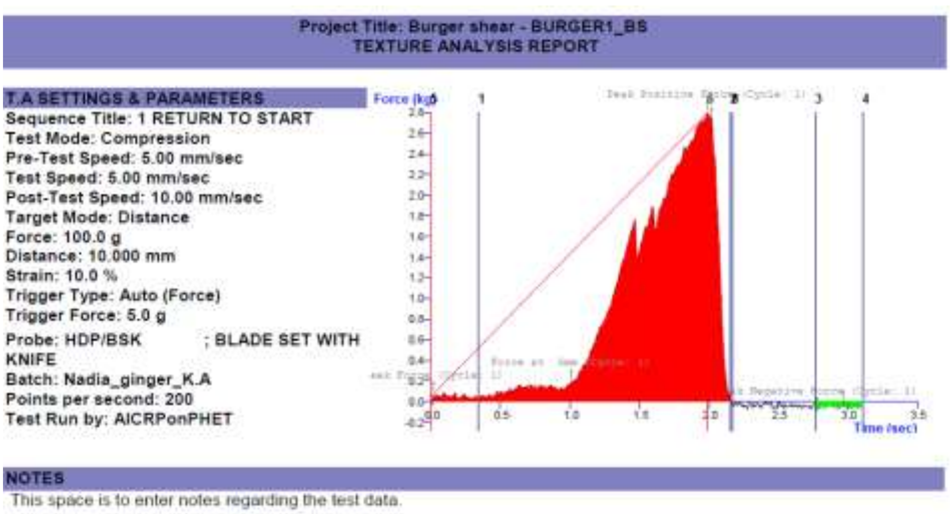
The red area under the curve shows the total work done (i.e., energy required) to shear through the sample. A wider base and more area mean more resistance to shearing and a tougher sample. Peak Positive Force (~3.8 kgf). This is the maximum force required to shear the ginger sample. Compared to the previous ginger sample (Nadia ginger K.A with ~2.6 kgf), this sample is tougher/harder. Indicates stronger tissue strength, possibly due to denser fibers, higher maturity, or lower moisture content.

The steep rise to the peak and slower fall after the peak suggests a more ductile or fibrous failure compared to a brittle one.



Graph.3: The graph shows how the axial dimensions of the ginger variety Jatiyo Ada varies in terms Length vs. width and Thickness.

From this study the importance of integrating physical and mechanical properties into machinery design are is that the physical and mechanical properties of indigenous ginger varieties in North-East India are diverse and directly impact the suitability of mechanized operations. There is a pressing need for variety-specific characterization and tailored mechanization to enhance processing efficiency, reduce drudgery, and support sustainable livelihood for tribal communities. Focused R&D in this area can significantly contribute to India's organic and export-oriented ginger sector.
From the study of the Mechanical Properties of ginger results of the compression test derived from the texture analyzer could be elaborated as:



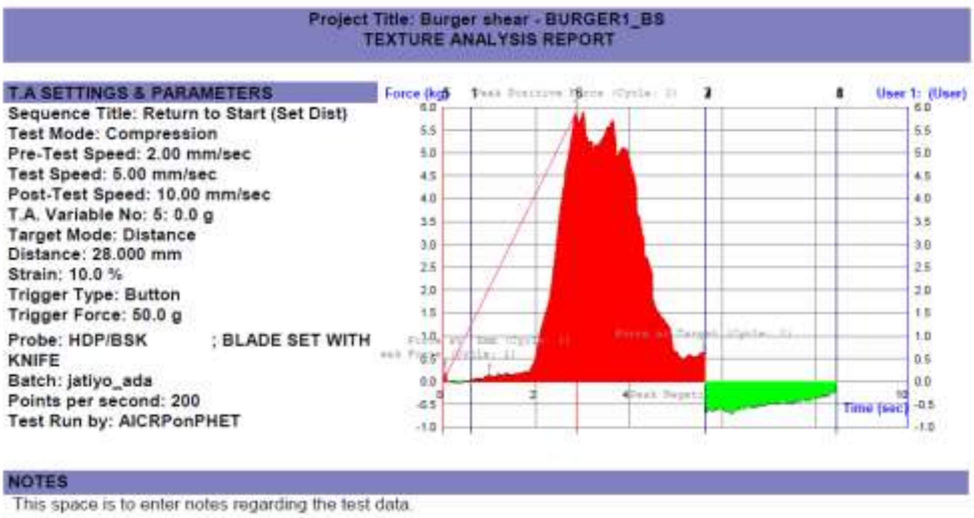
Graph 4: The graph shows the test of compression using HDP/BSK blade on ginger variety Nadia where Force (Kg) is analyzed with time.

