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SHORT COMMUNICATION

Physical and chemical characteristics of different cultivars of Indian gooseberry (*Emblica officinalis*)

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Abstract Indian gooseberry (*Emblica officinalis*) commonly known as amla is one of the important fruit of Ayurveda. Nutritional and medicinal properties of amla make it a well known fruit. It is an excellent source of vitamin C, phytochemicals and minerals. Several cultivars of amla are grown throughout different parts of India. Physical characteristics are imperative for designing the equipments for processing, handling and storage. Processing of fruit into value added products is governed by chemical composition of fruit. The current work was aimed to examine the various physical and chemical characteristics of fruits of six cultivars viz. NA-7, NA-9, NA-10, Chakaiya, Balwant and Hathijhool. Characteristics namely height, diameter, geometric mean diameter, sphericity, surface area, aspect ratio, volume, density, rolling resistance, color, textural characteristics, proximate composition, ascorbic acid and polyphenol content was studied. Results showed that the highest fruit size was obtained in NA-7 and the lowest in Hathijhool cultivars while the highest density in Hathijhool and lowest in NA-10 cultivar. The fruit volume of different cultivars varied from 15.00 to 44.93 cm^3. Moisture content was highest in Chakaiya followed by NA-7 cultivar. No significant difference was observed in surface hardness and moisture content of the fruit of different cultivars. The highest ascorbic acid and polyphenols content were found in Chakaiya cultivar. In the different cultivars, ash content ranged between 2.08 and 2.97% and NA-10 cultivar had the highest value followed by Chakaiya cultivar.

Keywords Physical · Chemical · Characteristics · Indian gooseberry · Principal component analysis

Introduction

Indian gooseberry (*Emblica officinalis*) popularly known as amla, is a deciduous tree of the Phyllanthaceae family. According to belief in ancient Indian mythology, it is the first tree to be created in the universe (Khan 2009). Amla fruits are fleshy, round, attractive, deeply ribbed and yellowish green in color. India produced 0.972 million MT of amla in 2015–2016. Uttar Pradesh, Madhya Pradesh and Tamil Nadu are the major states, which accounts 75.88% share in the total production of amla in India (NHB 2016). Amla fruit is the second richest source of vitamin C among fruits after Barbados cherry (*Malpighia glabra* L.) (Singh et al. 2006). It is also an excellent source of amino acid and minerals along with phytochemicals such as polyphenols, tannins, emblicol, linoleic acid, corilagin, phyllemblin and rutin (Murthy and Joshi 2007; Baliga and D'souza 2011). The fruit is acclaimed for being a solution for various ailments including diabetes, inflammation, atherosclerosis, acidity, asthma, skin disorders and corpulence. Indian gooseberry is also reported to possess hypolipidemic, hypoglycemic and antimicrobial activities (Kumar et al. 2013). Therefore, it is utilized as a part of numerous conventional medicinal systems such as Chinese, Tibetan and Ayurvedic drugs.

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Internal quality evaluation of a fruit plays a vital role but the external appearance of fresh produce continues to be the essence of consumer acceptance and marketability. Various physical and mechanical characteristics of fruit such as size and firmness are important quality attributes for the attraction of consumers (Jha et al. 2010). Information regarding dimensional attributes is used in describing fruit shape which is often necessary in horticultural research for a range of differing purposes including cultivar descriptions in applications for plant rights or cultivar registers (Beyer et al. 2002; Schmidt et al. 1995). In addition to this, physical properties of fruits are imperative parameters to establish proper standards of design frameworks for processing, handling, packaging and grading processes. The lack of availability of physical properties data, the currently used systems by and large are devised without taking these criteria into account and the resulting designs leads to inadequate applications, inefficient working and increased product losses. Since, the fresh consumption of amla is limited due to astringent taste therefore most of the produce is converted into value added products through various processing operation. So, the determination and consideration of physical parameters as well as chemical composition of fruit have a paramount importance. Consumer demands for vitamin rich value-added products focuses on adopting fruit cultivar having more vitamin content. High fiber rich fruit cultivars are not suitable for making pulp based value-added products. Therefore, need arises for understanding the chemical composition of fruits. In the same vein, a chemical characteristic of fruits and vegetables are important to reveal food value of the product and exposes the nutritional facts for safety concerns.

