

# Variability studies of physico-chemical properties of pomegranate (*Punica granatum* L.) using a scoring technique

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## Variability studies of physico-chemical properties of pomegranate (*Punica granatum* L.) using a scoring technique.

**Abstract – Introduction.** India is the largest producer of pomegranate in the world, with rich genetic diversity. The wide range of utility of pomegranate in human health, nutrition and livelihood security has triggered its heavy demand in India and other countries. At present, more than 300 germplasm accessions from indigenous and exotic sources are available in India, but meagre information on the physico-chemical properties of their fruits is available. In our study, the physico-chemical properties of varieties grown under a semi-arid climate were investigated. **Materials and methods.** Our study was carried out at the experimental farm of the National Research Centre on Pomegranate, Solapur, India, during the harvests of 2008–2009 and 2009–2010. Twenty pomegranate varieties were studied with respect to the physico-chemical properties of their fruits. **Results and discussion.** A considerable variation (coefficient of variation: 3.37% to 101.13%) was observed with respect to the 16 characters studied. The values ranged from 12.64 °Brix to 15.39 °Brix for TSS; 0.38% to 3.40% for acidity; 16.67 g to 27.82 g for 100-aril weight; 4.31–38.62 for the maturity index; 59.22% to 77.40% for aril percentage; and 43.30% to 61.00% for juice percentage. Fruit size, rind weight, total aril weight, 100-aril weight, juice weight and aril width were found to have a strong positive correlation ( $P < 0.01$ ) with fruit weight. Based on the total index score obtained, the varieties ‘Bassein Seedless’, ‘Dholka’, ‘Ganesh’, ‘Jyoti’, ‘Kandhari’, ‘KRS’, ‘Mridula’ and ‘P-13’ were found to be suitable for processing and table purposes.

**India / *Punica granatum* / genetic resources / fruits / physico-chemical properties / genetic variation / selection index**

## Étude de la variabilité de propriétés physico-chimiques de grenades (*Punica granatum* L.) par une technique de notation.

**Résumé – Introduction.** L'Inde est le plus grand producteur de grenades dans le monde ; l'espèce présente une vaste diversité génétique dans ce pays. Un large éventail d'utilisation de la grenade pour la santé humaine et la sécurité alimentaire a déclenché une forte demande en Inde et ailleurs. À l'heure actuelle, plus de 300 accessions de matériel génétique d'origine locale ou exotique sont disponibles en Inde, mais peu d'informations sur les propriétés physico-chimiques de leurs fruits sont disponibles. Dans notre étude, les propriétés physico-chimiques de certaines variétés cultivées sous climat semi-aride ont été étudiées. **Matériel et méthodes.** Notre étude a été réalisée à la ferme expérimentale du Centre national de recherche sur la grenade (Solapur, Inde) pendant les campagnes de récolte de 2008–2009 et 2009–2010. Vingt variétés de grenadiers ont été étudiées quant aux propriétés physico-chimiques de leurs fruits. **Résultats et discussion.** Une variation considérable (coefficient de variation : 3,37 % à 101,13 %) a été observée pour 16 caractères étudiés. Les valeurs ont été de 12,64 °Brix à 15,39 °Brix pour les sucres solubles totaux ; 0,38 % à 3,40 % pour l'acidité ; 16,67 g à 27,82 g pour le poids de 100 arilles ; 4,31 à 38,62 pour l'indice de maturité ; 59,22 % à 77,40 % pour le pourcentage d'arille dans le fruit et 43,30 % à 61,00 % pour le pourcentage de jus. Les caractères de dimension des fruits, poids de la coque, poids total de l'arille, poids de 100 arilles, poids de jus et largeur de l'arille se sont révélés être fortement corrélés positivement ( $P < 0,01$ ) avec le poids du fruit. En se basant sur le score total obtenu, les variétés ‘Bassein Seedless’, ‘Dholka’, ‘Ganesh’, ‘Jyoti’, ‘Kandhari’, ‘KRS’, ‘Mridula’ et ‘P-13’ ont été jugées aptes à la transformation et à une consommation à table.

**Inde / *Punica granatum* / ressource génétique / fruits / propriété physicochimique / variation génétique / index de sélection**

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## 1. Introduction

Pomegranate (*Punica granatum* L.) is an ancient fruit with a wealthy history in legend, symbols, art, medicine and religion [1]; this species is capable of growing under tropical to temperate climates. However, its commercial cultivation is mostly confined to tropical and subtropical regions [2, 3]. Its fruits are widely consumed fresh or processed into juice, jams, syrup and sauce [4]. Recent articles reported that biologically active components isolated from different parts of the pomegranate plant can help in treating several human diseases such as cancer (skin, breast, prostate and colon), inflammation, hyperlipidemia, diabetes, ageing, etc. [5–7]. Its wide range of utility in human health, nutrition and livelihood security has triggered heavy demand for its fruits in India and other countries.

