



Fruit size contributing traits in pomegranate (*Punica granatum*) cv Dholka under temperate condition

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ABSTRACT

The present investigation conducted to study the fundamental aspects of fruit development that determine fruit size would indicate how and when size could be affected and to specify which components could be environmentally manipulated and which are fixed under genetic control. With this objective fruit compositional changes in pomegranate (*Punica granatum* L.) cv Dholka, comprises length, volume and weight, seed+aril weight and number of seed+aril per fruit, rind weight, rind thickness seed, calyx length, calyx diameter and juice content were evaluated in fruits of variable sizes. Pearson correlations and factor analysis were determined to find out association among fruit and aril traits. Results indicated that fruit length, fruit volume, fruit weight, seed+aril weight per fruit and number of seed+aril per fruit are closely correlated therefore; any of these traits could be utilized as an indicator of fruit size. The number of seed+arils per fruit was highly correlated with fruit size with larger fruit containing greater numbers of arils. This is in contrast to individual average aril weight, which showed no significant relationship to fruit size. These results will be useful to breeding programs that require awareness of fruit qualities in the selection of traits for improvement. For production strategies which aim in increasing aril numbers for obtaining larger fruits in pomegranate cv Dholka under temperate condition.

Key word: Correlation, Factor analysis, Fruit size, Pomegranate, Temperate, Traits

Pomegranate (*Punica granatum* L.) has been traditionally cultivated since ancient times under diverse agro-climatic conditions (Evreinoff 1949). In the world, production and consumption of pomegranate fruits is increasing rapidly. The fact that pomegranate fruit has different industrial usage, such as fruit juice, conserve, vinegar, citric acid and medicine, lead to its gaining popularity in the world markets (Cemeroglu 1977, Dokuzoguz and Mendilcioglu 1978 and Aviram and Dornfeld 2001). The calorific value of fruit is 65 and juice is easily digestible which contains about 15% invert sugar. Fruit is also a rich source of sodium (3 mg), riboflavin (0.012-0.03 mg), thiamin (0.003 mg), niacin (0.180-0.3 mg), Vitamin C (4-4.2 mg), calcium (3-12 mg) and phosphorous (8-37 mg) per 100 g of edible portion (Pareek *et al.* 2000). As a cultivated crop the pomegranate is grown in many states of India like Maharashtra, Gujarat, Rajasthan, Uttar Pradesh, Haryana, Andhra Pradesh, Karnataka and Tamilnadu and to a limited extent in Jammu and Kashmir, Himachal and Uttarakhand. In India pomegranate consists area of 125 000 ha, 820 MT production and 6.60 MT/ha productivity ((NHB

2010) mostly in subtropical and tropical regions but in sub temperate and temperate regions (J& K, Himachal Pradesh and Uttarakhand) area is very meager due to under exploitation of this non-traditional crop. There is a wide variability in fruit size, even with trees of the same genotype grown under similar cultivation practices (Narzary 2009). Although pomegranates have been cultivated since antiquity, fruit attributes, particularly those related to size are poorly defined. With market premiums for large-sized fruits and producer targeted traits including high total aril weight and juice content, understanding fruit traits contributing fruit size is essential. Most of the research studies conducted to address quantitative evaluations of pomegranate fruit characteristics or to compare genotypes for selection and breeding programs or to evaluate growth under different climatic conditions (Barone *et al.* 2001, Dafny-Yalin *et al.* 2010, Drogoudi *et al.* 2005, Mars and Marrakchi 1999, Martinez *et al.* 2006). Despite the long history of pomegranate culture as a fruit crop, literature is lacking on how fruit characteristics and traits relate to changes in fruit size. Pomegranate exhibits considerable phenotypic diversity in fruit size among different genotypes (Drogoudi *et al.* 2005, Mars and Marrakchi 1999, Martinez *et al.* 2006). However, the literature lacks on evaluations of within-genotype fruit attributes and how fruits

