Journal of Scientific & Industrial Research
Vol. 82, August 2023, pp. 892-898
DOI: 10.56042/jsir.v82i08.3182

A Study on the Physical, Biochemical, Thermal and Textural Properties of Key Lime Fruit

Birhang Basumatary, Puja Das, Prakash Kumar Nayak, Deepanka Saikia & Radha krishnan Kesavan*

Dept. of Food Engineering and Technology, Central Institute of Technology, Deemed to be University, Kokrajhar 783370, Assam, India

Received 24 December 2021; revised 21 June 2023; accepted 26 June 2023

In the current study, the properties of key lime (*Citrus X aurantiifolia*) fruit which is abundantly available in north eastern part of India was studied. The outcomes of this work might be helpful for the design and development of machineries required for post-harvest processing of key lime fruits. Key lime fruits are round or elliptical in shape with average mass, volume, sphericity and surface area values of 74.88 ± 12.85 g, 132 ± 13.00 ml, 1.03 ± 0.02% and 79.38 ± 18.32 cm^2, respectively. The average moisture and vitamin C content of key lime fruit was recorded as 88.64 ± 0.97% and 31.27 ± 0.98 mg/100g. Although the production of key lime fruits is great as well as the nutritive importance and market potential, but the utilization of fruits are less due to lack of information regarding nutritional value, perishability, astringency and poor processing technologies. Therefore, the outcomes from this work might be utilized in the manufacturing of value-added products from key lime (*Citrus X aurantiifolia*) through development new machineries and modification of available processing equipments.

Keywords: Citrus fruit, Dimensional, Gravimetric, Lemon, Properties

Introduction

Key lime (*Citrus X aurantiifolia*) fruits are hybrid citrus fruits which constituted with higher juice content. The origin of the fruit is Southeast Asia, but it can also be found in tropical and subtropical areas all around the world. China ranks first in the production of citrus fruits in world, whereas India ranks 5th in the production of citrus fruits. Worldwide production of citrus fruits in 2019 was around 143.755 million tonnes, as per the report of FAO, 2021.[(1)] Key lime fruits are well known as a major source of ascorbic acid, phenolic compounds, flavonoids, dietary fiber and minerals[2–4] and has a positive impact on health. Consumption of key lime fruit juices are associated with the prevention/reduction of risk factors for various diseases including cardiovascular diseases, cancers, obesity, stroke.[5] The health benefits of this juice are attributed to the presence of vitamin C, flavonoids and carotenoids.[6] Almost sixty flavonoid components were detected in citrus fruits and most of them occurring as glycoside or aglycone forms.[5] Furthermore, flavanone and especially hesperidin are flavonoids which are obtainable only from citrus fruits.[6]

*Author for Correspondence
E-mail: k.radhakrishnan@cit.ac.in

Generally, citrus fruits were consumed either in fresh form such as fruit slices or in processed forms such as fruit juices, concentrates, squashes, etc. in order to make it available in the market throughout the year. Manufacturing of fruit juices/concentrates has been carried out by squeezing/pressing in the industries followed by moderate heat treatment process like pasteurization. Further, citrus based fruit drinks are manufactured from citrus fruit concentrates.[7,8] In recent times, intake of citrus fruit juices has been increasing steadily which reflects the commercial potential of citrus fruits in the market.[9]

Several research works on determining the various (physical, thermal, textural, etc.) properties of fruits and other plant-based products have been carried out in order to design the suitable processing machineries or to improve the existing machineries. Few examples of such works on fruits were, myrobalan fruits[10], *Terminalia chebula* fruit[11], cashew apple fruit[12], sohiong fruit[13]and bael fruit.[14] The basic knowledge on the different properties of fruits and other plant-based products will be useful for all the technologists, industry professionals, researchers, etc.[10] Further, the information on the properties of fruits will be helpful in designing the processing equipment used in various unit operations such as, handling, sorting, grading, etc.[11] In addition, the study on the biochemical properties of the fruits will be advantageous in the development of valuable products from fruits and it's by products.[12] The earlier research works indicated that larger number of research works on different properties of fruits were available. The production of key lime in northeastern parts of India is larger and the research studies on the properties of key lime were very limited, according to our knowledge. So, the knowledge on the properties of key lime will be useful in designing as well as developing equipments for the processing of key lime fruits.