India, Iran, China, the USA and Turkey are the five major producers of pomegranate. Now, India has become the largest cultivator and producer of pomegranate in the world [8]. The agro-climatic conditions of the Deccan Plateau of India are highly congenial for fruit production throughout the year [9]. In fact, the composition of pomegranate fruit strongly depends on the type of cultivar, growing region, climate, maturity and cultural practices [10]. India is rich in pomegranate biodiversity, especially the Western Himalayas, where seedling trees locally known as *Daru* come up naturally in abundance. The fruits of such varieties are highly acidic and commercially used for preparation of *anardana* (dried arils), particularly in Uttarakhand and Himachal Pradesh [11, 12]. Sweet-type pomegranate germplasm is widely available in different parts of India and plants have wide variations in their fruit characters [13, 14]. In the recent past, various reports revealed significant variation in fruit physico-chemical traits of pomegranate grown under different agro-climatic conditions of the world.

The aim of our investigation was to study the physico-chemical characteristics of twenty pomegranate varieties and to develop a quality index score thereof that may help in selecting suitable cultivars for various purposes.

## 2. Materials and methods

### 2.1. Experimental site, climatic conditions and varieties

The study was carried out at the experimental farm of the National Research Centre on Pomegranate, Solapur, India, during the harvest periods of 2008–2009 and 2009–2010. The farm is located at 17°68' N lat., 75°91' E long. and 457 m alt. During the experimental period, the mean monthly minimum and maximum temperatures of the area ranged between 16.02 °C and 40.51 °C; the average annual rainfall of both the years was 717 mm, occurring mostly during the months of July to September.

The planting of pomegranate was done on a newly developed experimental plot with marginal to sub-marginal gravelly land with good drainage. Twenty varieties were studied. Two of them were of exotic origin ('Kabuli Yellow' and 'Tabesta'); seventeen were indigenous varieties (Bassein Seedless, Bedana Suni, Bedana Thinskin, Dholka, G-137, Ganesh, Jyoti, Kandhari, Kasuri, KRS, Mridula, P-13, P-16, P-23, P-26, Patna-5 and Yercaud-1); one was an Indian wild type (IC-318728) (*table D*). Four-year-old trees were selected for our investigation. A late *Hasta babar* (autumn season) crop (October–November flowering) was taken in both the years and fruits were harvested during February–April. Fresh ripe fruits of pomegranate varieties at the commercial stage were harvested from all the directions of the tree canopy. Five fruits were randomly selected in each variety per replication with three replications per variety. The fruits were kept at 4 °C until analysed.

### 2.2. Fruit traits

Fifteen fruits of each variety were individually analysed for different physico-chemical characteristics. The fruits were weighed using a high-precision electronic balance. The length and diameter of the fruit, aril length and width, and rind thickness were measured using a Vernier Caliper (Besto<sup>®</sup>, India). After measuring the fruit size, the arils were separated manually from the fruits

**Table I.**

Collection source, fruit rind colour, aril colour and juice taste of 20 different varieties of pomegranate (India).

Varieties	Parentage	Collection source	Rind colour	Aril colour	Juice taste
Bassein Seedless	Bassein Seedless	Indigenous	RHS01 28A	RHS01 158C	Sweet
Bedana Suni	Bedana Suni	Indigenous	RHS01 30B	RHS01 19B	Sweet
Bedana Thinskin	Bedana Thinskin	Indigenous	RHS01 32B	RHS01 11C	Sweet
Dholka	Dholka	Indigenous	RHS01 23A	RHS01 159A	Sweet
G-137	Selection from 'Ganesh'	Indigenous	RHS01 16C	RHS01 38C	Sweet
Ganesh	Selection from 'Alandi'	Indigenous	RHS01 8C	RHS01 38 C	Sweet
IC-318728	Wild type from Western Himalayas	Indigenous	RHS01 37C	RHS01 159 D	Sour
Jyoti	Selection from mixed seedling population of 'Bassein Seedless' and 'Dholka'	Indigenous	RHS01 17A	RHS01 1D	Sweet
Kabuli Yellow	Kabuli Yellow	Exotic	RHS01 1B	RHS01 1D	Sweet
Kandhari	Kandhari	Indigenous	RHS01 25D	RHS01 28A	Sweet
Kasuri	Local Selection	Indigenous	RHS01 25C	RHS01 1D	Sweet
KRS	Local selection	Indigenous	RHS01 22D	RHS01 2D	Sweet
Mridula	'Ganesh' × 'Gul-e-Shah Red'	Indigenous	RHS01 41B	RHS01 46A	Sweet
P-13	Selection from 'Muskat'	Indigenous	RHS01 23C	RHS01 159D	Sweet
P-16	Selection from 'Muskat'	Indigenous	RHS01 7D	RHS01 159 D	Sweet
P-23	Selection from 'Muskat'	Indigenous	RHS01 7D	RHS01 159D	Sweet
P-26	Selection from 'Muskat'	Indigenous	RHS01 40D	RHS01 159D	Sweet
Patna-5	Local collection	Indigenous	RHS01 19B	RHS01 159D	Sweet
Tabesta	Tabestani malas Biranden saveh	Exotic	RHS01 19A	RHS01 158C	Sweet
Yercaud-1	Yercaud local	Indigenous	RHS01 24C	RHS01 158C	Sweet

to estimate total arils and rind weight per fruit. Total aril weight was taken and, subsequently, a hundred arils were counted manually and weighed. The juice was extracted manually by squeezing a hundred arils in muslin cloth and the juice collected from these hundred arils was weighed. Finally, the aril, rind and juice per cent were calculated by dividing their corresponding weight by fruit weight and expressed in percentage. Fruit rind colour and aril colour were determined by using the Royal Horticultural Society Colour Chart<sup>1</sup>.