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change in relation to size. Scantly information are available on fruit development, fruit composition changes with fruit size, fruit, proportion of aril to pericarp and membrane, changes with varying fruit size, changes in juice content with fruit size and increasing aril numbers per fruit or promoting more aril enlargement. Understanding the fundamental aspects of fruit development that determine size would indicate how and when size could be affected and specify which components can be environmentally manipulated versus which are fixed and under genetic control (Webb *et al.* 1974). Additionally, such knowledge would be useful to breeding programs that require awareness of fruit qualities in the selection of traits for improvement (Leon *et al.* 2004). The aim of present study is to evaluate fruit characteristics in pomegranate and to identify which attributes are related to size. Fruit attributes, including fruit length, fruit volume and weight, aril weight and number, rind thickness, rind weight, fruit calyx length, fruit calyx diameter, seed weight, and juice content were evaluated in variable size of fruits of cv Dholka pomegranate. Correlations between fruit characteristics were determined. In addition, factor analysis was used to establish a relationship among traits.

MATERIALS AND METHODS

The present study was carried out at the research farm of Central Institute of Temperate Horticulture (CITH), Srinagar, for three years, i.e. from the year 2008 to 2011. The experimental farm is situated at latitude of 34°05' N and longitude of 74°50' E at an altitude of 850 m above the sea level. Promising pomegranate cv Dholka was selected in the study. The average maximum 19.63°C and minimum 6.52°C temperature, the amount of rainfall 160.72 mm, relative humidity 58.35%, evaporation 2.45 and soil characteristics, viz pH 6.81, EC 0.36 dS/m recorded in growing season. The trees were spaced 2.5m and 2.5m between and along the rows, respectively. Trees were grown under drip irrigation and routine cultural practices suitable for commercial fruit production. The experiment was laid out in randomized block design (RBD) with three replications and 5 plants per replication as suggested by Gomez and Gomez 1984. The data were collected from initial fruiting years (6 years of tree) to final fruiting years (8 years) where yields almost stabilize. Commercially ripe fresh fruits were harvested from different mature trees (6-8-year-old) randomly selected to represent the population of the plantation in first week of October of every year from 2008 to 2011. Fruits were transported immediately to the laboratory soon after harvest, where pomegranates with defects (sunburns, cracks, cuts and bruises in peel) were discarded. The observations were recorded on fruit characteristics (fruit weight, fruit diameter, fruit length, fruit volume, rind weight, rind thickness, calyx length, calyx diameter). Twenty five variable size fruits were individually analyzed for physical characteristics. Fruits were weighed in the air on a Sartorius balance of accuracy of

0.001 g. Fruit volume was estimated using the equation for a sphere ($V = 4/3 \pi r^3$). The length and diameter of the fruit and calyx were measured with a digital vernier caliper. The measurement of fruit length was made on the polar axis, i.e. between the apex and the end of stem. The maximum width of the fruit, as measured in the direction perpendicular to the polar axis, is defined as the diameter. After measuring the whole fruit size, fruits were carefully opened to avoid damaging arils. The arils were separated from pericarp/membrane fractions, the total number of arils for each fruit was determined, and total aril weight/fruit recorded. To determine aril seed and juice characteristics, 40 arils were randomly selected from each of 25 fruits and fresh aril weights were measured. Arils were then manually juiced and residual pulp carefully cleaned from the seeds using muslin cloth. Seeds were immediately weighed to obtain fresh seed weight. Juice in percentage was calculated by subtracting fresh seed weight from whole aril fresh weight. Correlation coefficient was worked out as per the method given by Al-Jibouri *et al.* (1958) to determine relations among fruit characteristics and fruit characteristic correlation matrix was constructed. Factor analysis was done using principal component analysis method as described by Harman (1976) to describe variability within fruit characteristics. All statistical analysis carried out using SAS 9.2 software (SAS institute, Cary, NC).