From this textural graph, the following points can be observed.

- Initial rise (0 – 0.5 s): The probe touches and starts compressing; force increases gradually.
- Steady rise (0.5 – 2.0 s): Force builds up as the blade penetrates, reflecting tissue firmness and resistance.
- Peak positive force (~2.6 kgf at ~2.0 s): Maximum resistance before structural failure/shear of the ginger. This is the shear force or hardness value.
- Sudden drop after peak: Indicates structural breakdown (ginger tissue cut/broken).
- Negative force (brief dip): Often due to elastic recovery or blade withdrawal.

The following points can be illustrated as:

- The ginger sample **Nadia_ginger_K_A** has a maximum shear resistance of about **2.6 kgf**.
- The tissue resists compression up to this point, then fractures sharply.
- The shape of the curve shows **strong firmness** (steep rise) and **less ductility** (sudden drop instead of gradual decline).
- Useful for **comparing varieties** (e.g., softer vs. harder gingers), **quality assessment**, and **machine design parameters** for slicers/harvesters.

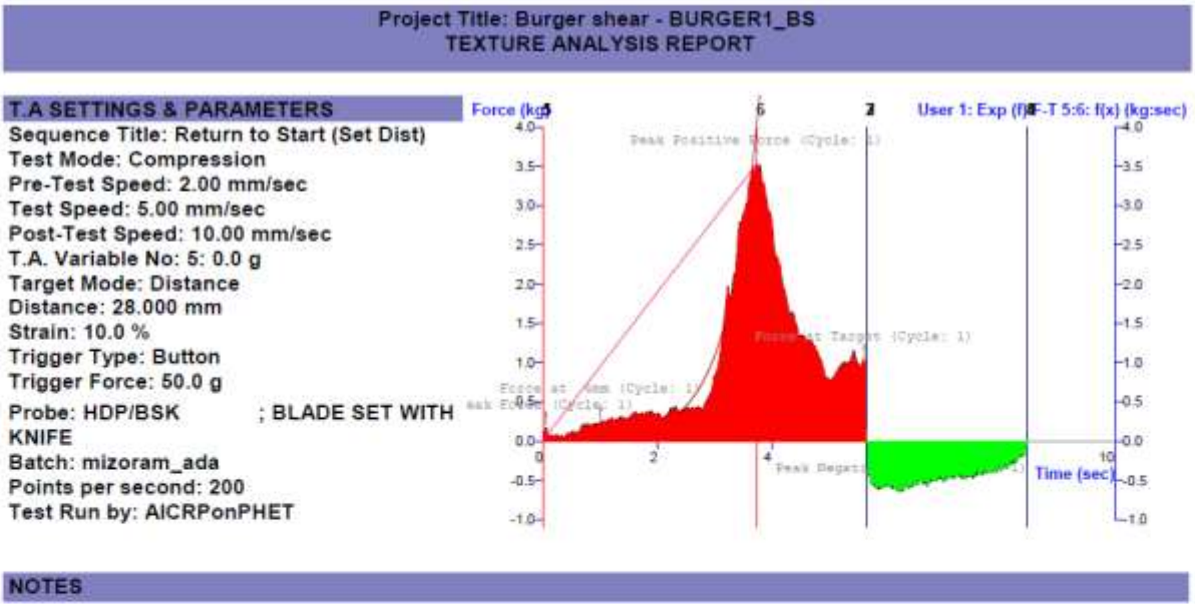


Graph 5: The graph shows the test of compression using HDP/BSK blade on ginger variety Jatiyo Ada where Force (Kg) is analyzed with time

The following points are observed from this textural report such as:

- Initial low slope (0–2 sec): The sample offered mild resistance at the beginning (softer outer tissue).
- Steady rise (2–5 sec): Force increased significantly as blade penetrated deeper.
- Peak force (~5.8–6.0 kgf): Maximum resistance before major structural breakdown. This is the hardness/shear strength of this ginger variety.
- Irregular force drops after peak: Indicates tissue heterogeneity (fibrous zones inside ginger caused stepwise resistance and fracture).
- Negative force (green region): Elastic recovery and blade-sample interaction during withdrawal. Which can be further illustrated as
- Higher hardness: Peak shear force (~6.0 kgf) is much higher than the first sample (~2.6 kgf), suggesting jatiyo_ada is significantly tougher/firmer.