### 2.3. Acidity, TSS and maturity index

The titratable acidity (TA) was determined by titration against 0.1 N NaOH solution and

<sup>1</sup> Royal Horticultural Society Colour Chart, <http://azaleas.org/index.pl/rhsmafan1.html>, Azalea Soc. Am., 2001.

expressed in terms of g citric acid per 100 mL of juice [15]. The total soluble solids (TSS) were determined using a digital refractometer (model SMART-1, ATAGO, Tokyo, Japan) and reported as °Brix at 21 °C. Subsequently, the maturity index (MI) was calculated by dividing total soluble solids by titratable acidity [16].

### 2.4. Statistical analysis

The experiment was conducted following a randomised block design with three replications. The mean data of two years was subjected to analysis of variance (ANOVA) and differences among the treatment means were determined for significance at  $P < 0.05$  [17]. Pearson's correlation matrix between various traits of twenty varieties was computed by using SPSS Windows version 10 (SPSS Inc., Chicago, USA). The coefficient of variation for various traits was also calculated.

**Table II.**  
Scoring criteria for different traits of pomegranate varieties.

Score	Fruit weight (g)	Aril (%)	Juice (%)	100-aril weight (g)	TSS (°brix)	Acidity (%)	Maturity index	Rind colour <sup>1</sup>	Aril colour <sup>1</sup>
(1)	< 200	< 55	< 45	< 20	<13.5	> 2	< 20	Yellow / yellowish green	Yellowish white / pale yellow / pale yellowish pink
(2)	[200–250[	[55–60[	[45–50[	[20–25[	[13.5–14.0[	]1.5–2.0]	[20–25[	Reddish yellow / orange-yellow / yellowish pink	Pink / yellowish pink
(3)	[250–300[	[60–65[	[50–55[	[25–30[	[14.0–14.5[	]1.0–1.5]	[25–30[	Reddish orange	Deep pink
(4)	[300–350[	[65–70[	[55–60[	[30–35[	[14.5–15.0[	]0.5–1.0]	[30–35[	Deep red	Deep red
(5)	≥ 350	≥ 70	≥ 60	≥ 35	≥ 15	≤ 0.5	≥ 35	Vivid red	Dark red / vivid red

<sup>1</sup> Universal colour language (<http://azaleas.org/index.pl/rhsmacfan1.html>).

## 2.5. Scoring of varieties based on quality parameters

The acceptability of the fruits to the consumer and processor depends on a combination of several quality attributes that are related to the physico-chemical properties of fruits. However, among various physico-chemical traits, fruit weight, percentage of arils and juice, hundred-aril weight, TSS, per cent acidity, the maturity index, and rind and aril colour are found to be the important fruit quality parameters in pomegranate, and were thus considered for scoring of pomegranate varieties; index scores of 1 to 5 were assigned to these traits based on market and consumer preferences (*table II*).

## 3. Results

### 3.1. Variability among varieties

The coefficient of variation in respect of all the 16 quantitative characters studied ranged between 3.37% and 30.82%, except for acidity, where the coefficient of variation value was 101.13% (*table III*). The maximum variability (101.13%) was noted for acidity followed by rind weight (30.82%) and the maturity index (27.58%). However, total aril weight, fruit weight and

rind thickness also showed high variation (21.75% to 24.20%). The correlation of fruit weight with different physico-chemical parameters was worked out (*table IV*). On the correlation matrix, the data showed that fruit weight was significantly and positively correlated ( $P < 0.01$ ) with fruit length ( $r = 0.855^{**}$ ), fruit diameter ( $r = 0.960^{**}$ ), 100-aril weight ( $r = 0.769^{**}$ ), juice weight ( $r = 0.659^{**}$ ), aril width ( $r = 0.588^{**}$ ), total aril weight ( $r = 0.953^{**}$ ) and rind weight ( $r = 0.811^{**}$ ), while it was negatively correlated ( $P < 0.05$ ) with per cent acidity ( $r = -0.555^*$ ).