Very limited studies related to physical and chemical characteristics of few cultivars of amla fruit have been reported in the literature (Goyal et al. 2007; Parveen and Khatkar 2015). However, consolidated physical and chemical characteristics of most commercial cultivars of amla like NA-7, NA-9, NA-10, Chakaiya, Balwant and Hathijhool is yet to be investigated to expose information needed for proper design of appropriate machines for handling and processing of this valuable fruit. Hence, the current work was aimed to determine physical and chemical characteristics of six most commercial cultivars of amla.

Materials and methods

Fruits of six amla cultivars namely, NA-7, NA-9, NA-10, Chakaiya, Balwant and Hathijhool were selected for this study. The fresh matured fruits were harvested from agriculture farm located at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. Fruits of each cultivar were randomly harvested from the six marked trees located in the farm during the months of November and December. Maturity of the fruits was assessed by visual appearance like color, size and firmness of the fruit. Fully mature fruits were lighter and shinier in color as compared to immature fruits. The diseased, wounded and spotted fruits were sorted out and then healthy fruits were thoroughly washed in running tap water to remove dirt and other extraneous materials from the surface of fruits. The fruits were stored in cool place at 10 ± 1 °C for further analysis. Thirty fruits of each cultivar were randomly selected for experiment and each experiment was performed in three replications.

Determination of physical characteristics

Geometrical characteristics

The axial dimensions of the fruit viz. height (H), diameter1 (D_1) and diameter2 (D_2) was measured using a vernier calipers with an accuracy of 0.01 mm (Fig. 1). The arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (ϕ), surface area (SA), aspect ratio (R_a) was calculated by the following relationships, respectively (Karababa 2006; Goyal et al. 2007; Mohsenin 1986; Aydin and Özcan 2002; Li et al.2011)

$$D_a = \frac{(H + D_1 + D_2)}{3}$$

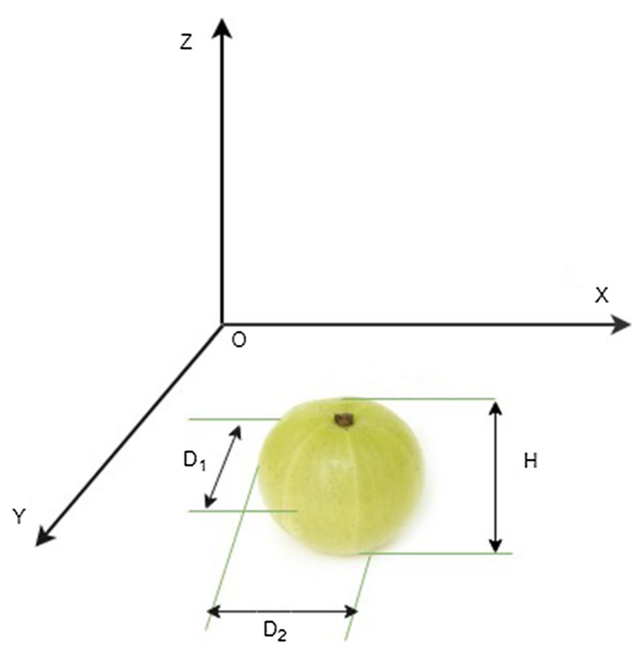

Fig. 1 Three major dimensions of Indian gooseberry fruit

$$D_g = (H \times D_1 \times D_2)^{\frac{1}{3}}$$

$$\Phi = \frac{(H \times D_1 \times D_2)\frac{1}{3}}{H}$$

$$SA = \pi(H \times D_1 \times D_2)^{\frac{2}{3}}$$

$$R_{a=}\frac{D_1}{D_2} \times 100$$

The minimum radius of curvature (R_{min}) and maximum radius of curvature (R_{max}) were calculated using the following formula

$$R_{min} = \frac{H}{2}$$

$$R_{max} = \frac{\left(h^2 + \frac{D_1^2}{4}\right)}{2}$$

where h represents average of height (H) and diameter2 (D_2).