The prime objective of the present work was to assess the physical, biochemical, nutritional and thermal properties of key lime (*Citrus X aurantiifolia*) fruits.

Materials and Methods

Materials

Fresh key lime (*Citrus X aurantiifolia*) fruits were purchased from the main market of Kokrajhar, Kokrajhar, Assam. Fully ripen and matured key lime fruits were sorted out and fruits free from any injuries, defects and diseases were selected for the study. Fruits were transported to Food Engineering Laboratory, CIT Kokrajhar, BTR, Assam, India. Fruits were cleaned with tap water before processing and sorted according to their size and stored in a refrigerator at 4 ± 1°C before subjected to any treatments.

Physical Properties

Fifty randomly selected key lime (*Citrus X aurantiifolia*) fruits samples were used for assessment of physical characteristics at room temperature. Key lime's physical attributes (*Citrus X aurantiifolia*) fruits were examined relating to dimensional and gravimetric properties.

Dimensional Properties

Dimensional characteristics such as geometric mean diameter (D_g), arithmetic mean diameter (D_a) and equivalent mean diameter (D_e) of key lime fruits were computed by using Eq. 1–3.[13, 14] and dimensional properties were measured in terms of cm.

$$D_g = LWT^{\frac{1}{3}} \quad \dots (1)$$

$$D_a = \frac{L + W + T}{3} \quad \dots (2)$$

$$D_e = \{ \frac{L(W+T)^2}{4} \}^2 \quad \dots (3)$$

where, L,W and T denotes the length, width and thickness of the fruits.

Gravimetric Properties

Gravimetric attributes of key lime fruits were estimated by checking the weight of 50 fruits. The average weight of Key lime (*Citrus X aurantiifolia*) fruit was calculated by using the weighing balance (Denver instrument, Model-TP-313, Cole-Parmer India, Mumbai 400076, India). Gravimetric properties comprising bulk density (ρ_b), true density (ρ_t), and porosity (ε) were calculated by using Eqs (4–6). To obtain the true density of the fruit, a single fruit of known weight is dipped in water and the change in volume is recorded. Similarly, to obtain the bulk density, a single fruit of known weight is filled in a container whose volume is known.[11,13]

$$\rho_t = \frac{M_f}{V_f} \quad \dots (4)$$

$$\rho_b = \frac{M_f}{V_b} \quad \dots (5)$$

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad \dots (6)$$

where, M_f designates fruit mass; $V_f$specifies fruit volume i.e. volume of water displaced. V_b indicates volume of the box.

The shape of the fruits can be examined by analyzing the parameters such as, sphericity (ϕ), aspect ratio (R_a), flakiness ratio (F_r) and elongation ratio (E_r) by using Eq. (7)–(10).[13]

$$\emptyset = \frac{D_g}{L} \times 100 \quad \dots (7)$$

$$R_a = \frac{W}{L} \quad \dots (8)$$

$$F_r = \frac{T}{W} \quad \dots (9)$$

$$E_r = \frac{L}{W} \quad \dots (10)$$

The surface area of the key lime fruits was computed by using the value of geometric mean diameter and Eqs (11 – 15)[14] were used to determine the projected areas with respect to L,W and T.

$$SA = \pi D_g^2 \quad \dots (11)$$

$$P_T = \frac{\pi TW}{4} \quad \dots (12)$$

$$P_L = \frac{\pi LW}{4} \quad \dots (13)$$

$$P_W = \frac{\pi WW}{4} \quad \dots (14)$$

$$CPA = \frac{P_L + P_W + P_T}{3} \quad \dots (15)$$

Surface area, projected area perpendicular to thickness, geometric mean diameter, width, and length, as well as the standards for the projected area are denoted by the terms SA, P_L, P_T, CPA and P_W.

The shape of the key lime fruits was defined by different shape volumes and these shape volumes were estimated by using the Eqs (16–18).[12,13]

$$V_{ellip}=\frac{4\pi}{3}\times\left(\frac{L}{2}\right)\times\left(\frac{W}{2}\right)\times\left(\frac{T}{2}\right) \quad \ldots (16)$$

$$V_{prol}=\frac{4\pi}{3}\times\left(\frac{W}{2}\right)\times\left(\frac{L}{2}\right)^2 \quad \ldots (17)$$

$$V_{osp}=\frac{4\pi}{3}\times\left(\frac{L}{2}\right)\times\left(\frac{W}{2}\right)^2 \quad \ldots (18)$$

where, V_{ellip} is (volumes of ellipsoid), V_{prol} (prolate spheroid) and V_{osp} (oblate spheroid) of key lime fruits respectively.

