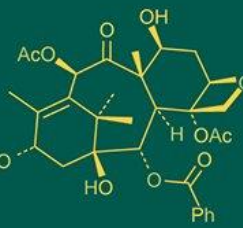
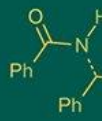


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Studies on engineering properties of green bell pepper (*Capsicum annuum* L.)

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Abstract

The physico-mechanical properties of bell pepper (*Capsicum annuum* L.) are important in agriculture, food processing, packaging, transportation, and machinery design. Knowledge of these properties is essential for maintaining product quality, reducing post-harvest losses, and optimizing handling and processing operations. In this study, the physical and mechanical characteristics of green bell pepper was systematically evaluated. The physical parameters measured included moisture content, length, width, thickness, projected area, surface area, sphericity, aspect ratio, mass, and volume. Additionally, the coefficients of static was determined on stainless steel, galvanized iron, and glass surfaces.

Keywords: Bell pepper, capsicum, engineering properties, horticulture

Introduction

Bell pepper (*Capsicum annuum* L.) is an economically important horticultural crop cultivated worldwide for both fresh-market consumption and processing. Understanding the engineering and mechanical properties of these colour-maturity classes is therefore crucial for designing harvesting tools, grading and sorting equipment, transport containers, and packaging systems that minimize mechanical damage and postharvest losses (Zhang *et al.*, 2025) [16]. Engineering properties commonly assessed in horticultural crops include physical dimensions (length, width, thickness, and equivalent diameters), sphericity, mass, volume, projected and surface area, and bulk density. These parameters serve as the basis for sizing sorting openings, calibrating conveyors, and modelling mass and heat transfer during processing. Equally significant are the mechanical properties, such as firmness, compressive and shear strength, tensile behaviour, bruise susceptibility, and frictional behaviour on contact surfaces. These factors determine the threshold loads that cause damage during handling and are essential for the design of low-damage handling systems. Studies have shown that these attributes vary significantly with variety, maturity stage, moisture content, and postharvest treatments, highlighting the importance of maturity-specific data for engineering applications (Adhikari, *et al* 2020) [2].

Moreover, modern postharvest treatments such as modified atmosphere packaging (MAP), film-active packaging (FAP), and cold storage require updated, variety-and maturity-specific mechanical data to design effective interventions. Recent studies emphasize linking Physico-mechanical characterization with practical device design for example, defining compressive stress thresholds for low-damage conveyors or selecting surface coatings that reduce bruising based on measured friction coefficients (Yeboah *et al.*, 2023; Zhang *et al.*, 2025) [15, 16]. Given these considerations, this study systematically evaluates the engineering and mechanical properties of green peppers. The findings aim to provide reference data to guide the design and optimization of sorting, conveying, and packaging equipment, thereby supporting technological advancements in the bell pepper supply chain (Díaz-Pérez *et al.*, 2024; Zhang *et al.*, 2025) [6, 16].

Understanding these properties is important for optimising mechanised processes and minimizing mechanical damage during harvesting and handling. This study aims to address this gap by systematically evaluating these properties to inform the development of advanced engineering solutions for bell pepper production and post-harvest management.

Materials and Methods

Fresh and healthy fruits of bell pepper (Green) were sourced from a local market of Udaipur, Rajasthan for the purpose of conducting this research. The freshly harvested fruits were manually cleaned and sorted to remove any diseased or damaged specimens, ensuring only high-quality samples were used in the study.

Measurement of physical properties

To determine the physical properties of bell pepper, the standard procedures suggested by Mohsenin (1986) were followed. The details of the properties determined and the methods followed are described below. Some selected physical properties of capsicum were determined. Standard procedures were followed to measure the following properties of fresh capsicum. The moisture content (MC, % w.b.) of pepper samples was determined using the dry oven method as described by (Shoba *et al.*, 2025) [14].

The linear dimensions of the peppers, namely length (L, cm), width (W, cm), and thickness (T, cm), were measured using a digital vernier calliper with a precision of 0.01 mm. The mass (g) of each sample was recorded using an electronic balance with an accuracy of 0.01 g. The aspect ratio (Ra) was calculated following the method proposed by Maduako and Faborode (1990) [9]. In addition, the geometric mean diameter (Dg, cm), arithmetic mean diameter (Da, cm), and equivalent diameter (De, cm) were determined using standard formulas.

$$Da = \frac{L+W+T}{3} \quad \dots(1)$$

$$Dg = 3\sqrt{LWT} \quad \dots(2)$$

$$De = \left(\frac{L(W+T)^2}{3}\right) \quad \dots(3)$$

Where,

L = Length, (cm)

W = Width, (cm)

T = Thickness (cm) of the whole bell pepper.

