International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(12): 1096-1101
www.biochemjournal.com
Received: 05-09-2025
Accepted: 10-10-2025

Sushant Bakal
Ph.D. Student, Agricultural Engineering Section, D Y Patil Agriculture & Technical University, Talsande, Maharashtra, India

Sagar M. Chavan
Assistant Professor, Department of Agricultural Engineering (PFE), D Y Patil Agriculture & Technical University, Talsande, Maharashtra, India

Mangal A. Patil
Associate Dean, Agricultural Engineering Section, D Y Patil Agriculture & Technical University, Talsande, Maharashtra, India

Sujata V Patil
Ph.D. Student, Agricultural Engineering Section, D Y Patil Agriculture & Technical University, Talsande, Maharashtra, India

Corresponding Author:
Sushant Bakal
Ph.D. Student, Agricultural Engineering Section, D Y Patil Agriculture & Technical University, Talsande, Maharashtra, India

Physical and engineering characterization of selected vegetables for post-harvest handling applications

Sushant Bakal, Sagar M Chavan, Mangal A Patil and Sujata V Patil

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i12Sn.6669

Abstract
Accurate characterization of the physical and engineering properties of fresh vegetables is fundamental for optimizing post-harvest processing technologies. This study systematically quantified the dimensional, geometric, and flow-related attributes of carrots, tomatoes, and spinach to support the design and performance assessment of advanced vegetable handling and washing systems. Carrots exhibited an average length of 158 mm, while tomatoes and spinach leaves measured 51.38 mm and 120 mm, respectively. Geometric mean diameter and sphericity values highlighted distinct morphological patterns, with tomatoes approaching spherical geometry and carrots exhibiting pronounced elongation. Bulk density varied substantially among samples, with spinach displaying the lowest density and highest porosity, indicating greater aeration and reduced packing resistance. True density, frictional properties on stainless steel, surface area, and angle of repose were also evaluated to determine their implications for flowability and equipment-material interactions. The comprehensive dataset generated in this study provides critical empirical inputs for computational modelling, equipment calibration, and the development of energy-efficient, non-destructive post-harvest processing systems. These findings serve as a valuable reference for designing industrial vegetable washers, graders, and transport mechanisms that minimize product loss while enhancing operational efficiency.

Keywords: Fruits and vegetable cleaning machine, Geometric mean diameter, bulk density, true density, surface area, angle of repose

1. Introduction

The physical and engineering properties of agricultural produce play a critical role in the efficient design, operation, and performance evaluation of post-harvest handling and processing systems (Mohsenin, 1986; McCabe *et al*., 1984) [6, 4]. Vegetables such as carrots, tomatoes, and leafy greens are highly perishable commodities that require gentle yet effective washing, grading, conveying, and storage processes to maintain quality and ensure consumer safety. The mechanical behavior, flow characteristics, and structural dimensions of these commodities directly influence equipment design parameters, including hopper angles, conveyor surface materials, bubble-wash performance, aeration requirements, and overall energy consumption.

Understanding fundamental characteristics—such as size, geometric mean diameter, sphericity, density, porosity, surface area, frictional properties, and angle of repose—is therefore essential for developing modern automated and semi-automated vegetable processing systems. These properties determine how vegetables interact with water, air, and contact surfaces during washing, cleaning, and transport, and they provide crucial input for computational modeling, material flow simulations, and the optimization of washing mechanisms.

Despite the increasing adoption of mechanized washing units, particularly bubble-wash and hydrodynamic systems, equipment performance often varies due to insufficient knowledge of commodity-specific physical attributes. Carrots, tomatoes, and spinach exhibit considerable variation in shape, density, and textural characteristics, necessitating detailed quantification for accurate process design. For instance, spherical or near-spherical vegetables such as tomatoes require different flow and agitation conditions compared with elongated or leafy commodities, while porosity and frictional behaviour influence residence time, turbulence, and mechanical stress during processing (Athmaselvi & Varadharaj, 2002) [1].