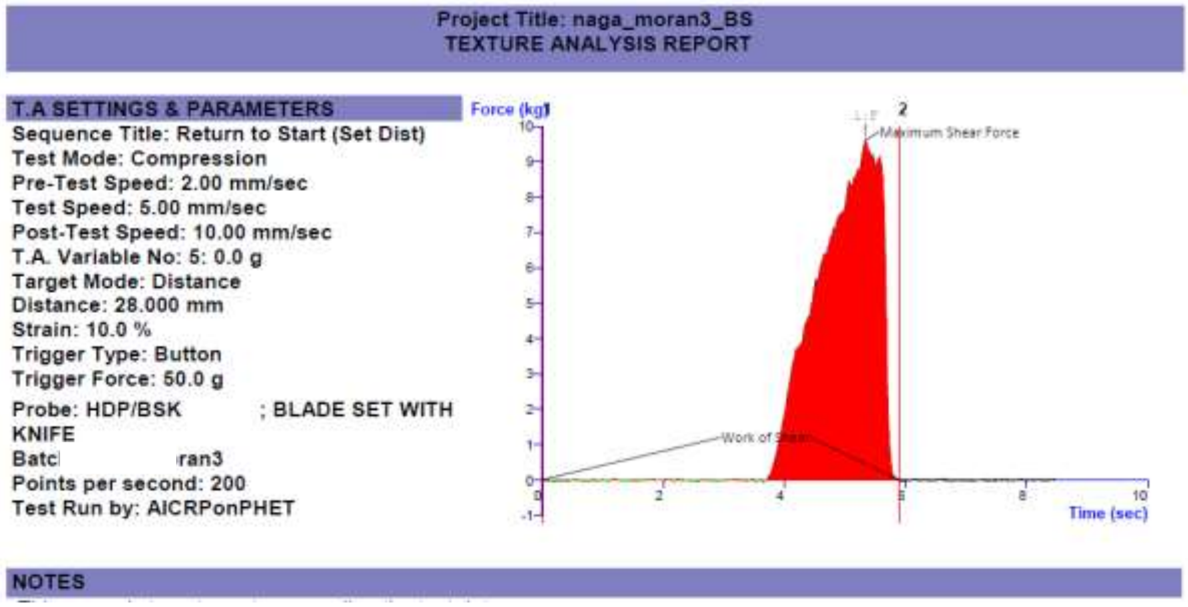
- Toughness (work done): Larger red area under the curve → higher energy required to shear, meaning more fibrous/tougher texture.
- Non-uniform structure: Saw-tooth pattern after the peak suggests varying fiber bundles being cut.
- Elastic recovery: Noticeable green area shows the sample exerted pull-back force after compression.



Graph 6: The graph shows the test of compression using HDP/BSK blade on ginger variety Sawthing (Mizoram ada) where Force (Kg) is analyzed with time.

From the texture analyser graph, the following observation can be derived:

- **Initial zone (~0–2 sec):** Gradual increase, indicating softer outer layer being cut.
- **Sharp rise (2–4 sec):** Rapid force build-up as blade engages denser fibrous tissues.
- **Peak positive force (~3.8–4.0 kgf):** Maximum resistance before tissue fracture. This value reflects **hardness/shear strength**.
- **Sudden drop after peak:** Structural breakdown once fibers are cut.
- **Post-peak force fluctuations:** Suggest heterogeneous internal structure (uneven fibers, tough bundles).
- **Negative force (green region):** Recovery force as blade exits → indicates elasticity and adhesion.
  The following points can further be elaborated as:
- **Moderate hardness:** Peak force of ~3.8–4.0 kgf → lower than *jatiyo_ada* (~6.0 kgf), but higher than *nadia* (~2.6 kgf).
- **Toughness (area under curve):** Significant, but not as high as *jatiyo_ada*. Still requires substantial energy for cutting.
- **Fibrous but less resistant than jatiyo_ada:** The slope and peak suggest *mizoram_ada* is firm but not as tough as *jatiyo_ada*.
- **Elastic recovery:** Noticeable green area shows the sample pulled back on the probe upon release.



