Physicochemical Characterization and Mass Modeling of Blood Fruit (Haematocarpus Validus) – An Underutilized Fruit of Northeastern India

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ABSTRACT
Blood fruit is an underutilized and highly nutritious fruit available in the Northeastern part of India. Proper design and development of sorting and grading systems help in improving the utilization of the fruit. Mass-based grading is more economical than the size-based grading of fruits. The main aim of this study is to investigate the physical, biochemical, thermal, and textural properties of blood fruit and also to determine the best models for predicting the mass of blood fruit using its physical properties. Various physical properties include dimensions, diameters, area, and volume were measured. The fruit is also a good source of phytochemicals like total phenolic compounds (678.21 ± 10.71), flavonoids (489.80 ± 6.72), and anthocyanins (581.21 ± 5.31), respectively. Four different empirical models such as linear, quadratic, power, and s-curve were used to correlate the mass of blood fruit with its physical properties. Fruit width and projected area perpendicular to width in the quadratic model and ellipsoidal volume in the linear model were found best based on the highest R² for predicting the mass of blood fruit. The present study would significantly increase the knowledge base and useful to design and fabricate postharvest equipment like graders and sorters, which in turn increases the value and commercialization of the fruit.

KEYWORDS
Blood fruit; physical properties; correlation; mass modeling; textural properties

Introduction
Blood fruit (Haematoocarpus validus) is an underutilized fruit belongs to the family Menispermaceae and grown in the Northeastern part of India (Rahim et al., 2015). The blood fruit tree is an evergreen perennial woody climber that grows up to 100 m (Momin et al., 2018). It produces flowers in the middle of the August-September (Singh et al., 2012). The flower gradually develops into fruits and attains the ripening stage from March to May (Momin et al., 2018; Singh et al., 2012). The local name of the blood fruit is khoonphal (Figure 1a,b). Local tribes of the Northeastern part of India widely use this fruit for its medicinal properties, such as blood purification, treatment for jaundice, anemic, itching condition, and heart diseases (Rahim et al., 2015; Raigar and Mishra, 2017; Sasikumar and Deka, 2018). The fruit is a rich source of polyphenols and exhibits high antioxidant properties (Sasikumar et al., 2020a, 2020b; Sasikumar and Deka, 2018; Sasikumar et al., 2019b). Despite its countless benefits, the fruit still remains underutilized and did not commercialized due to the high...
perishable nature of the fruit, lack of postharvest technology, and processing knowledge (Sasikumar et al., 2020a, 2019b).

The design and development of post-harvest machinery and proper value addition of any fruits and vegetables requires comprehensive knowledge of physical, biochemical, thermal, frictional, and textural properties (Sasikumar et al., 2019b, 2019a; Vivek et al., 2018). Any system designed without taking these properties into consideration results in decreasing work efficiency with increased product loss (Cavalcante et al., 2012). The physical characteristics such as weight, volume, density, sphericity, porosity, and projected area are useful in postharvest handling, transportation, and storage (Singh and Meghwal, 2019). The biochemical properties include pH, acidity, organic acids, and total soluble solids.
are useful in defining the degree of acceptability in the market with an assurance of safety (Khawas et al., 2014). Proper knowledge of the physical and chemical properties of fruit is useful in assessing the external and internal quality of the fruits (Vivek et al., 2018). Fruits with similar weight and uniform shape have high consumer acceptability in the market. The development of a proper grading system is important for achieving the homogeneous dimensions and mass of the fruits. Size-based grading using mechanical or electrical means for classifying the fruits is the widely followed commercial grading technique. Some indirect methods, like the computer vision system, have also been proposed for grading the fruits based on size (Phate et al., 2020). All these methods involve high initial capital investment and maintenance costs. The cost effective grading system could be developed by constructing the relation between fruit physical properties and mass (Vivek et al., 2017). Various authors have reported the advantage of mass-based grading of apple, orange, and sohiong (Mansouri et al., 2018; Mihailović et al., 2018; Vivek et al., 2018). Mass grading also reduces packaging and handling costs. The determination of fruit mass based on easily measurable geometrical properties could decrease the grading time and avoid excessive workloads and labor costs in the industries (Demir et al., 2020). Therefore, the main objective of this work is to determine the physical, biochemical, textural, and thermal properties of blood fruit and establishing a valid correlation between the physical properties and the fruit mass. The validated regression models like quadratic, s-curve, power, and linear were used to predict the mass of the fruit to develop an accurate automatic grading mechanism. This improves further utilization and commercialization of the fruit and also boost the livelihood of the local tribes of Northeastern India.

Materials and Methods

**Raw Material Collection and Sample Preparation**

Blood fruits were procured from the local market of Tura, West Garo Hills, Meghalaya, India. The fruit was identified and authenticated in the Department of Botany, Guwahati University, Assam, India (Sasikumar et al., 2019a). Collected fruits were initially washed with Potassium permanganate solution (1% w/v) then with distilled water. Later, the fruits were wiped with the tissue paper to remove the excess surface water. The pulp and seed portions were separated manually for further analysis.