In this context, the present study aims to comprehensively evaluate key physical and engineering properties of selected vegetables to support the design and optimization of vegetable washers and other post-harvest machinery. The collected data—including dimensional characteristics, density parameters, porosity, angle of repose, surface area, and coefficient of static friction—provide a foundational reference for improving equipment efficiency, ensuring uniform cleaning, minimizing bruising, and reducing post-harvest losses. The findings contribute to developing scientifically informed, energy-efficient, and commodity-specific washing systems suitable for both industrial and small-scale processing applications.

2. Methodology

2.1 Raw Materials

The selected farm vegetables like spinach, carrots and tomatoes were procured directly from field (local language called as wadi) located at Amravati and were used for experimental trials.

2.2 Moisture content: The initial moisture content of the selected vegetable samples was determined using the vacuum oven method, following the AOAC standard procedure 934.06 (1995), as cited by Rosello *et al*. Prior to the experiment, aluminium moisture dishes (60-80 mm in diameter and 25 mm in depth) with tight-fitting lids were cleaned, dried, and conditioned in a desiccator containing silica gel for 48 hours. Two subsamples of 10 g each were weighed using an analytical balance (Make: Adir-Dutt; precision±0.001 g) and transferred into pre-weighed dishes. The samples were then placed in a vacuum oven and dried at 70 °C under a pressure of 13.3 kPa for 24 hours to ensure complete removal of moisture. After drying, the dishes were immediately returned to the desiccator for cooling, and the final mass was recorded to an accuracy of 0.1 mg. Moisture content was calculated based on the loss in weight during drying, representing the mass of water removed from the sample. The dry matter content of each sample was then obtained from the final recorded weight.

Weight of moisture box, g = W1

Weight of moisture box + fresh sample, g = W2

Weight of moisture box + oven dried sample, g = W3

Weight of moisture evaporated, (Ww), g = W2 - W3

Weight of dry matter, (Wd) g = W3 - W1

The moisture content of samples on dry basis (db) was computed, using eqn.

$$\text{Percent moisture content (db)} = \frac{W_w - W_d}{W_d} \times 100 \qquad \text{(i)}$$

2.3 Size

The selected spinach, carrot, and tomato specimens were characterized based on their length, width, and thickness. The width of a leaf was measured by laying it flat on a surface, and the measuring tool was positioned perpendicular to the midrib or central vein. The tool was aligned carefully to measure the widest section of the leaf, spanning from one side to the other. Length measurement was conducted by placing each leaf on a uniform flat surface and aligning a scale along the midrib to record the distance from base to apex, in accordance with Nag *et al*., (2024) [9]. The dimensional analysis was performed on 50 randomly selected units of spinach, carrot, and tomato shown in fig 1 to 3.

The major, medium, and minor axes of each sample were measured with a digital Vernier caliper (±0.01 mm accuracy) and measuring scale, in accordance with the method outlined by Mohsenin (1986) [6].

2.4 Sphericity

Sphericity, which represents the degree to which an object approaches spherical form, was calculated by treating each sample as a tri-axial ellipsoid with intercepts a, b, and c, where the largest axis corresponds to the sphere diameter. The geometric mean diameter (Dg) and sphericity (ϕ) of ripe and unripe carrot and tomato,

$$D_g = \left\{\frac{abc}{a}\right\}^{x/3} \qquad \text{(ii)}$$

$$\varphi = \left\{\frac{(abc)^{1/3}}{a}\right\} \times 100 \qquad \text{(iii)}$$

Where,

a = Longest intercept, mm

b = Longest intercept normal to a, mm

c = Longest intercept normal to a and b, mm

2.5 Bulk density

Bulk density is defined as the ratio of the mass of a material to the total volume it occupies, including the spaces between particles. The measurement was carried out using a 1000 mL graduated cylinder, which was filled from a constant height to ensure uniform settling of the sample, as recommended by Mohite and Sharma. The average value obtained from three trials was reported.

2.6 True density

True density refers to the ratio of the mass of the material to its true volume, which excludes any pore spaces or air gaps within the sample. True density was determined using the liquid displacement method at 25 °C, where the volume displaced by the sample was measured in a liquid medium in which the material was insoluble. Benzene was used as the displacement liquid, and the true density was calculated based on the weight of the sample and the volume of benzene displaced.

$$\text{Density of benzene } (\rho) = \frac{(W3 - W1)\, 0.9971}{W2 - W1} \qquad \text{(iv)}$$

Density of benzene (ρ) = (Density of water at 25°C = 0.9971 g/cc).