### 3.2. Physical characteristics

The analysis of variance showed significant differences ( $P < 0.05$ ) among the 20 varieties with respect to all the quantitative traits (*table V*). The mean fruit weight ranged between 96.00 g ('IC-318728' variety) and 288.51 g ('P-23' variety) (*table III, V*). Interestingly, the 'P-23', 'Patna-5', 'P-26' and 'P-13' varieties had bigger fruits (260.30 g to 288.51 g) and their fruit weights were on par with each other. The fruit length ranged from 6.91 cm ('IC-318728' variety) to 9.83 cm ('Patna-5' variety), and diameter from 5.93 cm ('IC-318728' variety) to 8.86 cm ('Patna-5' variety), and even these parameters had positive strong correlations ( $P < 0.01$ ) with fruit weight. The wild variety

**Table III.** Range, mean, standard deviation and coefficient of variation for physico-chemical parameters of fruits of 20 different pomegranate varieties (India, mean 2008–2009 and 2009–2010).

Parameter	Fruit		100-aril		Juice		Aril		Rind weight (g)	TSS (°Brix)	Acidity%	Aril%	Rind thickness (mm)	Juice%	Rind%	Maturity index	
	weight (g)	length (cm)	diameter (cm)	weight (g)	length (cm)	weight (g per 100 arils)	length (cm)	width (cm)									Total weight (g)
Range	Min	96.00	6.91	5.93	16.67	7.51	0.94	0.62	61.41	34.59	12.64	0.38	59.22	2.7	43.30	22.53	4.31
	Max	288.51	9.83	8.86	27.82	15.25	1.09	0.74	205.79	120.03	15.39	3.40	77.40	6.4	61.00	41.19	38.62
Mean		209.61	8.68	7.70	22.77	12.14	1.03	0.68	148.50	61.18	14.44	0.65	70.66	3.54	52.84	29.21	28.53
Standard deviation		49.68	0.74	0.66	3.09	2.40	0.03	0.03	35.94	18.86	0.65	0.65	4.46	0.77	5.40	4.51	7.87
Coefficient of variation (%)		23.70	8.52	8.62	13.57	19.73	3.37	4.41	24.20	30.82	4.48	101.13	6.31	21.75	10.22	15.44	27.58

**Table IV.** Correlation of different fruit physico-chemical characters measured by studies of the crops of 20 different pomegranate varieties in India.

Character	Fruit weight	Fruit length	Fruit dia.	100-aril weight	Juice weight	Aril length	Aril width	Total aril weight	Rind weight	Aril%	Juice%	Rind%	Rind thickness	TSS	Acidity%	Maturity index
Fruit weight	1.000	0.885**	0.960**	0.769**	0.659**	0.484*	0.588**	0.953**	0.811**	0.062	0.301	-0.060	0.534*	0.071	-0.555*	0.472*
Fruit length		1.000	0.857**	0.704**	0.524*	0.484*	0.475*	0.791**	0.812**	-0.080	0.167	0.078	0.516*	-0.040	-0.564**	0.434
Fruit diameter			1.000	0.666**	0.565**	0.461*	0.629**	0.923**	0.777**	0.131	0.248	-0.136	0.618**	0.024	-0.635**	0.495*
100-aril weight				1.000	0.907**	0.499*	0.396	0.778**	0.522*	0.143	0.533*	-0.150	0.182	0.458*	-0.447*	0.576**
Juice weight					1.000	0.526*	0.463*	0.728**	0.334	0.342	0.837**	-0.344	0.087	0.549*	-0.496*	0.712**
Aril length						1.000	0.710**	0.470*	0.372	0.112	0.423	-0.095	0.402	0.138	-0.179	0.329
Aril width							1.000	0.551*	0.489*	0.152	0.416	-0.112	0.605**	-0.067	-0.470*	0.473*
Total aril weight								1.000	0.608**	0.347	0.414	-0.359	0.330	0.152	-0.595**	0.555*
Rind weight									1.000	-0.495*	0.001	0.509*	0.777**	-0.092	-0.334	0.201
Aril%										1.000	0.452*	-0.993**	-0.450*	0.146	-0.371	0.429*
Juice%											1.000	-0.445*	-0.048	0.512*	-0.444*	0.713**
Rind%												1.000	0.470*	-0.143	0.372	-0.405
Rind thickness													1.000	-0.163	-0.249	0.074
TSS														1.000	-0.003	0.376
Acidity%															1.000	-0.800**
Maturity index																1.000

\* , \*\* Significant at the 5% and 1% level of significance, respectively.

(‘IC-318728’) collected from a wild population had small fruits. Aril weight among different varieties also showed considerable variation and 100-aril weight ranged between 16.67 g and 27.82 g in different varieties. The ‘P-26’, ‘Bedana Suni’, ‘P-16’ and ‘P-23’ varieties were found to have medium bold arils (26.07 g to 27.82 g). Hundred-aril juice weight ranged from 7.51 g to 15.25 g.