**Physical Properties**

Physical properties include mass, length, width, thickness, surface area (SA), geometric mean diameter ($D_g$), arithmetic mean diameter ($D_a$), projected area perpendicular to length (PA_L), projected area perpendicular to width (PA_W), projected area perpendicular to thickness (PA_T), criteria projected area (CPA), true density, bulk density, porosity, measured volume ($V_m$), ellipsoid volume ($V_e$), and oblate spheroid volume ($V_o$) were measured for 100 fruits. Digital weighing balance (XS-6001 M, Mettler Toledo, India) with 0.001 g precision was used for measuring the mass of blood fruit. While fruit dimensions were measured using a digital Vernier caliper (IP67, Mitutoya, Japan). The volume of the fruit was measured following the water displacement method suggested by Akbolat et al. (2008). The remaining properties include $D_g$, $D_a$, SA, true density, bulk density, porosity, $V_e$, $V_o$, PA_L, PA_W, PA_T, and CPA were calculated using the standard empirical Equations. (1–12).

\[
D_a = \frac{(L + W + T)}{3} \tag{1}
\]

\[
D_g = (L \times W \times T)^{\frac{1}{3}} \tag{2}
\]

where $D_a$ and $D_g$ are the arithmetic mean and geometric mean diameter; $L$, $W$, and $T$ represent the length, width, and thickness of fruit.
where $SA$ is the surface area, and $D_g$ is the geometric mean diameter.

$$\rho_t = \frac{M}{V_m}$$

where $\rho_t$ represents true density; $M$ is the mass of fruit and $V_m$ is the measured volume of fruit (volume of water displaced)

$$\rho_b = \frac{M}{V_b}$$

where $\rho_b$ represents bulk density; $M$ is the mass of fruit and $V_b$ is the volume of a box.

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t}$$

where $\varepsilon$ represents porosity.

$$V_o = \frac{4\pi}{3} \left( \frac{L}{2} \right) \left( \frac{W}{2} \right)^2$$

where $V_o$ represents the volume of an oblate spheroid, $L$ represents the length, $W$ represents the width.

$$V_e = \frac{4\pi}{3} \left( \frac{L}{2} \right) \left( \frac{W}{2} \right) \left( \frac{T}{2} \right)$$

where $V_e$ represents ellipsoidal volume, $L$ represents the length, $W$ represents the width, $T$ represents the thickness.

$$PA_L = \frac{\pi LW}{4}$$

where $PA_L$ represents a projected area perpendicular to the length, $L$ represents the length of the fruit, $W$ represents the width of the fruit.

$$PA_W = \frac{\pi WW}{4}$$

where $PA_W$ represents a projected area perpendicular to width, $W$ represents the width of the fruit.

$$PA_T = \frac{\pi TW}{4}$$

where $PA_T$ represents a projected area perpendicular to the length, $T$ represents the thickness of the fruit, $W$ represents the width of the fruit.

$$CPA = \frac{PA_L + PA_W + PA_T}{3}$$

where $CPA$ represents criteria projected area; $PA_L$, $PA_W$, and $PA_T$ represents projected area perpendicular to the length, width, and thickness, respectively.

**Frictional Properties**

**Angle of Repose**

The angle of repose of blood fruit was measured according to Singh and Meghwal (2019). The whole fruit was filled in a hollow cylinder (12.5 x 20.7 cm) placed on a circular platform. The cylinder was gently moved upward direction leaving the fruits to create a heap. The steepest angle ($\theta$) of descent
relative to a horizontal plane was calculated using the heap height (h) and diameter (d) of the base using the following Eq.13.

\[ \theta = \tan^{-1}(2h/d) \]  

\textbf{Static Coefficient of Friction}

The static coefficient of friction between whole fruit and three different surfaces like plywood, aluminum, and rubber sheets was measured according to (Zare et al., 2012). A hollow rectangular (12.3, 12.3, and 9.3 cm) frame was used to properly arrange the fruits on the variable surface. The frame was lifted and slowly the surface was tilted until the fruits start to slide. The tilt angle was noted, and the coefficient of friction of blood fruit on different surfaces was calculated using the following Eq.14.

\[ \mu = \tan \alpha \]  

where \( \mu \) is the coefficient of friction, and \( \alpha \) is the angle of tilt.

\textbf{Textural Properties}

Various textural properties of blood fruit such as hardness, adhesiveness, cohesiveness, springiness, gumminess, and chewiness values were calculated using texture profiles obtained from texture analyzer (Model: EZ-SX, Shimadzu Corporation, Japan). The texture analysis for blood fruit was carried out using a 5 mm diameter cylindrical steel probe and 50 kg load cell. The samples were compressed (4 mm) by the probe with a deformation speed of 0.7 mm/s.