Sphericity and aspect ratio

The shape of the fruit can be determined by calculating the sphericity (Φ) and aspect ratio (Ra) as suggested by Ramyashree., 2023 [12]; Abidin *et al.*, 2023 [1]

$$\Phi = \frac{3\sqrt{LWT}}{L} \quad \dots(4)$$

$$Ra = \frac{W}{L} \quad \dots(5)$$

Where,

Φ = Sphericity, fraction

L = Length of fruit, cm

W = Width of fruit, cm

T = Thickness of fruit, cm

Projected area

The projected areas of the capsicums perpendicular to three dimensions (length, width and thickness) and criteria projected areas for the whole capsicum were determined using following equations (Barbhuiya *et al.*, 2020) [3].

$$PA_L = \frac{\pi WL}{4} \quad \dots(6)$$

$$PA_W = \frac{\pi WW}{4} \quad \dots(7)$$

$$PA_T = \frac{\pi WT}{4} \quad \dots(8)$$

$$CPA = \frac{PA_L + PA_W + PA_T}{3} \quad \dots(9)$$

Where,

W = Width of capsicum, cm

T = Thickness of capsicum, cm

PA_L = Projected area perpendicular to length of capsicum, cm^2

PA_W = Projected area perpendicular to width of capsicum, cm^2

PA_T = Projected area perpendicular to thickness of capsicum, cm^2

CPA = Criteria projected area of capsicum, cm^2

Surface area

The surface area is total area of different surfaces and expressed in cm^2 for agricultural commodities. The surface area of was calculated by using the following formula (Barbhuiya *et al.*, 2020) [3].

$$SA = \pi D_g^2 \quad \dots(10)$$

Where,

SA = Surface area of bell pepper, cm^2

Dg = Geometric mean diameter, cm

True volume

The capsicum was first weighed on the scale in air and then dipped into water by means of a sinker rod. The second reading of the scale with the fruit submerged minus the weight of the container and water is the weight of displaced water which was used in the following expression to calculate the volume (Abidin *et al.*, 2023) [1].

$$\text{True volume (m}^3\text{)} = \frac{\text{Weight of water displayed (Kg)}}{\text{Density of water (Kg/m}^3\text{)}} \quad \dots(7)$$

The volume of capsicum was also determined in terms of an oblate spheroid volume (OSV), prolate spheroid volume (PSV) and ellipsoid volume by following formula as suggested by Pathak *et al.*, 2019 [10];

$$OSV = \frac{4\pi}{3} \frac{L}{2} \frac{W}{2} \frac{W}{2} \quad \dots(8)$$

$$PSV = \frac{4\pi}{3} \frac{L}{2} \frac{W}{2} \frac{W}{2} \quad \dots(9)$$

$$EV = \frac{4\pi}{3} \frac{L}{2} \frac{W}{2} \frac{W}{2} \quad \dots(10)$$

Density measurement

A rectangular wooden box was used to determine bulk density. The volume of the box was calculated by multiplying its length, width, and height ($l \times b \times h$). The box was then completely filled with bell peppers of the same colour, and the total weight of the fruits required to fill the box was recorded. Bulk density was calculated using the

standard relationship (Rokayya *et al.*, 2016; Abidin *et al.*, 2023) [13, 1]. Porosity of the bulk bell pepper samples was calculated using the values of true density and bulk density, following standard equations (Darfour *et al.*, 2022) [5].

$$\text{Bulk Density (kg/m}^3\text{)} = \frac{\text{Weight of fruits (Kg)}}{\text{Volume of wooden box (m}^3\text{)}} \dots(11)$$

$$\text{True Density (kg/m}^3\text{)} = \frac{\text{Weight of fruits (Kg)}}{\text{Volume of fruits (m}^3\text{)}} \dots(12)$$

$$\text{Porosity } (\epsilon) = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \dots(13)$$

Where,

ρ_t = Bulk density, Kg/m³

ρ_b = True density, Kg/m³

ϵ = Porosity

Frictional properties

The coefficients of static friction on four different frictional surfaces, namely stainless steel, galvanic iron, and glass were measured for capsicum using the inclined plate method. The dynamic coefficient of friction was computed by the following formula (Shoba *et al.*, 2025) [14]. The friction tests were replicated 20 times for each surface. The coefficient of static friction was calculated from the following equation:

$$\mu_s = \tan(\theta) \dots(14)$$

Where,

μ_s was the static coefficient of friction and

θ (deg) was the tilt angle of the friction device.