The varieties ‘P-26’, ‘P-16’, ‘P-13’, ‘P-23’, ‘Jyoti’, ‘Ganesh’, ‘Kandhari’ and ‘KRS’ were more juicy, as evidenced from their high juice contents of 100 arils, while the ‘Tabesta’, ‘Yercaud-1’, ‘IC-318728’ and ‘Bedana Thinskin’ varieties had very low juice contents with hard seeds. Similarly, aril length and width ranged from 0.94 cm to 1.09 cm and 0.62 cm to 0.74 cm, respectively. ‘Ganesh’ and ‘G-137’ showed significantly greater aril dimensions (size). However, the smallest aril size was recorded in the ‘IC-318728’ variety. The values of mean total aril weight per fruit in the ‘P-26’, ‘P-23’ and ‘P-13’ varieties were on par with each other but significantly higher than the other varieties, while rind weight of fruit was maximum in ‘Patna-5’ (120.03 g) owing to its correspondingly greater rind thickness (6.4 mm) (*table Va*).

There were significant differences among varieties with respect to arils (59.22% to 77.40%), juice (43.30% to 61.00%) and rind percentage (22.53% to 41.19%). Aril recovery was found to be quite high in ‘P-16’ (77.40%), ‘P-26’ (75.35%), ‘Jyoti’ (74.10%), ‘Yercaud-1’ (74.08%) and ‘Mridula’ (73.92%), but juice percentage was highest in the ‘Mridula’, ‘P-13’, ‘Jyoti’, ‘Ganesh’, ‘P-16’ and ‘Dholka’ varieties, and their values ranged between 57.41% and 61.00% (*table Vb*).

### 3.3. Total soluble solids, titratable acidity and maturity index

The results for total soluble solids (TSS), acidity % and the maturity index (MI) of different pomegranate varieties revealed significant differences ( $P < 0.05$ ) among the varieties, and their values ranged from 12.64 °Brix to 15.39 °Brix (TSS), 0.38% to 3.4% (acidity) and 4.31 to 38.62 (MI)

(*table Vb*). The ‘Jyoti’, ‘Bedana Thinskin’, ‘Kabuli Yellow’, ‘P-26’ and ‘P-16’ varieties showed high TSS that ranged from 14.91 °Brix to 15.39 °Brix and their values were on par with each other. Despite the higher TSS of ‘Kabuli Yellow’ and ‘Bedana Thinskin’, their other quality parameters such as fruit weight, aril colour, etc., were undesirable. Significantly higher acidity (3.4%) was noted in the ‘IC-318728’ variety, although the titratable acidity in the other varieties was in a preferable range that varied from 0.38% to 0.71%. Similarly, the maturity index [TSS / TA] also varied considerably among the different varieties (4.31 to 38.62). A comparatively higher maturity index was observed in the ‘Bassein Seedless’, ‘Jyoti’, ‘KRS’, ‘Kandhari’ and ‘Ganesh’ varieties; their values varied from 35.90 to 38.60 and they were statistically on par. Interestingly, the lowest maturity index (4.31) was observed in the ‘IC-318728’ variety, indicating its poor quality for table purposes, although it may be suitable for preparation of anardana (dried arils).

### 3.4. Source of collection and qualitative parameters

Most of the collections used in our study were native to India (*table D*). The cultivar ‘Mridula’ has a deep red-coloured rind and arils with a sweet taste, and is thus preferred in the Indian market. Rind colour in other varieties varied from reddish/orangish yellow to yellowish green, while aril colour varied from light pink to pink.

### 3.5. Selection index score based on quality parameters

All the 20 varieties were assessed based on nine selected quality parameters (*table VI*). The ‘Mridula’ variety scored the maximum (34 points) out of a total index score of (45 points), followed by ‘Jyoti’ (31 points). However, the ‘Kandhari’, and ‘KRS’ varieties were also rated as promising types suitable for the processing industry because of their high total index scores (29 points each). Among the other high-scoring varieties, ‘Bassein Seedless’, ‘Dholka’ and ‘Ganesh’



are already commercial, while selections such as 'G-137', P-16' and 'P-26' also have market potential.

## 4. Discussion

### 4.1. Variation among varieties

The 16 quantitative traits that we studied showed a wide variability, and thus can be

considered as traits of interest in breeding programmes of pomegranate. These quantitative traits are influenced by many factors such as variety, climate, soil, etc., and thus bound to vary [10]. The coefficient of variation for these traits ranged from 3.37% to 30.82%, except for acidity, where the coefficient of variation value was 101.13%, as only one variety ('IC 318728') was found to have approximately six times more acidic fruits than the average fruit acidity. Thirteen pomegranate varieties grown in

**Table V.**

Physico-chemical characteristics of fruits of 20 different pomegranate varieties (India, mean 2008-2009 and 2009-2010).

a) Physical characteristics.