Thermal Properties

Determination of thermal properties including specific heat capacity (Cp), thermal conductivity (k), and thermal diffusivity (α) were essential in order to study the relationship between food products and different stages in food processing. Thus, Eqs (19–21) were used for calculating the values of Cp (KJ/kg °C), k (J/ms °C) and α (m^2/s).[12]

$$C_p = 1.675 + 0.025\ M \quad \ldots (19)$$

$$k = 0.148 + 0.00493\ M \quad \ldots (20)$$

$$\alpha = K/\rho C_p \quad \ldots (21)$$

Biochemical Properties

For estimating the biochemical properties of key lime, the juice was prepared by cutting the key lime fruit into two halves and pressed in a juicer. Then, the juice was filtered using muslin cloth to get clear juice and it was used for determining the biochemical properties.

pH of the key lime juice was estimated by using a digital pH meter. Standardization of pH meter with buffer solutions (pH of 4, 7, 10) was carried out prior to the analysis.

Refractometer was used to compute the Total Soluble Solids (TSS) content of key lime juice. The TSS values were expressed in terms of °Brix.

AOAC (1999)[15] method was used for the determination of Titrable Acidity (TA) of key lime juice & the findings of the study were expressed citric acid percentage (%).

The level of ascorbic acid in key lime juice was assessed as per the method of Ordóñez-Santos and Vázquez-Riascos (2010).[16]

The proximate parameters such as moisture, protein, fat, fibre and ash content of the sample was determined using AOAC (2000) method.[17]

Mechanical Properties

The mechanical characteristics of key lime were assessed by using texture analyzer.

Statistical Analysis

All the analysis (physical, thermal, bio-chemical and mechanical properties) was conducted in triplicates. Microsoft Excel 2016 was used to examine the data collected from the analysis. The results of the experiments were given as mean and with the standard error.

Results and Discussion

Physical Properties

Physical properties of fruits provide the information required for the designing of a new processing equipment as well as to improve the existing processing equipment. In this research work, the physical attributes of key lime fruit were analysed and the observed values of various physical analysis were given in Table 1. As observed from the table, the average mass of the key lime was recorded as 74.88 ± 12.85 g (with peel). The average length, width, thickness and volume of key lime was found to be 4.89 ± 0.66 cm, 4.94 ± 0.47 cm, 5.18 ± 0.59 cm and 132 ± 13.00 mL, respectively. These principal values were very significant in the design of equipments used in the pre-processing of key lime fruits such as, cleaners, sorters, etc.[12] The mean value of GMD,

Table 1 — Physical properties of key lime (*Citrus X aurantiifolia*) fruit

S. No	Parameters	Min	Max	Mean	SD
1	Mass (g)	64.17	89.76	74.88	±12.85
2	Length (cm)	4.32	5.64	4.89	±0.66
3	Width (cm)	4.51	5.46	4.94	±0.47
4	Thickness (cm)	4.62	5.81	5.18	±0.59
5	Volume (mL)	120	145	132	±13.00
6	D_g (cm)	4.48	5.63	5.01	±0.57
7	D_a(cm)	4.49	5.64	5.01	±0.57
8	D_e (cm)	4.48	5.64	5.01	±0.57
9	ρ_t(g/cm^3)	0.54	0.62	0.57	±0.04
10	ρ_b(g/cm^3)	0.43	0.47	0.44	±0.02
11	ε (%)	20.00	23.69	22.40	±1.87
12	∅ (%)	1.04	0.998	1.03	±0.02
13	R_a	1.05	0.967	1.02	±0.03
14	F_r	1.02	1.065	1.05	±0.02
15	E_r	0.96	1.034	0.99	±0.03
16	SA (cm^2)	63.11	99.69	79.38	±18.32
17	P_T (cm^2)	16.37	24.88	20.28	±4.26
18	P_L (cm^2)	15.31	24.17	19.16	±4.44
19	P_W(cm^2)	15.99	23.37	19.30	±3.69
20	CPA(cm^2)	15.89	24.14	19.58	±4.13
21	V_{ellip} (cm^3)	47.16	93.61	67.43	±23.29
22	V_{prol}(cm^3)	44.11	90.92	63.85	±23.50
23	V_{osp} (cm^3)	46.08	87.91	64.09	±20.98