Results and Discussion

The physical properties of green capsicum presented in the Table 1 indicate considerable variability in size, shape, and mass of the fruits. The mean mass of the capsicum was 141.62 g, ranging from 90.85 to 176.53 g with a standard deviation of ± 26.81 g, reflecting natural biological variation influenced by cultivar, maturity stage, and growing conditions. Similar variations in fruit weight have been reported by Pathak *et al.* (2019) [10] and Abidin *et al.* (2023) [1], who attributed these differences to genetic variability and agronomic practices.

The principal dimensions showed that the mean length (L), width (W), and thickness (T) were 7.45 cm, 6.45 cm, and 5.51 cm, respectively. The relatively higher length compared to width and thickness indicates that the fruits are slightly elongated in shape. The observed variability in these dimensions (SD ranging from ± 1.18 to ± 1.28 cm) may be due to differences in fruit development, moisture content, and structural composition of tissues. (Maduako and Faborode, 1990; Pathak *et al.*, 2019) [9, 10].

The mean arithmetic diameter (Da), geometric mean diameter (Dg), and equivalent diameter (De) were 6.47 cm, 6.29 cm, and 6.31 cm, respectively. Such parameters are particularly useful in the design of grading, sorting, and packaging equipment (Ramyashree, 2023) [12]. The mean sphericity of green capsicum was 0.84, with values ranging from 0.72 to 0.93, indicating that the fruits are moderately spherical but deviate slightly from a perfect sphere. Sphericity values less than unity indicate elongation, which affects rolling behaviour, stacking, and packaging

efficiency. According to Maduako and Faborode (1990) [9], sphericity is an important parameter in determining the flow properties of agricultural materials.

The aspect ratio ranged from 0.73 to 0.97, with a mean value of 0.86, further supporting that the fruits are close to spherical but slightly elongated. Higher aspect ratio values indicate greater roundness, which facilitates better packing and reduces mechanical damage during handling and transportation.

Table 1: Physical properties of coloured capsicum

Parameters	Green capsicum			
	Mean	Max	Min	±SD
Mass (g)	141.62	176.53	90.85	26.81
Major intercept (Length, L cm)	7.45	9.68	5.65	1.19
Intermediate intercept (Width, W cm)	6.45	8.92	4.11	1.18
Minor intercept (Thickness, T cm)	5.51	7.79	2.98	1.28
Arithmetic mean diameter Da (cm)	6.47	8.80	4.25	1.17
Geometric mean diameter Dg (cm)	6.29	8.57	4.05	1.15
Equivalent mean diameter De (cm)	6.31	8.59	4.08	1.14
Sphericity (decimal)	0.84	0.93	0.72	0.05
Aspect ratio	0.86	0.97	0.73	0.07

Area and volume-related properties of capsicum

The projected area of green capsicum varied depending on the orientation of the fruit. The mean projected area perpendicular to length (PA_L) was 49.27 cm², ranging from 29.85 to 80.96 cm² with a standard deviation of ± 13.64 cm². Similarly, the projected area perpendicular to width (PA_W) recorded a higher mean value of 54.63 cm² (35.55-90.04 cm²; ± 13.38), while the projected area perpendicular to thickness (PA_T) showed a comparatively lower mean of 46.21 cm² (29.59-80.54 cm²; ± 12.41). The criteria projected area averaged 50.04 cm², ranging between 31.66 and 83.85 cm² with ± 12.89 cm² variation. The higher PA_W values indicate that capsicum fruits present a larger surface when oriented along width, which is important in sorting and optical grading systems. The mean surface area was found to be 174.70 cm², with values ranging from 108.04 to 297.50 cm² and a standard deviation of ± 47.16 cm², indicating substantial variability in fruit size. Similar variations in projected and surface area of horticultural produce have been reported by Pathak *et al.* (2019) [10] and Darfour *et al.* (2022) [5], who noted that such differences arise due to varietal characteristics and growth conditions and significantly influence heat and mass transfer during storage.