Varieties	Fruit weight (g)	Fruit length (cm)	Fruit dia. (cm)	100-aril weight (g)	Juice weight for 100 arils (g)	Aril length (cm)	Aril width (cm)	Total aril weight (g)	Rind weight (g)	Rind thickness (mm)
Bassein Seedless	215.54 cde	8.79 cd	7.80 defg	23.98 cde	13.02 bcde	1.01 e	0.66 hi	150.80 de	64.74 cd	3.3 defg
Bedana Suni	218.92 cd	9.76 a	7.50 fgh	26.64 ab	12.66 bcdef	1.03 de	0.67 gh	137.52 ef	81.40 b	3.2 defgh
Bedana Thinskin	189.78 def	8.48 de	7.69 efgh	19.87 gh	9.41 gh	1.03 de	0.66 hi	133.69 ef	56.09 cdefg	3.5 cde
Dholka	184.21 ef	8.89 cd	7.39 gh	21.17 fg	12.15 cdef	1.03 de	0.69 de	133.18 ef	51.04 defgh	3.5 cdef
G-137	221.63 cd	8.72 cde	8.02 bcde	24.28 bcd	13.01 bcde	1.09 a	0.73 ab	159.98 cd	61.65 cdef	4.4 b
Ganesh	231.27 bc*	8.97 bcd	7.89 def	22.97 def	13.34 abcd	1.09 a	0.74 a	164.31 cd	66.97 bcd	3.8 c
IC-318728	96.00 i	6.91 h	5.93 j	17.63 hi	7.89 h	1.01 e	0.62 j	61.4 1j	34.59 i	2.7 i
Jyoti	228.21 c	8.70 cde	7.98 cde	23.84 cde	14.33 abc	1.04 cd	0.72 ab	167.99 bcd	60.22 cdefg	3.7 c
Kabuli Yellow	140.91 h	7.37 gh	6.78 i	20.68 fg	11.32 defg	0.94 g	0.64 ij	93.67 i	47.24 efghi	3.4 defg
Kandhari	221.35 cd	8.88 cd	7.71 defgh	24.70 bcd	13.30 abcd	1.04 cd	0.67 efgh	161.62 cd	59.74 cdefg	3.1 gh
Kasuri	191.61 def	9.05 bc	7.74 defg	21.17 fg	10.59 fg	1.01 e	0.64 ij	136.98 ef	54.63 def	3.6 cd
KRS	228.88 bc	8.72 cde	8.06 bcde	24.55 bcd	13.27 abcd	1.03 de	0.72 bc	167.22 cd	63.01 cde	3.5 cde
Mridula	146.26 gh	7.72 fg	6.83 i	21.67 efg	13.22 abcde	1.06 b	0.69 defg	108.08 gh	38.18 hi	3.0 ghi
P-13	260.33 ab	9.18 bc	8.18 bcd	24.51 bcd	14.67 ab	1.04 cd	0.68 efgh	188.22 ab	72.10 bc	3.1 fgh
P-16	226.77 c	8.89 cd	8.03 bcde	26.12 abc	14.77 ab	1.05 bcd	0.70 cd	175.46 bc	51.31 defg	3.3 defg
P-23	288.51 a	9.49 ab	8.43 abc	26.07 abc	14.29 abc	1.03 de	0.67 fgh	205.44 a	83.07 b	3.6 cd
P-26	272.71 a	9.07 bc	8.49 ab	27.82 a	15.25 a	1.03 de	0.69 def	205.79 a	66.92 bcd	3.5 cde
Patna-5	288.16 a	9.83 a	8.86 a	22.89 def	11.01 efg	1.06 bc	0.74 ab	168.13 bcd	120.03 a	6.4 a
Tabesta	168.13 fgh	7.91 fg	7.23 hi	16.67 i	7.51 h	0.97 f	0.68 efgh	122.28 fg	45.85 fghi	2.9 hi
Yercaud-1	173.06 fg	8.21 ef	7.42 fgh	18.16 hi	7.870 h	0.99 f	0.66 hi	128.21 fg	44.86 ghi	3.2 efgh
Mean	209.61	8.68	7.70	22.77	12.14	1.03	0.68	148.50	61.18	3.5
LSD ( $P = 0.05$ )	32.02	0.56	0.48	2.46	2.24	0.02	0.02	20.60	15.75	0.39