\textbf{Determination of Biochemical Properties}

The pH, titrable acidity (TA), total soluble solids (TSS), ascorbic acid (AA), and reducing sugars of blood fruit were determined according to the method suggested by Khawas et al. (2014). While the nonreducing sugars were determined by subtracting the amount of reducing sugars from the total sugars present in blood fruit. The pH was measured by an electronic pH meter (Mettler Toledo, UK), the titrable acidity was determined by titrating the sample with standard alkaline, and the results were expressed as a percentage of anhydrous citric acid, the hand refractometer (ATAGO-S-28E model) was used to estimate the total soluble solids (TSS) and the values were expressed as °Brix and ascorbic acid content of the sample was titrimetrically estimated by indophenol dye method. The proximate composition like moisture content, protein, ash, crude fat, and fiber of blood fruit was also determined according to the standard AOAC procedures (AOAC, 2010). Moisture content was determined using an oven dryer (Lab-210, ICT, India) at 105°C. Kjeldahl apparatus (KES 06 L, Pelican, India) was used to determine nitrogen content, the amount of nitrogen was multiplied by a factor of 6.25 to get total protein in the blood fruit. Ash content of blood fruit was determined by following dry ashing technique using a muffle furnace (Model-Pyro, Advanced microwave muffle furnace, Milestone, Italy) at 550°C for 90 min. Crude fat was determined using the Soxhlet apparatus (SCS-4, SOCS plus, Pelican, India), with n-hexane as solvent. Carbohydrate content was determined according to the method suggested by Nayak et al. (2016).

\textbf{Determination of Antinutritional Factors and Phytochemicals}

Antinutritional factors like phytate, oxalate, and saponin in the blood fruit was determined. The phytate content was estimated in accordance with Hassan et al. (2011) by taking 2 g of sample in a conical flask, which was previously filled with 100 mL of 2%-concentrated HCl, followed by mixing the solution and incubated in dark condition for 3 h. It was then filtered and 50 mL of obtained filtrate were mixed with 107 mL of distilled water and 10 mL of 0.3% of the ammonium thiocyanate solution. Titration was carried out using standard iron chloride solution (0.00195 g iron/mL) until endpoint i.e. brownish-yellow color observed. The phytate content of samples was measured by multiplying the
Phytin-Phosphorus (1 cm Fe = 1.19 mg Phytin-Phosphorus) with the factor 3.55. Oxalate content of blood fruit was determined in accordance with Abe-Inge et al. (2018) by taking a 0.2 g sample in 40 mL of 1.5 N H₂SO₄ in a beaker and stirred intermittently for a period of 1 h. It was then filtered using Whatman No 1 filter paper and the filtrate was titrated against 0.02 M KMnO₄ till the pink color was observed. Eq. 15 was used to calculate the oxalate content of samples.

\[
\text{Oxalate content} \left( \frac{\text{mg}}{100 \text{g}} \right) = \frac{0.004 \times 0.006303 \times \text{titrvalue}}{0.02 \times \text{Sampleweight}} \times 100
\]  

(15)

The saponin content of blood fruits was determined in accordance with Abe-Inge et al. (2018) by taking 2 g of sample in a Soxhlet extractor (SCS 4 R TS, Pelican, India) and defatted for 8 h using petroleum ether. Extraction was continued further for 8 h using methanol in a solvent containing flask, which was previously pre-heated, cooled, and weighed (W₁). The extract containing flask was dried on a hot plate followed by cooled and weighed (W₂). Eq. 16 was used to calculate the saponin content of samples.

\[
\text{Saponin content} \left( \frac{\text{mg}}{100 \text{g}} \right) = \frac{W_2 - W_1}{\text{weight of sample}} \times 100
\]  

(16)

Phytochemicals like phenols, flavonoids, and anthocyanins were determined in accordance with Singleton et al. (1999), Mihailović et al. (2018) and Chorfa et al. (2016), respectively. Total phenolic content was estimated by the Folin–Ciocalteu method by taking 10 mg of fruit sample mixed with 10 mL of 60% acetone. The mixture was then gently stirred at 30°C for 30 min and filtered through Whatman No-2 filter paper. The obtained supernatant (60 μL), Folin–Ciocalteau reagent (300 μL) and 20% sodium carbonate solution (750 μL) were added in 4.75 mL of water and incubated in dark for 30 min. After incubation, the absorbance of the sample was measured at 760 nm using UV–Vis spectrophotometer (Model-Genesys- S 10 S UV-Vis, Thermo Fisher, USA). The results were then expressed in mg of gallic acid equivalents (mg GAE/100 g). Total flavonoid content was estimated by taking 50 μL of fruit sample mixed with 30 μL of sodium nitrite (5%) and 60 μL of aluminum chloride (10%). The mixture was then measured for absorbance at 510 nm using a UV–Vis spectrophotometer. The results were expressed in mg of rutin equivalents (RE) per 100 g. Total anthocyanins were estimated by taking 1 g of fruit sample mixed with hydrochloric acid, methanol, and water (1:3:16 v/v) solution. Then, the mixture was incubated at dark for 72 h at 4°C and measured for absorbance at 653 nm using UV–Vis spectrophotometer. The results were expressed as mg of cyanidin-3-glucoside equivalent (mg C₃GE/100 g).