AMD and EMD of key lime was found to be 5.01 ± 0.57 cm, 5.01 ± 0.57 cm and 5.01 ± 0.57 cm, respectively. The values of different mean diameters will be useful in the estimation of aperture size for designing separation equipment as well as to calculate the passage of solids in different fluid flows of an air steam.[13] In the design of conveying equipments, specifically hydro conveyors where the fruits have transported in water systems, the values of true and bulk density of key lime were highly crucial. It has to be noted that the values related to shape and size of the fruits may not be sufficient in order to design the equipments related to transportation process.

The average values of true and bulk density of key lime (*Citrus X aurantiifolia*) fruits were found to be 0.57 ± 0.04 and 0.44 ± 0.02 g/cm^3, respectively. The relationship between the intergranular space and the total space engaged by the fruit can be obtained from the porosity of the particular fruit. The average porosity of key lime fruits was found to be 22.40 ± 1.87%. The reduction in the temperature of fruits has been occurring at a faster rate in the highly porous fruits as compared with the fruits with low porosity.[18] In his connection, fruits with low porosity values have considered to be advantageous in order to control the temperature of the fruit during the storage period.[13,19]

The value of sphericity is a major factor in the designing of equipments for sizing and separation processes. The average sphericity of key lime (*Citrus X aurantiifolia*) fruit was found to be 1.03 ± 0.02%. The high sphericity value of the fruit determines that the fruit will not slide, but roll-on specific surface. The sphericity values were helpful in the designing process of separators and sizing equipment.[12] The aspect ratio is known to relate the width of the fruit to its length and the value of aspect ratio is important in the estimation and prediction of fruit shape. Since the aspects ratio is considered to be the relationship between the width and length of the fruit, it gives a detailed idea about the oblong and the shape of the fruit. The average values of R_a, F_r and E_r of key lime (*Citrus X aurantiifolia*) fruits was found as 1.01 ± 0.03, 1.05 ± 0.02 and 0.99 ± 0.03, respectively.

The mean values of SA, $P_{T,}$ P_L and P_W of key lime (*Citrus X aurantiifolia*) were found to be 79.38 ± 18.32 cm^2, 20.28 ± 4.26 cm^2, 19.16 ± 4.44 cm^2, 19.30 ± 3.69 cm^2 and 19.58 ± 4.13 cm^2, respectively. The data related to surface area and different projected areas of key lime were very crucial in the heat and mass transfer study during cooling and heating processes as well as to estimate the gas permeability, reduction in water content, respiration value and ripening index of fruits.[13] The mean values of ellipsoid, prolate spheroid and oblate spheroid volumes of key lime were obtained as 67.43 ± 23.29 cm^3, 63.85 ± 23.50 cm^3 and 64.09 ± 20.98 cm^3, respectively. The data related to the physical properties of fruits such as bael fruit[14], sohiong fruit[10], jatropha fruit[20] were similar to the data registered in our work on the physical properties of key lime fruits.

Thermal Properties

The acquaintance on the thermal parameters of fruits is vital to understand the various heat transfer calculations for the designing of different thermal equipments for drying, cooling, freezing or concentrating food items. The values of thermal parameters of key lime such as, Cp, K and α of key lime fruit has been presented in Table 2 and the mean values of these parameters were recorded as 3.89 ± 0.024 KJ/kg°C, 0.59 ± 0.005 J/ms°C, 1.1 ± 0.1 × 10^{-3}m^2/s, respectively.