The true density was calculated from the following formula,

$$\text{Density of sample} = \frac{W4 - W1}{\left(\frac{W3-W1}{\rho}\right) - \left(\frac{W5-W4}{\rho}\right)} \qquad \text{(v)}$$

- **W1:** Weight of the empty container (e.g., a pycnometer).
- **W2:** Weight of the container filled with the reference substance (e.g., water).
- **W3:** Weight of the container filled with the sample.
- **W4:** Weight of the container filled with the sample and the reference substance.
- **W5:** Weight of the container with the sample and reference substance, after removing some of the reference substance.

2.7 Porosity

Porosity refers to the proportion of the total bulk volume that is not occupied by the solid material. In this study, the porosity of spinach, carrot, and tomato samples was calculated using the values of true density and bulk density, based on the relationship reported by Coskuner and Karababa and Nimkar *et al*., as expressed below

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad \text{(vi)}$$

Where, ρt and ρb are true density and bulk density of carrot & tomato respectively.

2.8 Angle of repose

The angle of repose was measured using a tapered metal hopper with top and bottom openings of 250 mm × 250 mm and 20 mm × 20 mm, respectively. A circular disc (100 mm diameter) was placed below the hopper during the test to allow the vegetables to form a natural heap as they flowed out. The angle of repose for the selected vegetables was determined using the following equation

$$\vartheta = tan^{-1}\left(\frac{2H}{D}\right) \qquad \text{(vii)}$$

Where, θ is the angle of repose, H is the height of the cone (cm) and D is the diameter of disc (cm).

2.9 Coefficient of static friction

The coefficient of static friction was measured using an apparatus consisting of a frictionless pulley, a rectangular box with open ends, a loading pan, and test surfaces made of stainless steel. The rectangular box was placed on the test surface, which was loaded with a known mass of the vegetable sample, while weights were gradually added to the loading pan until the box began to slide. The experiment was conducted for vegetables at different moisture levels, and the coefficient of static friction was calculated from the recorded force at the point of sliding.

3. Results and Discussion

The physical and engineering properties of the selected vegetables were systematically evaluated and shown in table 1. The physical and engineering properties of carrots, tomatoes, and spinach were systematically evaluated to understand their behaviour during handling, washing, agitation, and post-harvest processing. These measurements formed the basis for designing an efficient vegetable washing system, particularly one employing hydrodynamic or bubble-assisted cleaning principles. The recorded parameters included dimensional attributes, geometric mean diameter, sphericity, bulk and true densities, porosity, angle of repose, static friction coefficient, and surface area. Each parameter played a fundamental role in predicting how the vegetables interacted with water movement, air-water bubbling, mechanical agitation forces, and conveyor surfaces.

The evaluation revealed substantial morphological and structural variations among the tested vegetables. Carrot samples showed a substantially elongated and cylindrical shape, which inherently influenced rolling behaviour and water contact patterns. In contrast, tomatoes exhibited near-spherical geometry, allowing more uniform movement and rotational behaviour during immersion. Spinach, being leafy and lightweight, demonstrated unique hydrodynamic properties that demanded gentle yet effective washing approaches. Collectively, the measured values provided critical scientific insights for optimizing washing settings such as water depth, air pressure, agitation time, and flow rate.

The measured dimensions for carrots indicated an average length of 158 mm, width of 32 mm, and thickness of 27 mm. Tomatoes displayed mean dimensions of 51.38 mm in length, 46.38 mm in width, and 43.20 mm in thickness. Spinach leaves were characterized by a considerably larger spread in length (120±35 mm), moderate leaf width (54±5 mm), and extremely low thickness (2.20±0.06 mm). Result was found i.e. length 154 mm, width 28.6 and thickness 27.6 of carrot by Gaikwad *et al* (2018). Similar results were found by Nag *et al*., (2024) [9] in case of spinach. These dimensional values suggested that each vegetable type required distinctly different handling approaches. Carrots, due to their rigidity and elongated shape, would have experienced non-uniform hydrodynamic forces. Their tapered shape could have resulted in uneven exposure to washing currents unless agitation intensity was sufficiently high to compensate for limited rolling. Tomatoes, with a more uniform shape, would have rolled uniformly in turbulent flow regions, allowing for efficient contact of all surfaces with water currents and bubbles. Spinach leaves, on the other hand, had wide laminar surfaces and extremely low thickness, predisposing them to folding, curling, and floating under minimal flow disturbances.