**Table V.** (continued)

## b) Fruit content and chemical characteristics.

Varieties	Aril%	Juice%	Rind%	TSS (°Brix)	Acidity%	Maturity index
Bassein Seedless	69.92 de	54.24 bcd	30.04 cd	14.66 bcdef	0.38 h	38.62 a
Bedana Suni	62.57 fg	47.56 fgh	37.08 b	14.32 efg	0.54 def	26.36 de
Bedana Thinskin	70.30 cde	47.20 gh	29.70 de	15.21 ab	0.55 de	27.66 cd
Dholka	72.24 bcd	57.41 abc	27.64 defg	14.34 defg	0.47 g	30.73 bc
G-137	71.91 bcd	53.46 cdef	27.98 defg	14.62 bcdef	0.54 def	27.75 cd
Ganesh	71.50 bcd	57.95 abc	29.00 def	13.93 gh	0.39 h	35.90 a
IC-318728	63.95 f	44.63 gh	36.00 b	14.65 bcdef	3.40 a	4.31 h
Jyoti	74.10 abc	59.82 ab	26.41 defg	15.39 a	0.41 h	37.61 a
Kabuli Yellow	66.34 ef	54.64 bcd	33.51 bc	14.97 abcd	0.53 def	28.40 bcd
Kandhari	73.27 bcd	53.40 cdef	26.98 defg	14.60 bcdef	0.40 h	36.63 a
Kasuri	71.64 bcd	49.61 defg	28.46 def	14.28 fg	0.52 ef	27.46 cde
KRS	73.25 bcd	54.00 bcde	27.48 defg	14.66 bcdef	0.40 h	37.07 a
Mridula	73.92 abcd	61.00 a	26.09 efgh	14.57 cdef	0.46 g	31.98 b
P-13	72.77 bcd	59.81 ab	27.65 defg	14.44 cdefg	0.50 efg	28.79 bcd
P-16	77.40 a	56.51 abc	22.53 h	14.91 abcde	0.50 fg	30.07 bcd
P-23	70.09 cde	54.60 bcd	28.84 def	14.76 bcdef	0.53 def	28.15 cd
P-26	75.35 ab	54.82 bcd	24.38 gh	14.97 abc	0.50 efg	29.87 bcd
Patna-5	59.22 g	47.85 efgh	41.19 a	13.59 h	0.57 cd	23.70 ef
Tabesta	72.68 bcd	44.98 gh	27.39 defg	13.41 h	0.62 c	21.72 f
Yercaud-1	74.08 cd	43.30 h	25.78 fgh	12.64 i	0.71 b	17.82 g
Mean	70.82	52.84	29.21	14.44	0.65	28.53
LSD ( $P = 0.05$ )	4.07	6.17	3.80	0.63	0.04	3.78

Different letters within each column indicate that the values are statistically significant.

the arid region of Rajasthan also showed considerable variations for the physico-chemical properties of the fruits, which confirm our findings [18]. The physico-chemical traits of different pomegranate progenies ( $F_1$  hybrids) tested under a hot arid environment also showed variations, thus confirming our results [19].

Correlation studies conducted earlier in twenty-four varieties of pomegranate revealed a strong positive correlation of fruit weight with 100-aril weight [20], as arils form the major portion of the fruit, so aril weight and width directly affect the fruit weight. This result supports our findings. An inverse correlation of skin percentage with aril percentage was obtained

during physico-chemical study of Iranian pomegranate cultivars [4], which is in conformity with our results, where the aril percentage was also inversely correlated with the rind percentage ( $r = -0.993$ ;  $P < 0.01$ ).

#### 4.2. Physical characteristics

Almost all the physical attributes studied in our investigation displayed high variability. The variations in fruit weight found are in agreement with the reported results of earlier studies [21, 22], which leads to the conclusion that this variation in fruit weight depends on the cultivar and ecological conditions. High variations in aril (37.59% to 65.00%), juice (26.95% to



**Table VI.**

Selection index scores given for fruit quality parameters of 20 different pomegranate varieties studied in India.

Varieties	Fruit weight	Aril%	Juice%	100-aril weight	TSS	Acidity	Maturity index	Rind colour	Aril colour	Total selection index scores
Bassein Seedless	(2)	(4)	(3)	(2)	(4)	(5)	(5)	(2)	(1)	28
Bedana Suni	(2)	(3)	(2)	(3)	(3)	(4)	(3)	(2)	(1)	23
Bedana Thinskin	(1)	(5)	(2)	(1)	(5)	(4)	(3)	(2)	(1)	24
Dholka	(1)	(5)	(4)	(2)	(3)	(5)	(4)	(2)	(1)	27
G-137	(2)	(5)	(3)	(2)	(4)	(4)	(3)	(2)	(2)	27
Ganesh	(2)	(5)	(4)	(2)	(2)	(5)	(5)	(1)	(2)	28
IC-318728	(1)	(3)	(1)	(1)	(4)	(1)	(1)	(2)	(1)	15
Jyoti	(2)	(5)	(4)	(2)	(5)	(5)	(5)	(2)	(1)	31
Kabuli Yellow	(1)	(4)	(3)	(2)	(4)	(4)	(3)	(1)	(1)	23
Kandhari	(2)	(5)	(3)	(2)	(4)	(5)	(5)	(1)	(2)	29
Kasuri	(1)	(5)	(2)	(2)	(3)	(4)	(3)	(2)	(1)	23
KRS	(2)	(5)	(3)	(2)	(4)	(5)	(5)	(2)	(1)	29
Mridula	(1)	(5)	(5)	(2)	(4)	(5)	(4)	(4)	(4)	34
P-13	(3)	(5)	(4)	(2)	(3)	(4)	(3)	(2)	(1)	27
P-16	(2)	(5)	(4)	(3)	(4)	(4)	(4)	(1)	(1)	28
P-23	(3)	(5)	(3)	(3)	(4)	(4)	(3)	(1)	(1)	27
P-26	(3)	(5)	(3)	(3)	(4)	(4)	(3)	(2)	(1)	28
Patna-5	(3)	(2)	(2)	(2)	(2)	(4)	(2)	(2)	(1)	20
Tabesta	(1)	(5)	(1)	(1)	(2)	(4)	(2)	(2)	(1)	19
Yercaud-1	(1)	(5)	(1)	(1)	(1)	(4)	(1)	(2)	(1)	17