From the higher specific heat capacity of key lime, it can be understood that larger energy may be needed for the heating or cooling process of the fruits.[21–23] The higher value of Cp may also be attributed to the high moisture level of key lime or it might be the effect of high nutrient levels of key lime. Similar results for Cp, K and α have been reported for mango and cashew apple.[23,24] Bart-Plange *et al.,*(2012)[(25)] reported that the thermal properties of fruits tend to increase according to the rise in the processing temperature. The major thermal conductivity (K) application is to assess the food heat flux in different processing steps. It may be affected due to the moisture level and porosity of key lime as the escalation in moisture level results in the rise of K.[23] Commonly, the K value of fruits tend to be lower than the juice owing to low water level. Thermal

Table 2 — Thermal properties key lime (*Citrus X aurantiifolia*) fruit

S. No.	Parameters	Unit	Min	Max	Mean	SD
1	Cp	KJ/kg°C	3.87	3.92	3.89	±0.024
2	K	J/ms°C	0.58	0.59	0.59	±0.005
3	α	m^2/s	1.2 × 10^{-3}	1.0 × 10^{-3}	1.1 × 10^{-3}	±0.1 × 10^{-3}

Table 3 — Biochemical properties of key lime (*Citrus X aurantiifolia*) fruit

S. No.	Parameters	Min	Max	Mean	SD
1	Moisture content (%)	87.84	89.78	88.64	±0.97
2	pH	2.91	3.11	3.05	±0.10
3	Titratable acidity (%)	0.63	0.71	0.67	±0.04
4	TSS (°Brix)	9.00	10.00	9.67	±0.51
5	Ascorbic acid / Vitamin C (mg/100g)	31.20	32.90	31.27	±0.98
6	Dry matter (%)	12.16	10.22	11.36	±0.97
7	Carbohydrate (%)	11.04	8.85	10.14	±1.10
8	Protein content (%)	0.6	0.7	0.63	±0.05
9	Fat content (%)	0.21	0.25	0.23	±0.02
10	Fibre content (%)	0.88	0.92	0.90	±0.02
11	Ash content (%)	0.31	0.42	0.36	±0.06
12	Energy (Kcal/g)	54.46	46.47	51.16	±4.02

diffusivity values were used to estimate the rate of changes in the temperature of foods.[23]

Biochemical Properties

Biochemical properties of key lime fruits such as, pH, TSS, TA, ascorbic acid, moisture content, ash content, dry matter, protein content, fibre content, fat content, carbohydrate and energy value were estimated and the data from the biochemical analysis were presented in Table 3.

The moisture content of the fruit was observed to be greater and the mean value was recorded as 88.64 ± 0.97%. From the high moisture content of key lime fruit, it can be observed that it plays a major role in the microbial spoilage and physical deterioration of fruits. Therefore, the knowledge on the moisture content of key lime will be useful in estimation of shelf life and stability of the fruits under different atmospheric conditions.[22] Key lime is known to be having intense acidic fruit and the pH (average) value was found to be 3.05 ± 0.10. Owing to its high acidic in nature, microbial spoilage of key lime by yeast and mold is highly possible due to the resistance of these microbes in high acid conditions.[13] The average TA, TSS of the of key lime was found to be 0.67 ± 0.04%, 9.67 ± 0.51°Brix, respectively. TA level of key lime was found to be lower than Banana (0.18 – 0.58%)[26] and similar to be the TA of Mango (0.28 – 0.87%).[27]

Ascorbic acid has been found commonly in citrus fruits. The average ascorbic acid (Vitamin C) content was observed as 31.27 ± 0.97 mg/100g, respectively. The average dry matter content of key lime was recorded as 11.36 ± 0.97%. The average carbohydrate, protein, fat, fibre, and ash content of Key lime (*Citrus X aurantiifolia*) was found to be 10.14 ± 1.10%, 0.63 ± 0.05%, 0.23 ± 0.02%, 0.90 ± 0.02% and 0.36 ± 0.06%, respectively. The average energy value of key lime (*Citrus X aurantiifolia*) was recorded as 51.16 ± 4.02Kcal/g, respectively.