The geometric mean diameter (GMD) was calculated to describe the overall size and shape uniformity. Carrots recorded a GMD of 81.21±0.04 mm, while tomatoes exhibited a GMD of 29.19±0.03 mm. Sphericity values further highlighted morphological differences: carrots displayed a low sphericity of 0.39±0.02, reflecting their elongated shape, whereas tomatoes had a sphericity of 0.90±0.01, indicating near-spherical geometry. Spinach leaves exhibited a sphericity value of 0.78±12, implying moderate shape uniformity despite the natural variation in leaf geometry. Uba *et al*., (2020) [11] did study on physical properties of tomato and found length (mm), width (mm), thickness (mm) and sphericity were in between 36.90 to 63.30, 30.80 to 56.50, 35.80 to 55.80 and 93.21 to 91.84 respectively. High sphericity in tomatoes implied smooth, predictable behaviour in hydrodynamic washing environments. Such vegetables tend to roll easily, which enhances washing uniformity and microbial removal efficiency. Carrots, with significantly lower sphericity, required additional mechanical support to achieve consistent surface exposure. In systems that rely on bubbling action, the non-spherical geometry of carrots may reduce the efficiency of contact between the water-air mixture and the vegetable surface.

Spinach leaves, although moderately spherical in computed numerical terms, behaved differently due to their thin, flexible structure. Their shapes tended to collapse or fold during washing, leading to entrapment of microbial contaminants in crevices if agitation was insufficient. These findings reinforced the need for tailored washing mechanisms based on geometric properties.

Bulk density values were recorded as 473.2±0.02 kg/m³ for carrot, 310.5±0.01 kg/m³ for tomato, and 85±0.05 kg/m³ for spinach. In comparison, true density measurements were 1070 kg/m³ for spinach, 1050 kg/m³ for carrot, and 1230 kg/m³ for tomato. These values demonstrated that all vegetables were denser than water (1000 kg/m³), although their bulk densities varied dramatically due to differences in shape, air pockets, and packing behaviour.

Porosity values varied substantially among the vegetables: spinach exhibited the highest porosity at 90.65±2, followed by tomato at 63.63±1.10, while carrot had the lowest porosity at 6.67±1.20. High porosity in spinach indicated a significant amount of air trapped within and between the leaves. This led to flotation behaviour and prevented uniform wetting unless additional measures were implemented to force immersion. High porosity also meant that water could circulate easily through the leaf structure once submerged, potentially enhancing microbial removal. Tomatoes, with moderate porosity, allowed water to penetrate limited air spaces, supporting efficient washing. Carrots, however, due to very low porosity, restricted internal air movement and were less responsive to agitation-induced water penetration. Their smooth exteriors required higher mechanical turbulence for efficient cleaning.

The angle of repose was recorded as 30±1.2° for spinach, 42.5±1.3° for carrot, and 14.8±1.0° for tomato. On stainless steel surfaces, the static friction coefficient was measured as 0.78±0.05 for spinach, 0.66±0.03 for carrot, and 0.30±0.07 for tomato. Sphericity, bulk density (kg/m3), surface area (mm2), true density (kg/m3), porosity (%), angle of repose and coefficient of friction for stainless steel of carrot was found in between 0.39 to 0.49, 445 to 502 and 1080 to 1158, 57.08 to 59, 43 to 46 and 0.59 to 0.62 respectively by Nithyalakshmi (2024) [7].

These parameters reflected how vegetables moved on surfaces such as conveyor belts or washing channels. Tomatoes, with the lowest angle of repose and friction coefficient, moved smoothly and required minimal force to initiate motion. This characteristic was ideal for automated washing systems, minimizing mechanical resistance and reducing the likelihood of bruising.