**Thermal Properties**

The thermal properties of blood fruit like thermal conductivity, specific heat capacity, diffusivity, and latent heat of fusion were determined using the empirical equations as given below (Vivek et al., 2018).

\[
K = 0.148 + 0.00493 \times M
\]  

(17)

where K and M are the thermal conductivity (J/ms °C) and moisture content (%), respectively.

\[
C_p = 1.675 + 0.025 \times M
\]  

(18)

where \(C_p\) is the specific heat capacity (kJ/kg °C), and M is the moisture content (%).

\[
\alpha = \frac{K}{\rho C_p}
\]  

(19)

where \(\alpha\) is the thermal diffusivity (m²/s), K is the thermal conductivity (J/ms °C), \(\rho\) is the true density (kg/m³), and \(C_p\) is the specific heat capacity (kJ/kg °C).

\[
\lambda = 335 \times W
\]  

(20)
Where $\lambda$ is latent heat (kJ/kg) and $W$ is the weight (kg).

**Mass Modeling**

The mass modeling of blood fruit based on their physical properties was performed using four empirical models, i.e., linear, quadratic, power, and exponential given below. The correlation between mass and physical properties (dimensions, areas, and volumes) were developed according to the following expressions (Eq. 21 to 24).

\[
M = a_0 + a_1X 
\]

\[
M = a_0 + a_1X + a_2X^2 
\]

\[
M = a_0X^{a_1} 
\]

\[
M = a_0e^{a_1X} 
\]

where $M$ is mass (g), $X$ is the physical property of blood fruit, and $a_0$, $a_1$, and $a_2$ are curve-fitting constants. The coefficient of determination ($R^2$) value was used to evaluate the goodness of fit measure for empirical models. In general, for any regression equations, the $R^2$ value near to 1.00 shows the better fit (Lorestani and Ghari, 2012).

**Statistical Analysis**

The regression analysis was performed using IBM SPSS Statistics 26 softwares. The high value of the coefficient of determination ($R^2$) suggests the suitability of a regression model. The validation of the best mass models for dimensions, areas, and volume were performed using a hundred random blood fruit samples.

**Results and Discussions**

**Physical Characteristics**

All the physical characteristics of whole blood fruit were measured at a moisture content of 79.59 ± 0.51% (wet basis) and presented in Table 1. Knowledge of the physical characteristics of fruits are important for the successful design of pre-processing equipment like a cleaner, grader, and sorter (Vivek et al., 2017). Estimation of mass and volume of blood fruits are important for meeting quality standards, increasing market value, and for planning the handling, transportation, packaging, and marketing operations (Khoshnam et al., 2007). The mass of the whole blood fruit is 21.76 ± 0.02 g with the pulp portion available in the fruit varied between 6 and 7 g. The volume of the whole blood fruit is 9.32 cm$^3$. The mass and volume data are useful for calculating the fruit densities, i.e., true density (1.01 g/cm$^3$) and bulk density (0.98 g/cm$^3$), which would in turn favorable for identifying the hidden defects like insect damages in the fruit. Density values are also essential in the transportation and design of processing equipment (Bozalan and Karadeniz, 2011). The average dimensions of the blood fruit such as length, breadth, and thickness were 3.56, 2.49, and 2.51 cm, respectively. Dimensions of the fruits are useful in designing postharvest machinery (Bozalan and Karadeniz, 2011; Rao et al., 2014). The surface area of blood fruit was 10.15 cm$^2$, which is useful in determining the shape and image processing of the fruit. Surface area data is also useful in drying operations to predict the heat and mass transfer rates (Sasikumar et al., 2020a). The Porosity of blood fruit was 32.97%. Porosity data is useful in knowing the tendency of fruit to be partially submerged in water. Determination of average diameters (arithmetic and geometric) of blood fruit would help in obtaining the projected area of a fruit in the turbulent zone or near the turbulent zone of an air stream. These properties are also useful in evaluating the aperture size of the equipment, meant for the sorting of fruits (Vivek et al.,
Table 1. Physical characteristics of blood fruit.