Gravimetrical, frictional and color characteristics

Gravimetrical characteristics of fruits were evaluated in terms of weight, volume and density. Individual weight of fruit of different cultivar was measured on an electronic balance with an accuracy of 0.001 g, while its volume was determined by water displacement method. Frictional characteristics in terms of rolling resistance of fruits on stainless steel (SS), plywood (PS) and canvass (CS) surfaces was determined according to method suggested by Mohsenin (1986). The color characteristics were measured in terms of L* (lightness), a* (redness) and b* (yellowness) value using Hunter Color flex 45/0 (Hunter Associates Laboratory, Reston, Va., USA). Hue and chroma values were further computed using a* and b* values by the following equations.

$$Hue = \tan^{-1}\frac{b^*}{a^*}$$

$$Chroma = \sqrt{a^{*2} + b^{*2}}$$

Mechanical characteristics

Surface hardness and toughness of fruits were measured using Texture analyzer (TA-XT plus; Stable Micro Systems, Surrey, UK) with 3 mm diameter stainless steel probe. The initial force in compression or penetration which corresponds to the insertion of probe through the surface of amla fruits was taken as the surface hardness (SH). Area under curve was referred to as toughness, T which is a measure of the total energy required to penetrate through the fruit sample.

Determination of chemical characteristics

The moisture content of fruits was determined by drying the sample in an oven at 105 °C till constant weight (AOAC 2005). Protein was determined by the Kjeldahl method and calculated by using the conversion factor (Nitrogen content × 6.25). Fat content was determined by automatic Soxhlet unit (SOCS PLUS, Pelican equipment, India) using ether as solvent according to the method of AOAC (2005). Ash content was determined by incinerating dried fruit powder (3.0 g) in a muffle furnace at 550 °C for 6 h, then weighing the residue after cooling to room temperature in a desiccator (AOAC 2005). The crude fiber content was determined by standard method (AOAC 2005) whereas carbohydrate content of the fruits was calculated by the difference between 100 and the sum of moisture, fat, ash, proteins, and fiber percentages. Ascorbic acid content was determined by 2,6-dichlorophenol indophenol (2,6-DCPIP) method (AOAC 2005). Polyphenols were determined by the spectrophotometric method and expressed as gallic acid equivalent (Singleton et al. 1999).

Results and discussion

Principal component analysis

Principal component analysis (PCA) was used to visualize the variation in the physical and chemical characteristics among amla fruits of different cultivars. It is a useful statistical technique to reduce large number of variables into a few variables called principal components (PCs) that describe the greatest variance in the data analyzed. Eigen values for first two principal components (PC1 and PC2) were 52.40% and 25.20% respectively, and cumulatively they capture 77.60% of total variance in the data. The third principal components (PC3) captured lesser variability (16.10%), and are therefore not further discussed. As revealed from the PCA study, Balwant, NA-7 and NA-9 cultivars had positive correlation with both PCs. Chakaiya and NA-10 had negative correlation with first component but positive with second component. Hathijhool cultivar, on the other hand, was least related to any of the cultivar.

Geometrical characteristics

Geometrical characteristics of amla fruits of six cultivars are presented in Table 1. Diameter D_1 and D_2 of the fruits of different cultivars ranged from 3.26 to 4.66 cm and 3.19 to 4.61 cm, respectively. Height of the fruits of different cultivar varied from 2.65 to 4.10 cm. As evident from the Table 1, type of cultivar had a significant effect ($p \leq 0.05$) on all dimensions of the fruit. Highest axial dimensions

Table 1 Geometrical characteristics of fruits

Characteristics	NA-7	NA-9	NA-10	Balwant	Chakaiya	Hathijhool
D_1 (cm)	4.66 ± 0.22^a	4.11 ± 0.08^b	3.68 ± 0.11^c	3.93 ± 0.09^b	3.54 ± 0.11^c	3.26 ± 0.16^d
D_2 (cm)	4.61 ± 0.08^a	4.10 ± 0.06^b	3.30 ± 0.05^e	3.92 ± 0.09^c	3.52 ± 0.04^d	3.19 ± 0.18^e
H (cm)	4.10 ± 0.08^a	3.90 ± 0.10^b	3.36 ± 0.07^d	3.74 ± 0.05^c	3.13 ± 0.06^e	2.65 ± 0.04^f
D_a (cm)	4.45 ± 0.07^a	4.04 ± 0.06^b	3.44 ± 0.08^c	3.86 ± 0.05^b	3.40 ± 0.26^c	3.03 ± 0.03^d
D_g (cm)	4.44 ± 0.10^a	4.04 ± 0.05^b	3.44 ± 0.03^d	3.86 ± 0.10^c	3.39 ± 0.07^d	2.35 ± 0.06^e
SA (cm^2)	62.18 ± 1.67^a	51.30 ± 1.17^b	37.29 ± 1.94^c	48.96 ± 1.56^b	36.29 ± 1.87^c	17.42 ± 0.79^d
S_p (%)	1.08 ± 0.05^a	1.03 ± 0.06^a	1.02 ± 0.07^a	1.03 ± 0.09^a	1.08 ± 0.08^a	0.88 ± 0.03^b
R_a (%)	101.08 ± 0.19^b	100.14 ± 0.30^b	111.51 ± 1.64^a	100.22 ± 0.29^b	100.65 ± 0.25^b	102.09 ± 2.74^b
R_{min} (cm)	2.19 ± 0.17^a	2.00 ± 0.10^{ab}	1.66 ± 0.12^{cd}	1.91 ± 0.13^c	1.82 ± 0.09^{bc}	1.47 ± 0.07^d
R_{max} (cm)	12.30 ± 0.75^a	10.11 ± 0.21^b	6.96 ± 0.3^e	9.26 ± 0.34^c	8.18 ± 0.23^d	5.67 ± 0.63^f