Carrots, having higher friction and angle of repose, required more force for movement, which matched their robustness. Spinach, despite having a low to moderate angle of repose, showed the highest friction coefficient due to increased surface contact and moisture retention. This made spinach more prone to sticking on conveyor surfaces, particularly after washing.

Surface area values were recorded as 0.006 m² for spinach, 0.004 m² for carrot, and 0.012 m² for tomato. Sphericity (%), surface area (mm2) and true density (kg/m3) of carrot was found in between 0.28 to 0.38, 5270 to 10,599 and 1000 to 1170" by Jahanbakhshi *et al.*, (2018) [5]. Tomatoes exhibited the highest surface area, indicating a greater extent of exposure for microbial contamination as well as washing action. Carrots displayed comparatively lower surface area due to their compact structure. Surface area played a central role in determining washing requirements. Higher surface area allowed greater contact with wash water, facilitating contaminant removal. Tomatoes therefore responded well to hydrodynamic and bubble agitation mechanisms. Carrots, with lower effective surface area and smooth external structure, required greater turbulence for contaminant detachment. Spinach leaves, despite moderate surface area, required gentle but prolonged washing to allow water to enter folds and remove debris effectively.

3.1 Integrated Interpretation of Physical and Engineering Properties

When considered collectively, the measured parameters demonstrated that each vegetable type required specialized washing conditions:

Tomatoes

- High sphericity
- High true density
- Moderate porosity
- High surface area
- Low friction

These properties made tomatoes ideal for bubble-based and hydrodynamic washing systems. They rolled easily, submerged readily, and responded well to uniform turbulent forces.

Carrots

- Low sphericity
- High rigidity
- Low porosity
- Moderate surface area
- Higher friction

Carrots required more intense agitation and carefully controlled water flow to ensure uniform washing, given their tendency to resist rolling and maintain fixed orientations.

Spinach

- Extremely low bulk density
- High porosity
- High friction
- Very low thickness

This leafy vegetable demanded gentle washing conditions to prevent mechanical damage. High porosity caused flotation, requiring intervention to achieve proper immersion for cleaning.

3.2 Importance of Engineering properties in design of washing machine for selected vegetables

The results underscored several critical engineering considerations:

- Agitation intensity must differ by vegetable type. Tomatoes tolerate higher flow turbulence; spinach does not.
- Water flow patterns must be adjusted to ensure full immersion of leafy vegetables.
- Bubble size and pressure need to be modulated to minimize bruising while maintaining cleaning effectiveness.
- Conveyor belt material and inclination should be optimized based on frictional behaviour.

- Tank depth should accommodate floating and sinking behaviours simultaneously.

These findings ensure that washing systems can be finely tuned to maintain produce quality while achieving microbial decontamination.

3.3 Overall Discussion

The study demonstrated that physical and engineering properties significantly influenced how vegetables behaved under washing conditions. Tomatoes emerged as the most compatible with hydrodynamic and bubble agitation methods due to their geometry and density. Carrots required stronger agitation to overcome geometric constraints. Spinach needed specialized low-turbulence washing to avoid damage and ensure full immersion. This comprehensive understanding of material properties provided a foundation for developing efficient, safe, and produce-friendly washing systems capable of handling a wide variety of vegetables.

Table 1: Engineering properties of spinach, carrot and tomato

Parameters	Spinach	Carrot	Tomato
Moisture content (%)	92-96	88-94	91-95
Length (mm)	120±35	158±10	51±5
Width (mm)	54±5	32±10	46±15
Thickness (mm)	2.20±0.06	27±0.05	43.20±0.09
Geometric mean diameter (mm)	72.20±0.07	81.21±0.04	29.19±0.03
Sphericity	0.78±0.05	0.39±0.02	0.90±0.01
Porosity (mm)	90.65±0.02	6.67±0.10	63.63±0.10
Bulk density (kg/m3)	85±0.05	473±0.02	310±0.01
True density (kg/m3)	1070	1050	1230
Surface area (m2)	0.006	0.004	0.0012
Angle of repose (°)	30.65±1.2	42.50±1.3	14.80±1.0
coefficient of static friction for ss material	0.78±0.05	0.66±0.03	0.30±0.07

by Nithyalakshmi (2024) [7].