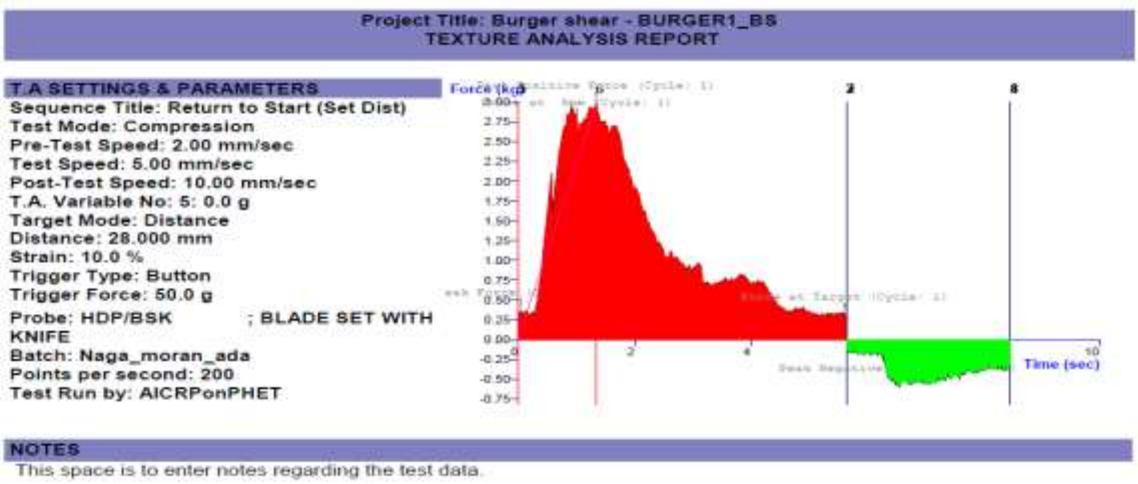
Graph 6: The graph shows the test of compression using HDP/BSK blade on ginger variety Naga Moran ada where Force (Kg) is analyzed with time.

The following points can be observed from this graph:

- **Gradual build-up (0–4 sec):** Indicates dense fibrous structure resisting the knife progressively.
- **Steep force rise (~4–5 sec):** Sudden high resistance due to strong fibrous bundles.
- **Peak force ~10 kgf:** The highest among all samples tested so far (twice *jatiyo_ada*, over 3x *mizoram_ada*, ~4x *nadia*).
- **Abrupt drop after peak:** Indicates complete rupture of fibers once maximum resistance is overcome.
- **Work of shear (area under curve):** Large → requires maximum energy to shear, confirming *Naga Ada* is the **toughest and hardest variety**.

Which can be further illustrated as:

- **Hardness / Shear Strength:** Extremely high (max ~10 kgf).
- **Toughness:** Very large work of shear → indicates very fibrous and compact tissue.
- **Cohesion:** Continuous force build-up suggests uniform and highly resistant fiber structure.
- **Elastic recovery:** Almost absent (no negative force seen), so it does not "spring back" after cutting – it fractures completely.



The following points can be observed from the textural analyzer report:

- Peak Positive Force (~3.8–4.0 kgf): This is the maximum shear force required to cut through mizoram_ada ginger.
→ It is higher than nadia (~2.5 kgf) but much lower than naga_moran3 (~10 kgf).
- Work of Shear (area under red curve): Indicates the energy required for cutting. Moderate compared to other varieties.
- Force at 5 mm: Recorded as part of the measurement, showing tissue resistance at shallow penetration.
- Negative Force (green zone, -0.5 to -0.6 kgf): Suggests some elastic recovery or blade adhesion after the cut. Unlike naga_moran3, mizoram_ada shows a tendency to spring back slightly after being cut.

4. Discussion: Engineering Implications

The experimental results from this study highlight the significant variability in the physical and mechanical properties of organic ginger varieties indigenous to North-East India. This diversity directly impacts the design and efficiency of mechanized post-harvest operations, such as planting, harvesting, and slicing.