RESULTS AND DISCUSSION

The data in Table 1 showed mean, minimum and maximum values for the fruit and aril characteristics recorded in the study. Fruits exhibited a wide range of sizes with the smallest and largest fruit having 70.53 mm and 85.69 mm diameters, respectively. Fruits ranged widely in length (68.16-84.65 mm), volume (251.16-280.98 cm³) and weight (211.08-280.25g). A range of fruit sizes was highly desirable for this study because it allowed comparisons of fruit characteristics over fruits ranging from small to large. Fruit separated into component parts similarly showed wide ranges in the proportion of edible and non-edible portions (Table 1). Fruit calyx length and diameter varied from (15.24-28.36 mm) and (12.51-19.22 mm) respectively. Rind characteristics rind weight and rind thickness ranges from (90.03-146.33 g) and (1.27-4.46 mm) respectively. Total aril weight/fruit and total number of arils/fruit exhibited (180.03-260.25 g) and (468.66-798.66 g) differences, respectively among all the fruits sampled. Aril characteristics also varied among fruits (Table 1) and exhibited considerable variation. Diversity in average weight/aril and seed weight (fresh) were recorded (200-388 mg) and (31.24-65.57 mg) respectively. Juice content found relatively stable and varied from 60.10 to 80.66. The highest coefficient of variation observed in rind thickness 32.24% and lowest in fruit volume 3.02%. Pomegranate germplasm exhibited considerable phenotypic diversity in physical and chemical characteristics, including fruit size, colour, pericarp

Table 1 Summary statistics of fruit and aril characteristics of pomegranate cv. Dholka

Traits	Mean	Std Dev	Sum	Minimum	Maximum	CV%
Fruit diameter (mm)	77.35	4.38	1470	70.53	85.69	5.66
Fruit length (mm)	75.69	4.19	1438	68.16	84.65	5.53
Fruit weight (g)	242.00	16.90	4598	211.08	280.25	6.98
Fruit volume (mm)	265.44	8.04	5043	251.16	280.98	3.028
Fruit calyx length (mm)	22.61	3.16	429.72	15.24	28.36	13.97
Fruit calyx dia. (mm)	15.54	2.26	295.38	12.51	19.22	14.54
Rind weight (g)	116.59	19.09	2215	90.03	146.33	16.37
Rind thickness (mm)	3.66	1.18	69.54	1.270	4.46	32.24
No. of seeds+aril/fruit	593.20	82.67	11271	468.66	798.66	13.93
Weight of seeds+aril/fruit (g)	219.78	21.30	4176	180.03	260.25	9.69
Juice %	71.76	6.57	1364	60.10	80.66	9.15
Average aril weight (mg)	302.42	54.93	5746	200.00	388.00	18.16
Average seed weight (mg)	43.26	8.23	822.12	31.24	65.57	19.02

thickness, seed hardness, and juice biochemistry (Barone *et al.* 2001, Borochoy-Neori *et al.* 2009, Dafny-Yalin *et al.* 2010, Drogoudi *et al.* 2005, Mars and Marrakchi 1999, Martinez *et al.* 2006, Schwartz *et al.* 2009).

The correlation matrix related to different pomegranate fruit characteristics is presented in Table 2. Six fruit characteristics were strongly correlated: fruit diameter, fruit length, fruit volume, fruit weight, No. of seeds+aril per fruit and weight of seeds+aril per fruit. The relationship between these fruit characteristics is shown in Fig 1. Fruit weight

and length (Fig 1A) and fruit weight and fruit diameter (Fig 1B) indicate strong positive relationships (significant at the 0.01 level) indicating that larger and longer fruits are heavier and having greater fruit weight. The strong linearity of the relationships is evident in the strong correlation coefficients of 0.995 and 0.985, respectively (Table 2). Fruit weight and volume were also strongly correlated with the number of arils and weight of seeds+aril in a given fruit ($r = 0.972, 0.925$ and 0.964 respectively) (Fig 1C, Table 2). The total number of seeds+arils and weight of seeds+arils per