D_1, Diamter1; D_2, Diameter2; H, Height; D_a, Arithmetic mean diameter; D_g, Geometric mean diameter; SA, Surface area; S_p, Sphericity; R_a, Aspect ratio; R_{min}, Radius of curvature (minimum); R_{max}, Radius of curvature (maximum)

Mean ± S.D. with different superscripts in a row indicate significantly different values determined by Duncan's Multiple range test ($p < 0.05$)

were observed in the fruits of NA-7 cultivar and lowest in Hathijhool cultivar. Diameter D_1 (4.66 cm), D_2 (4.61 cm) and height (4.10 cm) of NA-7 were significantly ($p \leq 0.05$) greater than other cultivars. Cultivars had significant difference in axial dimensions of amla fruit as reported by various researchers (Ingale et al. 2016; Ganachari et al. 2010). Highly positive correlation among D_1, D_2 and H was observed in the PCA analysis.

D_a and D_g of amla fruits of different cultivars varied in the range of 3.03–4.45 cm and 2.35–4.44 cm respectively (Table 1). The fruit of NA-7 cultivar had the highest D_a and D_g values, 4.45 and 4.44 cm respectively. D_a and D_g were positively correlated (r = 0.979) and mainly depended on axial dimensions as revealed from correlation analysis. Commercial importance of D_a and D_g are in the estimation of aperture size of the machines, particularly in separation of materials and manufacturing boxes for packaging and transportation to reduce mechanical injury of the fruit.

Surface area is a relevant property for determining the shape of the fruits. This actually indicates the behavior of the fruits on oscillating surfaces during processing (Alonge and Adigun 1999). Surface area, SA of fruits of different cultivars was found in the range of 17.42–62.18 cm^2. SA of the fruit of NA-7 cultivar (62.18 cm^2) was significantly greater than the fruits of other cultivars. Surface area of 51.30 cm^2 was observed in the fruit of NA-9 cultivar, followed by Balwant, NA-10, Chakaiya and Hathijhool cultivars with their means of 48.96, 37.29, 36.29 and 17.42 cm^2, respectively. Surface area is useful in estimating the amount of wax applied to fruit, amount of packaging film to wrap fruit and rate of heating, cooling, freezing, and drying. Thus, it can be derived out from the data that more amount of film will be required to pack fruit of NA-7 cultivar than the fruits of other cultivars. Among the fruit of three cultivars namely, Krishna, NA-7 and Chakaiya, the Krishna showed the highest SA of 37.25 cm^2as reported in the literature (Goyal et al. 2007). Surface area of fruit of Kanchan, Chakaiya and NA-7 cultivar was 3965, 4821 and 3825 mm^2 as reported by Ganachari et al. (2010). This difference could be the result of the individual characteristics of amla cultivars, grown in different environmental and cultivation conditions. PCA analysis revealed that SA had a highly positive correlation with all axial dimensions D_1 (r = 0.957), D_2 (r = 0.931) and H (r = 0.986).

Sphericity, S_p varied from 0.88 to 1.08% in different cultivar of amla fruit (Table 1). High sphericity of the fruit indicates the tendency of the shape towards a sphere. Results showed that the fruits of NA-7 and Chakaiya cultivars were more spherical in shape than the other cultivars fruit. Results are in agreement with Goyal et al. (2007), who reported highest Sp of 1.10% in Chakaiya followed by Krishna (1.08%) and NA-7 (1.04%) cultivars. Sphericity of the fruits of Chakaiya, Kanchan, Krishna and Francis cultivars were 0.958, 0.978, 0.954 and 0.988, respectively as reported by Ingale et al. (2016). PCA analysis indicated that the S_p was highly correlated with all dimensions of fruits which means, as sphericity is increased or decreased, fruit dimensions will follow tandem.