Table 4 — Textural properties of key lime (*Citrus X aurantiifolia*) fruit

S. No.	Properties	Unit	Min	Max	Mean	STD
1.	Hardness	N	2.51	3.02	2.78	± 0.26
2.	Fracturability	N	1.85	2.79	2.37	± 0.48
3.	Adhesiveness	J	−0.006	−0.01	−0.008	± 0.002
4.	Springiness	Mm	47.71	40.32	43.66	± 3.75
5.	Cohesiveness		20.32	19.33	19.03	± 1.37
6.	Gumminess	N	0.51	0.59	0.53	± 0.05
7.	Chewiness	J	0.24	0.24	0.23	± 0.02
8.	Resilience		5.50	7.13	6.32	± 0.82

Textural properties

The mean values of different textural properties of key lime were listed in Table 4. The average hardness of key lime as found to be 2.78 ± 0.26 N. The resistivity of the fruits to deform or to penetrate against different types of forces has been linked with the hardness value of any material.[12] The values of fracturability and adhesiveness were obtained as 2.37 ± 0.48 N and −0.008 ± 0.002 J respectively. From the value of fracturability, the force needed to make the first substantial interruption on the texture profile analysis curve can be understood.[13]

From Table 4, the values of springiness and cohesiveness of the texture analysis of key lime has been recorded as 43.66 ± 3.75 Mm and 19.03 ± 1.37, respectively. The fruit's ability to regain its height between the end of one bite and the beginning of the next is measured by its springiness value.[13]

Other textural properties including, gumminess, chewiness and resilience of key lime were commonly utilized for estimating the ripening of fruit & to explicit the flavor and taste of the fruit. The mean values of the above-mentioned parameters for key lime were acquired as 0.53 ± 0.05 N, 0.23 ± 0.02 J and 6.32 ± 0.82.

Conclusions

The medicinal and nutritional aspects of key lime (*Citrus X aurantiifolia*) fruit was good as it has higher amounts of various bioactive compounds. To improve the processing of key lime more efficient, the study on the physical, thermal, biochemical, and textural attributes of key lime was performed. The present work highlighted the mean values of some vital physical, biochemical, thermal, and textural characteristics of key lime fruit. The mass of key lime fruits was varied in between 64.17 and 89.76g. The mean values of length, width and thickness of key lime fruits were found as 4.89 ± 0.66 cm, 4.94 ± 0.47 cm and 5.18 ± 0.59 cm, respectively. By computing the values of sphericity R_a, F_r, Er, as 1.03 ± 0.02, 1.02 ± 0.03, 1.05 ± 0.02, 0.99 ± 0.03, respectively, the shape of the fruit was confirmed to be elliptical. The results of this work were crucial for the processing and the production of various products from key lime. Further research work on the different properties of key lime and correlation between the various varieties and maturity stages of key lime has to be carried out which may be employed in the development and design of new machineries for the various post-harvest processing of key lime. Appropriate value-addition methods and processing technologies of key lime fruits may improve the socio-economic status of the farmers.

References

1 FAO, *Citrus Fruit Statistical Compendium 2020* (Rome), 2021.

2 Xu G, Liu D, Chen J, Ye X, Ma Y & Shi J, Juice components and antioxidant capacity of citrus varieties cultivated in China, *Food chem*, **106(2)** (2008) 545–551.

3 Sicari V, Pellicanò T M, Giuffrè A M, Zappia C & Capocasale M, Bioactive compounds and antioxidant activity of citrus juices produced from varieties cultivated in Calabria, *J Food Meas Charact*, **10(4)** (2016) 773–780.

4 Li Z, Jin R, Yang Z, Wang X, You G, Guo J & Pan S, Comparative study on physicochemical, nutritional and enzymatic properties of two Satsuma mandarin (Citrus unshiu Marc.) varieties from different regions, *J Food Compost Anal*, **95** (2020) 103614.

5 Ramful D, Tarnus E, Aruoma O I, Bourdon E & Bahorun T, Polyphenol composition, vitamin C content and antioxidant capacity of Mauritian citrus fruit pulps, *Food Res Inter*, **44(7)** (2011) 2088–2099.

6 Polidori J, Dhuique-Mayer C & Dornier M, Crossflow microfiltration coupled with diafiltration to concentrate and purify carotenoids and flavonoids from citrus juices, *Innov Food Sci Emerg Technol*, **45** (2018) 320–329.

7 Orellana-Palma P, Petzold G, Torres N & Aguilera M, Elaboration of orange juice concentrate by vacuum-assisted block freeze concentration, *J Food Process Preserv*, **42(2)** (2018) e13438.

8 de Oliveira C R, Carneiro R L & Ferreira A G, Tracking the degradation of fresh orange juice and discrimination of orange varieties: An example of NMR in coordination with chemometrics analyses, *Food chem*, **164** (2014) 446–453.