| Physical characteristics               | Mean    | Max    | Min    | Std. dev |
|----------------------------------------|---------|--------|--------|----------|
| Mass (g)                               | 21.76   | 21.79  | 21.74  | 0.02     |
| Surface area (cm²)                     | 10.15   | 10.15  | 10.15  | 0.02     |
| Firmness (N)                           | 14.77   | 15.01  | 14.41  | 0.36     |
| True Density (g/cm³)                   | 1.010   | 1.014  | 1.007  | 0.03     |
| Bulk Density (g/cm³)                   | 0.980   | 0.986  | 0.975  | 0.05     |
| Porosity (%)                           | 32.97   | 33.31  | 32.01  | 0.81     |
| Length (cm)                            | 3.563   | 3.567  | 3.559  | 0.03     |
| Breadth (cm)                           | 2.489   | 2.495  | 2.483  | 0.05     |
| Thickness (cm)                         | 2.51    | 2.57   | 2.45   | 0.05     |
| Measured volume (cm³)                  | 9.324   | 9.327  | 9.320  | 0.02     |
| Oblate spheroid volume (cm³)           | 11.458  | 11.498 | 11.410 | 0.32     |
| Ellipsoidal volume (cm³)               | 11.597  | 11.605 | 11.590 | 0.06     |
| Arithmetic mean diameter (cm)          | 2.854   | 2.863  | 2.843  | 0.06     |
| Geometric mean diameter (cm)           | 2.813   | 2.819  | 2.804  | 0.05     |
| Projected area perpendicular to length (cm²) | 6.930 | 6.955 | 6.908 | 0.23 |
| Projected area perpendicular to width (cm²) | 4.828 | 4.834 | 4.822 | 0.04 |
| Projected area perpendicular to thickness (cm²) | 4.886 | 4.890 | 4.883 | 0.02 |
| Criteria projected area (cm²)          | 5.548   | 5.610  | 5.502  | 0.45     |
| % of consumable                        | 21.78   | 21.85  | 21.71  | 0.05     |
| % of non-consumable                    | 78.22   | 78.36  | 78.09  | 0.10     |
| Angle of repose (deg)                  | 21.58   | 25.11  | 18.32  | 3.15     |
| Plywood                                | 0.29    | 0.33   | 0.26   | 0.02     |
| Aluminum                               | 0.23    | 0.26   | 0.20   | 0.02     |
| Rubber                                 | 0.47    | 0.52   | 0.44   | 0.03     |

Note: Std. dev-indicate Standard deviation

2018). The projected area perpendicular to the length, width, and thickness, and criteria projected area of blood fruit were 6.93, 4.83, and 4.89 cm², respectively. These properties are useful in determining sizing systems, indicate gas permeability, water loss, respiration rates, ripeness index to forecast optimum harvest time, and accurate modeling of heat and mass transfer analysis during drying and cooling (Vivek et al., 2017).

Frictional Properties

Static Coefficient of Friction and Angle of Repose

The static coefficient of friction is important for designing conveyor belts, chute, and calculating the inclination angle (Elansari and Hobani, 2009; Mansouri et al., 2018). Friction depends on the surface roughness. The static coefficient of friction of blood fruit on varied surfaces (plywood, aluminum, and rubber) was determined and presented in Table 1. The coefficient of friction on rubber (0.47) surface was more compared to plywood (0.29) and aluminum (0.23). This may be due to the stronger frictional force. Fruits on the rubber surface slide slow due to the high friction between the rubber surface and the fruit. While fruits slip faster on the aluminum surface due to the weaker frictional force (Mansouri et al., 2018). Similar results were observed for jujube and sohiong (Vivek et al., 2017; Zare et al., 2012). The angle of repose is useful to understand the flow behavior of the product, which helps in the design of storage structures and conveyors (Singh and Meghwal, 2019). The results of the angle of repose are presented in Table 1. The values of the angle of repose of blood fruit was low (21.58) due to the smooth surface and shape of the blood fruit (Ekpunobi et al., 2014).

Biochemical Properties

All the Biochemical properties of blood fruit are presented in Table 2. These properties are important for determining the degree of acceptability in the market with an assurance of safety. The higher pH of blood fruit may be due to the higher concentration of organic acids (Vivek et al., 2017). This results in
high TA and ascorbic acid content. Ascorbic acid of fruits is generally low during the early stages of fruit development and advances toward the stage of physiological maturity (Elansari and Hobani, 2009). The ascorbic acid helps in the formation of collagen and promotes growth, development, and repair of all body tissues. It is also useful in the uptake of iron in the body. TA of fruits is a major quality parameter, which is correlated to the texture and composition (Ekpunobi et al., 2014). The TSS of the blood fruit is 17.11°Brix. The results of reducing (5.83%) and nonreducing (8.88%) sugars indicate the presence of sucrose in the blood fruit. The nonreducing sugar has been usually reported due to the oligosaccharide content of food calculated to be sucrose (Vivek et al., 2018). Moisture content is the most important parameter in the fruits. It influences the texture, taste, weight, appearance, and shelf life (Gani et al., 2018; Khawas et al., 2014). The moisture content of blood fruit is 79 ± 0.71% wb. The protein, ash, crude fat, and fiber content of blood fruits are higher than fruits belong to the berry category. This may be due to the low moisture content of blood fruit. Carbohydrates are the major macronutrients present in the fruit (Njoku et al., 2015; Vivek et al., 2017). The carbohydrate content of blood fruit is 11.20 ± 0.04%, which is higher than the sohiong fruit (Vivek et al., 2018). The determination of the proximate composition of blood fruit could help in the product development, meeting the standard laws and regulatory requirements. Antinutritional compounds are highly responsible for reducing the availability of one or more nutrients and limits the utilization of other nutrients (Davis, 1981). It is important to have knowledge of antinutritional factors present in the fruits. Phytate, oxalate, and saponins were the three antinutritional compounds present in the blood fruit. The results revealed that the phytate (197.25 ± 1.26 mg/100 g) was the most abundant antinutritional compound present in blood fruit followed by saponin 39.14 ± 0.33 mg/100 g and oxalate 11.66 ± 0.50 mg/100 g. Phytates and oxalate being the chief chelating agents in food could adversely affecting the bioavailability of minerals (Davis, 1981). The total polyphenol content of the blood fruit was 678.21 ± 10.71 mg GAE/100 g. The polyphenol content of blood fruit was slightly higher than blueberry (366–457 mg GAE/100 g) and lingonberry (436–636 mg GAE/100 g) (Drózdź et al., 2017). The high phenols may be due to the flavonoids and anthocyanins. The flavonoid content of blood fruit was found to be 489.80 ± 6.72 mg RE/100 g. Increasing flavonoid intake also appeared to be a way to reduce the risk of disease significantly. While anthocyanin content of blood fruit was 581.21 ± 5.31 mg C₃GE/100 g. The anthocyanins in blood fruit was highly compared to many berry varieties and similar fruits like rubus fruit (Bowen-Forbes et al., 2010). The anthocyanins are highly present in red to blue-colored fruits and vegetables, which also acts as a potent antioxidant and helps in increasing the function of the immune system (Sasikumar et al., 2019c).