Aspect ratio, R_a varied from 100.14 to 111.51% among the different cultivars of amla fruit. R_a of NA-10 cultivar was significantly greater than that of the other cultivars ($p \leq 0.05$). R_a values of Hathijhool, NA-7, Chakaiya, Balwant and NA-9 was 102.09, 101.08, 100.65, 100.22 and 100.14% respectively, which were non-significant at 5% probability level. Such a high R_a of NA-10 cultivar fruit reveals that it will roll rather than slide on the flat surfaces.

However, the results also suggested that amla fruit will undergo a combination of rolling and sliding action on their surfaces (Omobuwajo et al. 2000; Oyelade et al.2005). Proper understanding on these parameters is important, as modern packaging must comply with the shape of fruits (Wills et al. 1989). R_a was negatively correlated to height (r = − 0.215), D_1 and D_2 (r = − 0.247 and r = − 0.491 respectively).

Radius of curvature, R_{min} and R_{max} of fruit of different cultivar varied from 1.47 to 2.19 cm and 5.67 to 12.30 cm respectively. Radius of curvature was significantly different in all cultivars ($p \leq 0.05$). It was highest in the fruit of NA-7 cultivar and least in Hathijhool cultivar. This property determines how easily the object will roll. These data may be useful in the design of conveyors and hoppers for particulate materials. Both of these characteristics had a strong positive correlation with axial dimensions and weak negative correlation with weight.

Gravimetrical, frictional and color characteristics

Gravimetrical characteristics of the fruits have been represented in Table 2. As depicted from Table 2, fruit weight of different cultivars ranged from 22.30 to 40.12 g. Fruit weight of NA-10 cultivar was significantly ($p \leq 0.05$) higher than other cultivar fruits. Fruit weight of NA-7, NA-9, Balwant and Chakaiya cultivar was 32.50, 34.10, 36.45 and 35.34 g, respectively which were statistically non-significant at 5% probability level. Fruit weight of Hathijhool cultivar was lowest among all six cultivars. The volume of different cultivars ranged from 15.00 to 44.93 cm^3 (Table 2). Fruit of NA-10 cultivar showed significantly larger volume followed by Chakaiya, Balwant, NA-9, NA-7 and Hathijhool. Fruit volumes of NA-7 and NA-9 cultivars were very similar and statistically non-significant at 5% level. Volume of the fruit is important parameter for accurate modeling of heat and mass transfer during cooling and drying of fruit. The results are comparable with data reported by earlier authors (Goyal et al. 2007; Ingale et al. 2016). PCA study suggested a weak correlation of volume with D_2 (r = − 0.084) and H (r = 0.205). The density is an important parameter for screening of quality fruits. Density of fruits was significantly different ($p \leq 0.05$) among different cultivars and varied within the ranges of 1.12–1.48 $g/cm^3$with the highest in Hathijhool and lowest in NA-10 cultivar. Since the values are greater than 1, it can be deduced that amla fruits will sink, when dipped in water. Similar range of density 1.40–1.66 g/cm^3 and 1.063–1.16 g/cm^3 was reported by Goyal et al. (2007) and Ganachari et al. (2010) respectively, in different cultivars of amla fruit. The knowledge of the density of food materials is necessary to estimate floor space during storage and transportation (Mohsenin 1986; Rahman 1995). During hydraulic transportation of fruits and vegetables, the design of fluid velocities is related to both density and shape (Naderiboldaji et al. 2008).