9 Grumezescu A M & Holban A M (Eds.), Nutrients in Beverages in *The Science of Beverages*, vol 12, (Academic Press, New York) (2019).

10 Pathak S S, Sonawane A, Pradhan R C & Mishra S, Effect of Moisture and Axes Orientation on the Mechanical Properties of the Myrobalan Fruits and its Seed Under Compressive Loading, *J Inst Eng (India): A*, **101(4)** (2020) 679–688.

11 Pathak S S, Pradhan R C & Mishra S, Physical characterization and mass modeling of dried *Terminalia chebula* fruit, *J Food Process Eng*, **42(3)** (2019) e12992. https://doi.org/10.1111/jfpe.12992.

12 Singh S S, Abdullah S, Pradhan R C & Mishra S, Physical, chemical, textural, and thermal properties of cashew apple fruit, *J Food Process Eng*, **42(5)** (2019) e1394, https://doi.org/10.1111/jfpe.13094

13 Vivek K, Mishra S & Pradhan R C, Physicochemical characterization and mass modelling of Sohiong (*Prunus nepalensis L.)* fruit, *J Food Meas Charact*, **12(2)** (2018) 923–936.

14 Sonawane A, Pathak S S & Pradhan R C, Physical, thermal, and mechanical properties of bael fruit, *J Food Process Eng*, (2020) e13393. https://doi.org/10.1111/jfpe.13393

15 AOAC, *Official methods of analysis* (16^{th} ed.), (Associate of Official Analytical Chemist, Gaithersburg, Washington, DC, USA), 1999.

16 Ordóñez-Santos L E, Martínez-Girón J & Arias-Jaramillo M E, Effect of ultrasound treatment on visual color, vitamin C, total phenols, and carotenoids content in Cape gooseberry juice, *Food Chem*, **233** (2017) 96–100, https://doi.org/10.1016/j.foodchem.2017.04.114.

17 AOAC, *Official methods of analysis* (17^{th} ed.), (Associate of Official Analytical Chemist Washington, DC, USA), 2000.

18 Rao C G, Engineering for storage of fruits and vegetables: cold storage, controlled atmosphere storage, modified atmosphere storage, (Academic Press, New York) (2015).

19 Naderi-Boldaji M, Fattahi R, Ghasemi-Varnamkhasti M, Tabatabaeefar A & Jannatizadeh A, Models for predicting the mass of apricot fruits by geometrical attributes (cv. Shams, Nakhjavan, and Jahangiri), *Sci Hortic*, **118(4)** (2008) 293–298.

20 Pradhan R, Naik S, Bhatnagar N & Vijay V, Moisture dependent physical properties of jatropha fruit, *Ind Crops Prod*, **29(2–3)** (2009) 341–347, https://doi.org/10.1016/j.indcrop.2008.07.002

21 Ghodki B M & Goswami T K, Thermal and mechanical properties of black pepper at different temperatures, *J Food Process Eng*, **40(1)** (2017) e12342.
22 Shashikumar C, Pradhan R C & Mishra S, Influence of moisture content and compression Axis on Physico-mechanical properties of Shorea robusta seeds, *J Inst Eng (India): A*, **99(2)** (2018) 279–286.
23 Singh S S, Ghodki B M & Goswami T K, Effect of grinding methods on powder quality of king chilli, *J Food Meas Charact*, **12(3)** (2018) 1686–1694.
24 Ikegwu O J & Ekwu F C, Thermal and physical properties of some tropical fruits and their juices in Nigeria, *J Food Technol,* **7(2)** (2009) 38–42.
25 Bart-Plange A, Addo A, Kumi, F & Piegu A K, Some moisture dependent thermal properties of cashew kernel (*Anarcardium occidental L.*), *Aust J Agric Eng*, **3(2)** (2012) 65.
26 Shajib M T I, Kawser M, Miah M N, Begum P, Bhattacharjee L, Hossain A & Islam S N, Nutritional composition of minor indigenous fruits: Cheapest nutritional source for the rural people of Bangladesh, *Food Chem*, **140(3)** (2013) 466–470.
27 Ara R, Jahan S, Abdullah A T M, Fakhruddin A N M & Saha B K, Physico-chemical properties and mineral content of selected tropical fruits in Bangladesh, *Bangladesh J Sci Ind Res*, **49(3)** (2014) 131–136.