Fig 1: Physical properties of fresh spinach

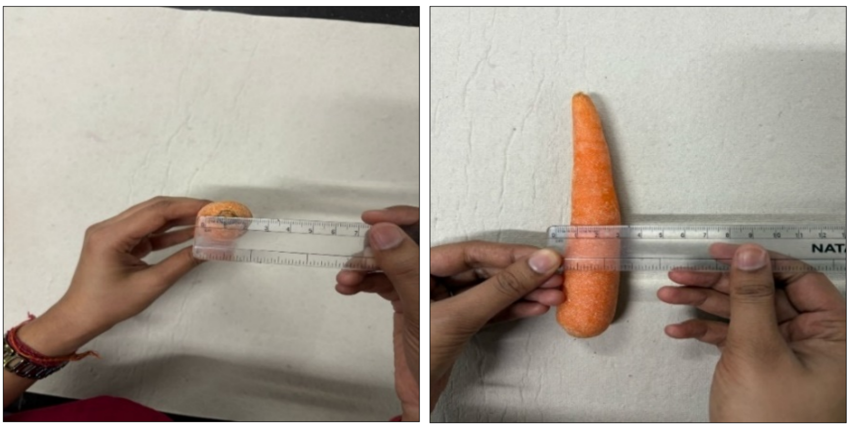

Fig 2: Physical properties of fresh carrot

Fig 3: Physical properties of fresh tomato

4. Conclusion

The study generated comprehensive data on the physical and engineering properties of carrots, tomatoes, and spinach, providing essential information for the design and optimization of vegetable washing and handling systems. Distinct differences were observed among the three commodities in terms of size, geometry, density, porosity, and flow behavior. Carrots exhibited elongated shapes with higher flow resistance, tomatoes showed near-spherical geometry with easy rolling and uniform hydrodynamic movement, while spinach leaves displayed low bulk density, high porosity, and high frictional characteristics that influence flotation and surface adherence.

References

1. Athmaselvi KA, Varadharaju N. Physical and thermal properties of turmeric rhizomes. Madras Agricultural Journal. 2002;89(10-12):666-671.
2. Balasubramanian S, Viswanathan R. Influence of moisture content on physical properties of minor millets. Journal of Food Science and Technology. 2010;47(3):279-284.
3. Jain RK, Bal S. Properties of pearl millet. Journal of Agricultural Engineering Research. 1997;66:85-91.
4. McCabe WL, Smith JC, Harriott P. Unit Operations of Chemical Engineering. New York (NY): McGraw-Hill; 1985.
5. Jahanbakhshi A, Abbaspour-Gilandeh Y, Gundoshmian TM. Determination of physical and mechanical properties of carrot in order to reduce waste during harvesting and post-harvesting. Food Science & Nutrition. 2018;[Epub ahead of print]. DOI:10.1002/fsn3.760
6. Mohsenin NN. Physical properties of plant and animal materials: Structure, physical characteristics, and mechanical properties. New York (NY): Gordon and Breach Science Publishers; 1986.
7. Nithyalakshmi V. Evaluating carrot (*Daucus carota* L.) physical properties and static coefficient of friction for equipment design. International Journal of Research in Agronomy. 2024;7(5):532-536.
8. Ozturk T, Esen B. Physical and mechanical properties of barley. Agricultura Tropica et Subtropica. 2008;41(3):117-121.
9. Nag RH, Sharma PK, Kushwaha HL, Madhusudan BS, Rathod SK, Kumar AK, Kushwah A. Assessing physical characteristics for precision harvester design: A comparative study of spinach, fenugreek, and coriander leafy vegetables. Journal of Scientific Research and Reports. 2024;30(9):631-639.
10. Sahoo PK, Srivastava AP. Physical properties of okra seed. Biosystems Engineering. 2002;83(4):441-448.
11. Uba F, Esandoh EO, Zogho D, Anokye EG. Physical and mechanical properties of locally cultivated tomatoes in Sunyani, Ghana. Scientific African. 2020;10:e00616.