Table 2. Biochemical properties of blood fruit.

| Composition               | Mean   | Max    | Min    | Std. dev |
|---------------------------|--------|--------|--------|----------|
| Moisture % (wb)           | 79.59  | 80.32  | 78.23  | 0.71     |
| pH                        | 3.86   | 3.97   | 3.73   | 0.18     |
| TA (g CA/100 g)           | 0.65   | 0.68   | 0.62   | 0.03     |
| TSS (°Brix)               | 17.11  | 18.14  | 16.09  | 1.01     |
| Reducing sugar (g/100 g)  | 5.86   | 5.98   | 5.71   | 0.12     |
| Non-Reducing sugar (g/100 g) | 8.88  | 9.02   | 8.70   | 0.14     |
| Carbohydrate (g/100 g)    | 11.20  | 11.28  | 11.18  | 0.04     |
| Protein (g/100 g)         | 4.83   | 5.02   | 4.77   | 0.21     |
| Ash (g/100 g)             | 2.12   | 2.37   | 2.07   | 0.24     |
| Crude fiber (g/100 g)     | 1.56   | 2.09   | 1.01   | 0.51     |
| Crude fat (g/100 g)       | 0.70   | 0.77   | 0.64   | 0.06     |
| Ascorbic acid (mg/100 g)  | 31.23  | 32.87  | 30.18  | 1.23     |
| Phytate (mg/100 g)        | 197.25 | 199.03 | 195.33 | 1.26     |
| Oxalate (mg/100 g)        | 11.66  | 12.13  | 10.54  | 0.50     |
| Saponin (mg/100 g)        | 39.14  | 39.48  | 38.12  | 0.33     |
| Total polyphenols (mg GAE/100 g) | 678.21 | 689.45 | 661.88 | 10.71   |
| Total Flavonoids (mg RE/100 g) | 489.80 | 495.22 | 473.11 | 6.72    |
| Total anthocyanins (mg C₃GE/100 g) | 581.21 | 586.77 | 576.81 | 5.31    |

Note: Std. dev indicate Standard deviation
**Thermal Properties**

All the thermal properties of blood fruit are presented in Table 3. Thermal properties such as thermal conductivity, thermal diffusivity, specific heat capacity, and latent heat of fusion of blood fruit pulp were high due to the high moisture content. The thermal properties are useful in the processing and storage of fruits, and these properties are highly influenced by the moisture content and composition of the fruit (Mansouri et al., 2018). The thermal conductivity of blood fruit was low (0.54 K J/ms°C) which indicates the material conducts less heat energy. Thermal conductivity data is useful in predicting the heat flux during processing (Zare et al., 2012). Thermal diffusivity is useful in finding the rate of temperature spread throughout the material. Thermal diffusivity of blood fruit is high (1.46 x 10^{-4} m²/s) due to the water present in the fruit conducts heat rapidly relative to its volumetric heat capacity (Mansouri et al., 2018; Zare et al., 2012). Results obtained in our study were also in agreement with those reported by Vivek et al. (2018) for their investigation carried out for sohiong fruit. Similarly, the specific heat capacity of the blood fruit is high compared to the orange and tomato (Mansouri et al., 2018).