Rolling resistance of the fruits of different cultivars on SS, PS and CS, ranged from 0.039 to 0.149, 0.044 to 0.153 and 0.049 to 0.166 respectively. Irrespective of the cultivars, rolling resistance of fruit was higher in CS and lower in SS. As depicted from the Table 2, the rolling resistance of fruit of Chakaiya cultivar was highest and Hathijhool cultivar was lowest whereas NA-10 cultivar was

Table 2 Gravimetrical, frictional and color characteristics of fruits

Characteristics	NA-7	NA-9	NA-10	Balwant	Chakaiya	Hathijhool
Weight (g)	32.50 ± 1.96^b	34.10 ± 2.51^b	40.12 ± 2.18^a	36.45 ± 1.18^b	35.34 ± 2.22^b	22.30 ± 2.27^c
Volume (cm^3)	27.50 ± 1.44^c	28.90 ± 1.39^c	44.93 ± 1.07^a	41.80 ± 1.87^b	44.52 ± 1.94^{ab}	15.00 ± 2.00^d
Density (g/cm^3)	1.18 ± 0.03^{cd}	1.17 ± 0.04^{cd}	1.12 ± 0.05^d	1.36 ± 0.06^{ab}	1.26 ± 0.07^{bc}	1.48 ± 0.11^a
Rolling resistance^{SS}	0.061 ± 0.010^{cd}	0.069 ± 0.027^{cd}	0.087 ± 0.024^c	0.052 ± 0.019^{cd}	0.149 ± 0.016^a	0.039 ± 0.015^d
Rolling resistance^{PS}	0.068 ± 0.013^{bc}	0.074 ± 0.015^{bc}	0.091 ± 0.010^b	0.058 ± 0.014^{bc}	0.153 ± 0.031^a	0.044 ± 0.016^d
Rolling resistance^{CS}	0.077 ± 0.018^{bc}	0.080 ± 0.017^{bc}	0.099 ± 0.014^b	0.065 ± 0.012^{bc}	0.166 ± 0.026^a	0.049 ± 0.024^d
L*	47.20 ± 1.85^a	46.38 ± 1.65^a	45.62 ± 2.27^a	47.12 ± 1.77^a	48.30 ± 1.36^a	46.67 ± 1.11^a
a*	-7.41 ± 1.38^b	-6.28 ± 1.66^b	-6.05 ± 1.59^b	-6.10 ± 1.47^b	-6.88 ± 1.46^b	-3.15 ± 1.11^a
b*	10.23 ± 1.16^b	11.65 ± 1.17^b	12.10 ± 1.87^b	12.85 ± 2.25^b	16.10 ± 1.82^a	18.72 ± 1.37^a
Hue	-54.07 ± 0.96^e	-61.60 ± 0.59^d	-63.43 ± 0.81^{cd}	-63.08 ± 1.09^c	66.86 ± 1.11^b	-80.44 ± 1.06^a
Chroma	12.63 ± 0.64^d	13.23 ± 0.73^{cd}	13.52 ± 0.76^{cd}	14.22 ± 0.37^c	17.50 ± 0.47^b	19.63 ± 0.40^a

Mean ± S.D. with different superscripts in a row indicate significantly different values determined by Duncan's Multiple range test ($p < 0.05$)

intermediate in all three surfaces. The fruits of NA-7, NA-9 and Balwant cultivar showed no significant difference ($p \leq 0.05$) in rolling resistance on any tested surface. Resistance and consequently its coefficient are affected mainly by the nature and type of the surface in contact. The knowledge of frictional characteristics of fruits is needed for design of handling equipment (Mohsenin 1986). Thus, these data will facilitate to design machinery and reduce damage to the products. Rolling resistance is also useful in designing partitions, lining materials and in bulk transportation of fruits in trucks (Jahromi et al. 2008). Rolling resistance of fruit was positively correlated with weight and negatively correlated with all axial dimensions as revealed from PCA analysis.

The color of the fruit is an important external quality attribute that determines consumer's behavior to accept or reject the sample (Ercisli et al. 2007). It is often used as an indication to the ripeness of fruit. The skin color of the fruit was determined in terms of three standard parameters L*, a* and b*. Lightness (L*) of the fruit of different cultivars showed no significant difference ($p \leq 0.05$) with ranging from 45.62 to 48.30. Chakaiya cultivar had highest value of L* depicting more whiteness amongst all cultivars. The color values, a* and b* varied from − 3.15 to − 7.41 and 10.23 to 18.72 respectively. Fruits of all cultivars were similar ($p \leq 0.05$) in terms of a* and b* values except Hathijhool cultivar. Negative values of a* and positive values of b* relates to more greenness and yellowness in the fruit respectively. The fruit of NA-7 cultivar had more greenish shade whereas Hathijhool cultivar had more yellowish shade on the surface. Results are in agreement with Goyal et al. (2007), who reported highest b* value (− 5.31) in NA-7 as compared to other cultivars Krishna (− 3.73) and Chakaiya (− 4.30). Hue and chroma of fruits of different cultivar varied from − 54.07 to − 80.44 and 12.63 to 19.63, respectively. The values of all cultivars for hue and chroma were significantly different at 5% level. The difference in color of the amla fruits may be due to the difference in genetic makeup and colored pigments, present in the fruit cultivars. PCA analysis observed a negative correlation of L* and a* (r = − 0.318) and positive correlation of L* and b* (r = 0.285).