46.55%) and rind (32.28% to 59.82%) contents were also found in Iranian cultivars of pomegranate [4]. Different proportions of pomegranate juice to fruit have been reported for Spanish and Iranian cultivars, which ranged from 25.00% to 64.17% [23, 24]. The maximum juice recovery was registered by cv. 'Mridula' (61.00%), followed by 'Jyoti' (59.82%). Previous studies also confirmed the better performance of these cultivars owing to their high juice and aril recovery with lower rind percentage [25, 26]. The varieties with high juice percentage and aril recovery have high potential for utilisation in the processing and beverage industry and are also preferred for table purposes. However, varieties with thick rind and high rind percentage can be incorporated in breeding programmes for

developing varieties with longer shelf life with less fruit cracking. A thick rind-type Iranian cultivar, 'Pust Siah' (6.5 mm), was also reported to have a longer shelf life and less fruit cracking problems [27]. Besides, such a variety can be utilised by the processing industry for preparing pomegranate rind powder and extracting tannin.

Rind and aril colour development is not only governed by the variety but also influenced by the prevailing temperature at fruit maturity and ripening stages; a mild temperature during ripening helps better colour development in pomegranate [28]. Pomegranate shows great variability as far as rind and aril colour of the fruits is concerned, which was also evidenced in our investigation. Similar findings have been published

for different pomegranate cultivars grown in Turkey [29].

### 4.3. Chemical characteristics

Variability among various chemical attributes occurs, as chemical properties of fruits are governed by a whole gamut of genetic and environmental factors. In our investigation, all the three attributes under study, namely, TSS, acidity% and the maturity index, showed significant variability among varieties. In pomegranate, a TSS range of 10.0 °Brix to 16.5 °Brix was also reported earlier, which supports our findings [22, 30]. In most of the Indian commercial cultivars, acidity is generally below 0.82% [22], which is in conformity with our findings, except for the wild accession 'IC 328728' (3.40%). Harvesting at the proper maturity index [TSS / acidity] is one of the important factors responsible for taste and flavour of fruits [31]. Findings related to the genotypic variability of the maturity index (4.31 to 38.62) was confirmed by various other studies which revealed variable ranges of the maturity index in different cultivars of pomegranate grown worldwide [4, 16, 23, 29].

The 'Mridula', 'Jyoti' and 'Kandhari' varieties had high TSS, juice recovery and maturity index along with better aril or rind colour, thus they are suitable for table purposes and processing. These high-scoring varieties can be used as parents in breeding programmes for breeding superior varieties, which will not only be helpful in increasing pomegranate productivity but also in boosting the pomegranate industry. Fortunately, India is blessed with sufficient diversity of this fruit crop and there is a great need to assess their physico-chemical properties for maximum utilisation.

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### **Estudio de la variabilidad de propiedades físico químicas de granadas (*Punica granatum* L.) empleando una técnica de notación.**

**Resumen – Introducción.** La India es el productor de granadas más grande del mundo. La especie presenta una vasta diversidad genética en este país. Las amplias posibilidades de aplicaciones de la granada para la salud humana y la seguridad alimentaria dio pie a una fuerte demanda en India y más allá. En la actualidad, en India, se dispone de más de 300 accesiones de material genético de origen local o exótico, sin embargo se conoce poca información acerca de las propiedades físico-químicas de sus frutos. En nuestro estudio, se analizaron las propiedades físico-químicas de ciertas variedades cultivadas en clima semiárido. **Material y métodos.** Nuestro estudio se realizó en la granja experimental del Centro nacional de investigación de la granada (Solapur, India) durante las campañas de cosecha de 2008–2009 y 2009–2010. Se estudiaron veinte variedades de granado en cuanto a las propiedades físico-químicas de sus frutos. **Resultados y discusión.** Se observó una variación considerable (coeficiente de variación: de un 3,37% a un 101,13%) para los caracteres estudiados. Los valores fueron 12,64 °Brix a 15,39 °Brix para los azúcares solubles; un 0,38% a un 3,40% para la acidez; 16,67 g a 27,82 g para el peso de 100 arilos; 4,31 a 38,62 para el índice de madurez; un 59,22% a un 77,40% para el porcentaje de arilo en el fruto y un 43,30% a un 61,00% para los porcentajes de jugo. Los caracteres de dimensión de los frutos, peso de la cáscara, peso total del arilo, peso de 100 arilos, peso del jugo y anchura del arilo resultaron estar fuertemente relacionados positivamente ( $P < 0,01$ ) con el peso del fruto. En base al resultado total obtenido, las variedades ‘Bassein Seedless’, ‘Dholka’, ‘Ganesh’, ‘Jyoti’, ‘Kandhari’, ‘KRS’, ‘Mridula’ y ‘P-13’ se determinaron como aptas a la transformación y a un consumo en la mesa.

**India / *Punica granatum* / recursos genéticos / frutas / propiedades físicoquímicas / variación genética / índice de selección**