4.1 Comparative Analysis of Physical Properties

The physical characterization revealed substantial differences in the axial dimensions and derived properties of the varieties studied:

- Nadia Variety (Assam): This G.I. tagged variety showed a length range of 62 to 131 mm, with a geometric mean diameter (GMD) between 41.52 and 61.36. Its sphericity (0.41 to 0.55) indicates a relatively elongated shape, which must be accounted for in the design of seed metering mechanisms for mechanized planters.
- Sawthing Variety (Mizoram): This variety exhibited a broader range in GMD (39.71 to 88.03) and surface area (0.40 to 0.62 cm^2) compared to Nadia, suggesting a more heterogeneous size distribution even within the same batch.
- Jatiyo Ada (Upper Assam): The axial dimension comparison (Graph 3) illustrates a distinct morphological profile compared to the other varieties, emphasizing the need for variety-specific machinery adjustments.

4.2 Mechanical Resistance and Texture Analysis

The force-deformation curves generated by the texture analyzer provide critical insights into the internal tissue structure and mechanical strength of each variety.

- Hardness and Shear Strength: A significant disparity was observed in peak shear force. Naga Moran (Naga Ada) emerged as the toughest variety, requiring a maximum shear force of ~10 kgf. In contrast, the Nadia variety was found to be the softest, with a peak shear force of only ~2.6 kgf, indicating a more brittle response. Jatiyo Ada (~6.0 kgf) and Mizoram Ada (~3.8–4.0 kgf) exhibited moderate hardness levels.
- Energy Requirements (Work of Shear): The "Work of Shear"—represented by the area under the red curve in the texture reports—was highest for the Naga Moran variety. This indicates that significantly more energy is required to slice or shred Naga Moran compared to varieties like Nadia or Mizoram Ada.
- Tissue Heterogeneity and Elasticity: The "saw-tooth" pattern observed in the Jatiyo Ada graph suggests a highly heterogeneous internal structure with dense fiber bundles. Furthermore, varieties like Mizoram Ada and Jatiyo Ada showed noticeable elastic recovery (indicated by negative force/green

area), whereas Naga Moran showed almost no elastic recovery, fracturing completely once the peak resistance was overcome.

4.3 Engineering and Socio-Economic Implications

These findings underscore the necessity of variety-specific characterization for agricultural engineering. For instance:

- Machinery designed for the relatively brittle Nadia variety would likely fail or suffer excessive wear if used for the tough, fibrous Naga Moran.
- The sharp rise and fall in force curves for certain varieties suggest a need for high-impact cutting blades, while the ductile behavior of others may require higher torque at slower speeds.

Tailoring mechanization to these indigenous varieties is essential to enhance processing efficiency and reduce the physical drudgery currently faced by tribal communities in North-East India.

Comparison with existing machinery, such as the garlic planter studied at the AICRP-FIM Lab, provides a benchmark for developing specialized ginger planters.

5. Conclusion

The comprehensive study of the physical and mechanical properties of five organic ginger varieties from North-East India—**Nadia**, **Jatiyo Ada**, **Naga Ada (Naga Moran)**, and **Sawhthing**—leads to the following conclusions:

- **Significant Varietal Diversity:** There is a diverse range of physical and mechanical properties among indigenous ginger varieties in North-East India, which directly impacts their suitability for mechanized operations.
- **Morphological Variability:** Physical dimensions vary significantly by variety. For the GI-tagged **Nadia** variety, lengths range from 62 to 131 mm. The **Sawhthing** variety exhibits a broader geometric mean diameter range (39.71 to 88.03) compared to Nadia (41.52 to 61.36), indicating greater size heterogeneity.
- **Mechanical Strength Disparity:** A critical finding of this study is the massive disparity in shear strength. **Naga Ada** is the toughest and hardest variety, requiring a peak shear force of ~10 kgf—nearly four times that of the **Nadia** variety (~2.6 kgf).
- **Internal Tissue Characteristics:** Texture analysis revealed that **Jatiyo Ada** possesses a highly heterogeneous internal structure with dense fiber bundles, while **Nadia** exhibits a brittle response with low elasticity. Varieties like **Mizoram Ada** show elastic recovery, whereas **Naga Ada** fractures completely without "springing back".
- **Engineering Requirements:** The high variation in cutting and penetration forces confirms that a "one-size-fits-all" approach to machinery is ineffective. Processing equipment, such as slicers and harvesters, must be designed with parameters—such as blade torque and impact force—tailored to the specific mechanical resistance of the target variety.
- **Socio-Economic Impact:** There is a pressing need for variety-specific characterization and tailored mechanization to enhance processing efficiency, reduce labor drudgery for tribal communities, and support the growth of India's organic and export-oriented ginger sector.

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