Mechanical characteristics

Mechanical characteristics of the fruits of different cultivars have been represented in Fig. 2. Surface hardness, SH of fruits ranged from 25.21 to 30.13 N with the highest in Balwant and lowest in NA-10 cultivar. As depicted from the figure, SH variation of fruit of different cultivar was statistically non-significant ($p \leq 0.05$). Similar range of surface hardness was reported by Ingale et al. (2016) in different varieties of amla fruits. Toughness, T representing

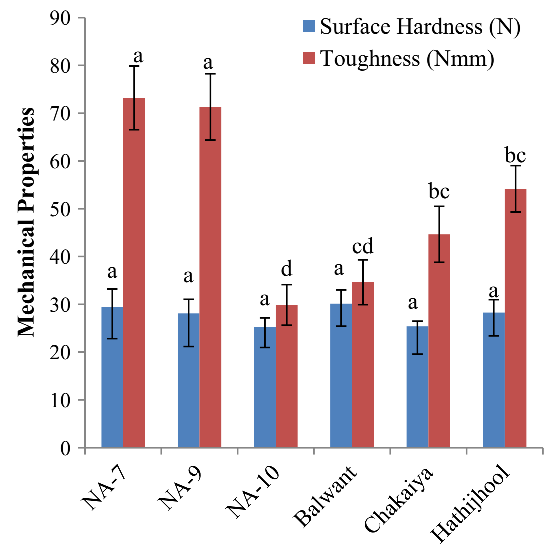

Fig. 2 Mechanical characteristics of different cultivars of Indian gooseberry fruit

the energy required to pass the probe through the fruit, varied from 29.88 to 73.20 Nmm in different cultivars. Highest T value of the fruit was recorded in NA-7 while lowest in NA-10 cultivar. Toughness of NA-7 and NA-9 cultivar was similar but it was significantly higher than the other cultivars ($p \leq 0.05$). Toughness of different cultivar of amla fruit as reported by Goyal et al. (2007) was higher than our findings. The difference in mechanical characteristics might be due to natural biological variance, agro-climatic conditions, physiological character and dynamic ripening processes of different cultivars. PCA study depicted a positive correlation of surface hardness with D_1 (r = 0.503) and D_2 (r = 0.614) but negative correlation with volume (r = − 0.460).

Chemical characteristics

Chemical characteristics of different cultivars of amla are presented in Table 3. As evident from the results that cultivar differences greatly affected the proximate composition as well as ascorbic acid and polyphenol content of the fruit. Evaluation of proximate composition of a food commodity is crucial for assessing the nutritional quality. Moisture content is an important parameter in assessing the quality of fresh fruits and vegetables. High moisture content is an indicative of less shelf life and hence suitable preservation methods must be applied for its better utilization. Moisture content of different cultivar fruits on fresh weight basis varied from 84.89 to 87.50% which was statistically non-significant ($p \leq 0.05$). A moisture content in the range from 81.26 to 84.65% was reported by Parveen and Khatkar (2015) in different varieties of amla fruit.