**Textural Properties**

Fruit texture is a good indicator of the eating quality and freshness of fruit and is a major factor in determining product acceptability. The texture profile analysis of blood fruit was conducted at 79.59% (wb) wet basis moisture content. Various textural properties of fruit like, hardness, cohesiveness, springiness, gumminess, and chewiness were measured and shown in Table 4. The average hardness to penetrate the fruit was found at 25.01 N. The hardness of blood fruit was found higher compared to sohiong fruit (Vivek et al., 2017) and low compared to jamun (Ghosh et al., 2017). The hardness of blood fruit in the second cycle was found at 20.45 N. The other properties like cohesiveness, springiness, and gumminess were found at 0.11, 1.13 mm, and 1.57 N, respectively.

**Mass Modeling of Blood Fruit**

High variation in the mass data of blood fruit could be minimized by mass modeling. The regression analysis was applied between mass and other physical properties of the blood fruit. Four models (linear, quadratic, power, and s-curve) were selected for building a correlation between response and independent variables. Here, the mass was chosen as a response variable and dimensions (L, W, T, and diameters, i.e., D_g, D_a); projected areas (PA_L, PA_W, PA_T CPA, SA)_; and volumes (V_m, V_o, V_e) were

| Table 3. Thermal properties of blood fruit. |
|-------------------------------------------|
| Thermal properties                         | Mean  | Max  | Min  | Std. dev |
|-------------------------------------------|-------|------|------|----------|
| Thermal conductivity (K) J/ms°C            | 0.540 | 0.546| 0.535| 0.05     |
| Specific heat capacity (Cp) kJ/kg °C       | 3.664 | 3.669| 3.660| 0.04     |
| Thermal diffusivity (α) m²/s               | 1.459 | 1.460| 1.458| 0.01     |
| Latent heat of fusion (h) kJ/kg             | 26661.53 | 26670.63 | 26652.66 | 8.43    |

Note: Std. dev-indicate Standard deviation

| Table 4. Textural properties of blood fruit. |
|---------------------------------------------|
| Textural property                           | Mean  | Max  | Min  | Std. dev |
|---------------------------------------------|-------|------|------|----------|
| Hardness (N)                                | 25.01 | 26.10| 24.00| 0.98     |
| Adhesiveness (J)                            | 0.00  | 0.00 | 0.00 | 0.00     |
| Cohesiveness                                | 0.11  | 0.13 | 0.09 | 0.02     |
| Springiness (mm)                            | 1.13  | 1.21 | 1.05 | 0.08     |
| Gumminess (N)                               | 1.57  | 1.63 | 1.51 | 0.06     |
| Chewiness (J)                               | 0.00  | 0.00 | 0.00 | 0.00     |

Note: Std. dev-indicate Standard deviation
chosen as independent variables. The model with a higher value of $R^2$ was selected as the best model for predicting the mass of the blood fruit.

**Mass Modeling Based on Dimensions**

The model coefficients and the value of $R^2$ for mass prediction of blood fruit based on fruit dimensions are presented in Table 5. The results revealed that width, arithmetic mean diameter, and geometric mean diameter, showed the quadratic model with the highest $R^2$ values of 0.984, 0.954, and 0.943, respectively. While length and thickness showed an exponential and linear model with the highest $R^2$ value of 0.954 and 0.943, respectively (Table 5). Among the dimension’s mass prediction based on width would give better results since the $R^2$ value of width was highest. Therefore, the mass modeling of blood fruit based on width was recommended. A quadratic model was suggested by Shahbazi and Rahmati (2013) for mass prediction of fig fruit based on width. Their recommended model was $M = 58.443-3.318 \, W + 0.064 \, W^2$, with an $R^2$ value of 0.969. The quadratic equation based on the width of blood fruit was shown in Eq. 25. The exponential and linear equations were used to predict the relationships between the mass with length, and thickness of blood fruit, respectively (Eq. 26 and 27).

$$M = 0.019W^2 - 0.463W + 26.88 \quad R^2 = 0.974 \quad (25)$$

$$M = 34.55e^{0.001L} \quad R^2 = 0.957 \quad (26)$$

$$M = 12.50T - 290.9 \quad R^2 = 0.943 \quad (27)$$

**Mass Modeling Based on Areas**

The mass modeling based on four projected areas such as $PA_L$, $PA_W$, $PA_T$, and CPA were analyzed. The model coefficients and the value of $R^2$ are presented in Table 5. The quadratic model was found best for $PA_L$, $PA_W$, $PA_T$, and CPA. However, for CPA the quadratic model was found best with the highest $R^2$ (Eq. 28). All the three projected areas were required to calculate the CPA. Hence, selecting CPA would result in reducing the cost and increases the speed of sorting and grading operations (Lorestan and Ghari, 2012). Therefore, among $PA_L$, $PA_W$, and $PA_T$, the $PA_W$ was selected due to the highest value of $R^2$. Similar result was also reported for sohiong fruit, where measurement of $PA_W$ would be more economical since it needs one camera as the main part of the grading system (Vivek