The volumetric analysis revealed that the mean oblate spheroid volume (OSV) was 280.06 cm³ (133.71-577.15 cm³; ± 113.38), which was higher than the prolate spheroid volume (PSV) with a mean of 214.12 cm³ (93.41-464.20 cm³; ± 96.71). The ellipsoid volume showed an intermediate mean value of 236.49 cm³, ranging from 111.26 to 516.26 cm³ with a standard deviation of ± 100.17 cm³, suggesting that the ellipsoidal assumption provides a more balanced estimation of fruit volume. The true density (ρ_t) of capsicum was found to be 0.34 g/cm³ (0.18-0.46 g/cm³; ± 0.08), whereas the bulk density (ρ_b) was significantly lower at 0.14 g/cm³ (0.09-0.34 g/cm³; ± 0.06), due to the presence of void spaces between fruits. Consequently, the porosity (ϵ) was relatively high, with a mean of 54.71%, ranging widely from 1.19 to 78.71% and a standard deviation of $\pm 19.17\%$. The high porosity indicates greater air spaces within bulk samples, which is beneficial for aeration but may reduce

packing efficiency. These findings are consistent with reports by Abidin *et al.* (2023) ^[1] and Ramyashree (2023) ^[12], who observed that bulk density and porosity are critical parameters in the design of storage structures, packaging systems, and ventilation requirements for fresh produce.

Table 2: Area and volume-related properties of capsicum

Parameters	Green capsicum			
	Mean	Max	Min	±SD
Projected area perpendicular to length (PA _L)	49.27	80.96	29.85	13.64
Projected area perpendicular to width (PA _W)	54.63	90.04	35.55	13.38
Projected area perpendicular to thickness (PA _T)	46.21	80.54	29.59	12.41
Criteria projected area	50.04	83.85	31.66	12.89
Surface area (cm ²)	174.70	297.50	108.04	47.16
Oblate spheroid volume OSV (cm ³)	280.06	577.15	133.71	113.38
Prolate spheroid volume PSV (cm ³)	214.12	464.20	93.41	96.71
Ellipsoid volume (cm ³)	236.49	516.26	111.26	100.17
True density ρ_t (g/cm ³)	0.34	0.46	0.18	0.08
Bulk density ρ_b (g/cm ³)	0.14	0.34	0.09	0.06
Porosity ε (%)	54.71	78.71	1.19	19.17

Frictional properties of capsicum (bell pepper)

The coefficient of friction (μ) of green capsicum was evaluated on different structural surfaces, namely plywood, mild steel, and glass. Among these, plywood exhibited the highest mean coefficient of friction of 0.32, with values ranging from 0.21 to 0.39 and a standard deviation of ± 0.05 . The higher frictional value on plywood can be attributed to its relatively rough and porous surface, which increases resistance to sliding. Similar observations have been reported by Maduako and Faborode (1990) ^[9] and Pathak *et al.* (2019) ^[10], who noted that rough surfaces tend to increase friction due to greater interlocking between the contact surfaces.

In contrast, the coefficient of friction on mild steel was lower, with a mean value of 0.26 (range: 0.22-0.29; ± 0.02), indicating smoother interaction compared to plywood. The lowest coefficient of friction was observed on glass, with a mean value of 0.24, ranging from 0.20 to 0.27 and a standard deviation of ± 0.02 . The smooth and polished nature of glass reduces surface resistance, facilitating easier sliding of capsicum fruits. These results are in agreement with findings by Darfour *et al.* (2022) ^[5] and Abidin *et al.* (2023) ^[1], who reported that smoother surfaces such as glass and metal generally exhibit lower frictional resistance compared to rough materials like wood.

Table 3: Frictional properties of capsicum (bell pepper)

Parameter		Green capsicum			
		Mean	Max	Min	±SD
Coefficient of friction (μ)	Plywood	0.32	0.39	0.21	0.05
	Mild steel	0.26	0.29	0.22	0.02
	Glass	0.24	0.27	0.20	0.02

Conclusion

The study of physical and frictional properties of green capsicum revealed considerable variability in size, shape, volume, and mass, with fruits exhibiting near-spherical geometry as indicated by sphericity (0.84) and aspect ratio (0.86). The dimensional and derived parameters such as

mean diameters, projected areas, and surface area confirmed uniformity suitable for engineering applications, while volumetric analysis showed that the ellipsoidal model provides a reasonable approximation of fruit volume. The lower bulk density (0.14 g/cm³) compared to true density (0.34 g/cm³) resulted in high porosity (54.71%), indicating significant void spaces that are important for aeration but may reduce packing efficiency. Frictional studies demonstrated that the coefficient of friction varies with surface type, being highest on plywood and lowest on glass, highlighting the influence of surface texture on flow behaviour. Collectively, these properties are essential for the design and optimization of grading, handling, storage, packaging, and transportation systems, ensuring improved efficiency and reduced post-harvest losses of capsicum.

Declaration of Competing Interest

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

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