Table 3 Chemical characteristics of fruits

Characteristics	NA-7	NA-9	NA-10	Balwant	Chakaiya	Hathijhool
Moisture (%)	87.04 ± 1.69^{a}	85.12 ± 1.50^{a}	84.89 ± 1.75^{a}	86.67 ± 1.50^{a}	87.50 ± 1.22^{a}	86.31 ± 1.03^{a}
Fat (%)	0.39 ± 0.02^{bc}	0.21 ± 0.01^{e}	0.40 ± 0.03^{b}	0.35 ± 0.01^{c}	0.46 ± 0.03^{a}	0.30 ± 0.01^{d}
Ash (%)	2.65 ± 0.04^{bc}	2.57 ± 0.07^{c}	2.97 ± 0.10^{a}	2.08 ± 0.16^{d}	2.88 ± 0.19^{ab}	2.18 ± 0.23^{d}
Protein (%)	3.80 ± 0.25^{b}	3.68 ± 0.57^{b}	3.02 ± 0.29^{c}	3.98 ± 0.15^{ab}	4.51 ± 0.50^{a}	3.06 ± 0.09^{c}
Fiber (%)	15.98 ± 0.13^{a}	15.42 ± 0.11^{a}	11.68 ± 0.52^{e}	12.64 ± 0.61^{d}	13.55 ± 0.57^{c}	14.40 ± 0.51^{b}
Carbohydrates (%)	77.18 ± 1.03^{c}	78.12 ± 0.98^{bc}	81.93 ± 1.63^{a}	80.95 ± 0.97^{a}	78.60 ± 1.25^{bc}	80.06 ± 0.97^{ab}
Ascorbic acid (mg/100 g)	559.61 ± 0.92^{b}	512.42 ± 1.00^{e}	535.08 ± 1.13^{c}	498.81 ± 0.75^{f}	585.00 ± 0.18^{a}	528.10 ± 1.08^{d}
Polyphenols (%)	26.92 ± 0.54^{c}	27.75 ± 0.29^{bc}	28.67 ± 1.07^{b}	24.61 ± 0.93^{d}	31.12 ± 1.01^{a}	27.40 ± 0.87^{bc}

Mean ± S.D. with different superscripts in a row indicate significantly different values determined by Duncan's Multiple range test ($p < 0.05$)

A significant ($p \leq 0.05$) variation in fat content was observed which ranged from 0.21 to 0.46%. Fruit of Chakaiya and NA-9 cultivar had the highest and lowest fat values, respectively. Ash content of a material could be used as an index of the mineral constituents. Ash content of the fruits ranged from 2.08 to 2.97%, being highest in NA-10 followed by Chakaiya cultivar. Results were statistically significant at ($p \leq 0.05$). Among the different cultivars, protein content of fruits was highest in Chakaiya (4.51%) and lowest in NA-10 (3.02%) cultivar. Crude fiber consists of cellulose and lignin and its estimation is an index of dietary fiber whose efficiency has been implicated in a variety of gastro-intestinal disorder. High fiber content is also related to textural characteristics of fruit. Fiber content among the cultivars varied from 11.68 to 15.98%. Fruits of NA-7 had the highest fiber content followed by NA-9, Hathijhool, Chakaiya, Balwant and NA-10 cultivar. The high fiber content of the NA-7 cultivar justifies its toughness (Fig. 2). The PCA results also showed the positive correlation of fiber with surface hardness (r = 0.350) and toughness (r = 0.978). The highest carbohydrate content of 81.93% was obtained in NA-10 cultivar but no significant difference was observed in carbohydrate content between NA-10 and Balwant cultivar. Ascorbic acid and polyphenols together accounts the antioxidant property of amla fruit. Wide range of health promoting benefits of antioxidant characteristics has been ascribed in the literature. Ascorbic acid content was significantly different ($p \leq 0.05$) in all cultivars which varied between 498.81 and 585.00 mg/100 g with highest value for Chakaiya cultivar. The polyphenol contents of the different fruit cultivars varied from 24.61 to 31.12%. Chakaiya cultivar had the highest polyphenols content which was significantly ($p \leq 0.05$) different to other cultivars. These results were well corroborated with Parveen and Khatkar (2015); Kulkarani et al. (2017) and Barthakur and Arnold (1991).

Conclusion

The average fruit diameter, D_1, D_2 and height of different cultivars varied in the range of 3.26–4.66, 3.19–4.61 and 2.65–4.10 cm respectively. The average weight and volume of the fruit of NA-10 cultivar were the highest among the different cultivars, whereas Chakaiya was the second cultivar after NA-10 on the basis of weight and volume of the fruit. Canvass surface had the highest rolling resistance whereas stainless steel had the lowest for different fruit cultivars. Therefore, stainless steel material can be used for fabrication of sorting and pricking machine for amla processing. All physical characteristics of amla fruits were found significantly different except surface hardness. The color of the different cultivars was light green-yellowish. Highest toughness was observed in the NA-7 cultivar followed by NA-9, Hathijhool, Chakaiya, Balwant and NA-10. The fruit of Chakaiya cultivar had the highest ascorbic acid and polyphenolic content. Based on the different parameters, chakaiya cultivar can be used for making commercial products and these results can be used for designing of amla processing machines.

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