| Dependent variable (g) | Independent variable | The best fitted model | $a_0$ | $a_1$ | $a_2$ | $R^2$ |
|------------------------|----------------------|----------------------|------|------|------|------|
| M                      | L (mm)               | Exponential          | 34.551 | 0.001 | - | 0.957 |
| M                      | W(mm)                | Quadratic            | 26.887 | -0.463 | 0.019 | 0.984 |
| M                      | T(mm)                | Linear               | 12.534 | -290.928 | - | 0.943 |
| M                      | $D_t$ (mm)           | Quadratic            | -17.361 | 5.072 | -0.129 | 0.954 |
| M                      | $D_g$ (mm)           | Quadratic            | -39.144 | 7.023 | -0.172 | 0.943 |
| M                      | SA (mm$^2$)          | Power                | 129.390 | -0.361 | - | 0.845 |
| M                      | $PA_L$ (mm$^2$)      | Quadratic            | -0.017 | 24.88 | -8895 | 0.923 |
| M                      | $PA_W$ (mm$^2$)      | Quadratic            | -0.027 | 27.44 | -6859 | 0.953 |
| M                      | $PA_T$ (mm$^2$)      | Quadratic            | -0.029 | 29.50 | -7455 | 0.937 |
| M                      | CPA (mm$^2$)         | Quadratic            | -0.014 | 16.99 | -4908 | 0.974 |
| M                      | $V_m$ (mm$^3$)       | Power                | 484.610 | -0.663 | - | 0.917 |
| M                      | $V_o$ ((mm$^3$))     | Linear               | -0.124 | 1447 | - | 0.903 |
| M                      | $V_e$ (mm$^3$)       | Linear               | -0.099 | 1179 | - | 0.953 |

- $M$: Mass, $L$: Length, $W$: Width, $T$: Thickness, $D_t$: Arithmetic mean diameter, $D_g$: Geometric mean diameter, $SA$: Surface area, $PA_L$, $PA_W$, and $PA_T$: Projected area perpendicular to length, width, and thickness respectively, $CPA$: Criteria projected area, $V_m$: Measured volume, $V_o$: Oblate spheroid volume, $V_e$: Ellipsoidal volume.
et al., 2017). The quadratic equation for PAw was shown in Eq. 29. The power model was found best for surface area to predict the mass of blood fruit based with the highest $R^2$ value of 0.845 (Eq. 30).

$$M = -0.014CPA^2 + 16.99CPA - 4908 \quad R^2 = 0.974$$  \hspace{1cm} (28)

$$M = -0.027PA_W^2 + 27.44PA_W - 6859 \quad R^2 = 0.953$$  \hspace{1cm} (29)

$$M = 129.3SA^{-0.36} \quad R^2 = 0.845$$  \hspace{1cm} (30)

**Mass Modeling Based on Volumes**

Volume measurement by water displacement method is time-consuming and impractical under field conditions. Hence, ellipsoid ($V_e$), prolate ($V_p$), and oblate ($V_o$) volumes were taken into consideration to predict the mass of the blood fruit. Among these volumes, the volume with the highest $R^2$ and appropriate model was chosen as the best model for predicting the mass of blood fruit. The linear model was found best for $V_o$ and $V_e$. However, for true volume, the power model was found best with the highest $R^2$ value of 0.917. The linear equation based on ellipsoid volume showed the highest $R^2$ value of 0.953 among ellipsoid and oblate volumes (Eq. 31). Similar results were shown for persimmon and sohiong (Shahbazi and Rahmati, 2013; Vivek et al., 2017). The recommended model for sohiong was.

$$M = 2.44 V_e - 0.179 V_e^2 - 0.758 \text{ with } R^2 \text{ value of } 0.945.$$

$$M = -0.099V_W + 1179 \quad R^2 = 0.953$$  \hspace{1cm} (31)

**Conclusion**

The present work aimed to determine various physical, biochemical, thermal, and textural properties of blood fruit. The measured physical properties were then correlated with the fruit mass for mass prediction. The average length, breadth, and thickness of the fruit were 3.56 ± 0.03, 2.49 ± 0.05, and 2.51 ± 0.05 cm, respectively. The surface area and porosity of blood fruit were obtained to be 10.152 ± 0.02 cm² and 32.97 ± 0.81%. The static coefficient of friction was highest for rubber surface and lowest in the case of the aluminum surface. The total phenolic compounds, flavonoids, and anthocyanins were 678.21 ± 10.71, 489.80 ± 6.72, and 581.21 ± 5.31 mg/100 g, respectively. This draws to the conclusion that the fruit is a rich source of phytochemicals. The thermal conductivity of blood fruit was low (0.54 K (J/ms)°C) which indicates the material conducts less heat energy. Among dimensions, areas, and volumes quadratic, quadratic, and linear models in width, projected area perpendicular to the width and ellipsoid volume, respectively, were found best with highest $R^2$. The results obtained from the study can be used to design, development and fabricate different grading and sorting machinery for smooth operation.

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**Disclosure Statement**

The authors declare no conflict of interest.

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