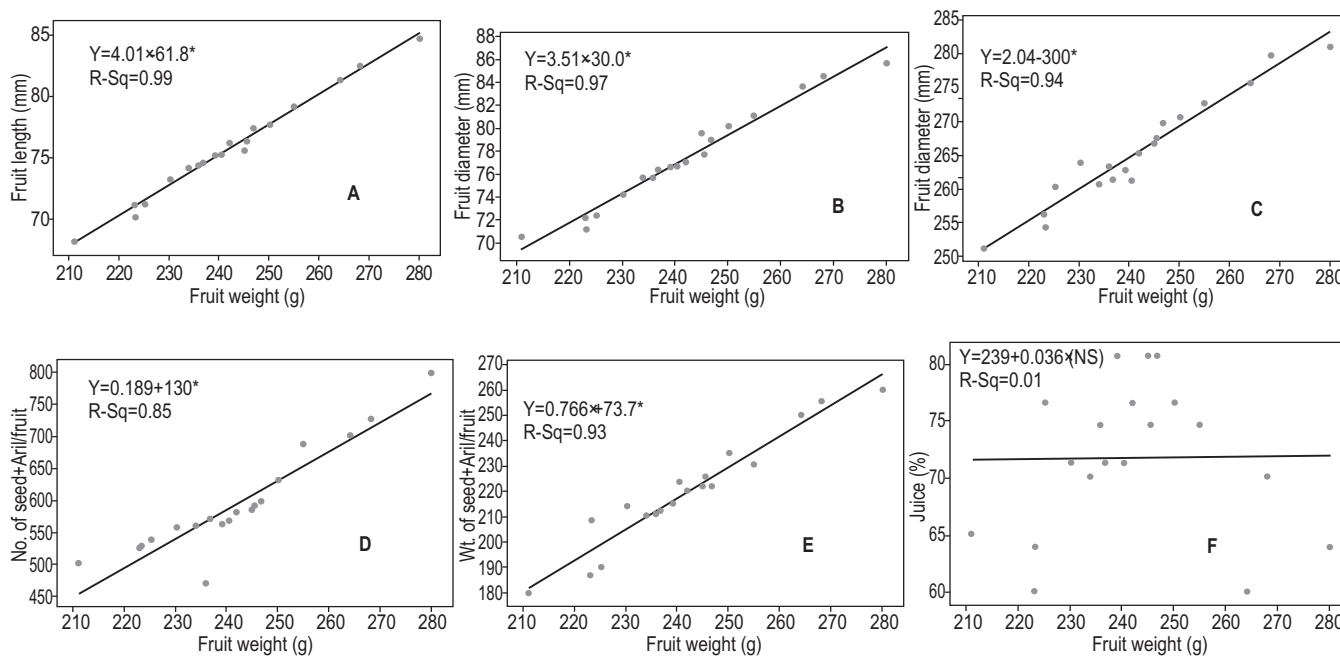


Fig 1 Relationships between fruit characteristics in pomegranate. (A) Fruit weight and fruit length, (B) Fruit weight and diameter, (C) Fruit weight and fruit volume, (D) Fruit weight and number of seed+aril per fruit, (E) Fruit weight and weight of seed+aril per fruit, (F) Fruit weight and juice percentage. Relationships are denoted as being significant (*) or non-significant (NS) at the 0.01 significance level.

Table 2 Pomegranate fruit and aril characteristic correlation matrix

Traits	Fruit diameter (mm)	Fruit length (mm)	Fruit weight (g)	Fruit volume (cm ³)	Fruit calyx length (mm)	Fruit calyx dia. (mm)	Fruit weight (g)	Rind thickness (mm)	No. of seeds+ aril/fruit	Wt. of seeds+ aril/fruit (g)	Juice (%)	Average aril weight (mg)	Average seed weight (mg)
Fruit diameter (mm)	1.000	0.985	0.985	0.969	0.331	0.302	0.294	0.203	0.909	0.949	0.06	-0.046	-0.071
Fruit length (mm)	<0.0001	1.000	<0.0001	<0.0001	0.1663	0.2087	0.2215	0.4045	<0.0001	<0.0001	0.8072	0.8501	0.7721
Fruit weight (g)	<0.0001	1.000	0.995	0.975	0.326	0.29	0.341	0.156	0.917	0.957	0.023	0.023	-0.046
Fruit volume (cm ³)	<0.0001	<0.0001	<0.0001	<0.0001	0.172	0.2276	0.1521	0.5224	<0.0001	<0.0001	0.9226	0.924	0.8486
Fruit calyx length (mm)	1.000	1.000	1.000	0.972	0.307	0.24236	0.339	0.12	0.925	0.964	0.013	0.00324	-0.090
Fruit volume (cm ³)	<0.0001	<0.0001	<0.0001	<0.0001	0.2001	0.3174	0.1556	0.6225	<0.0001	<0.0001	0.9549	0.9895	0.714
Fruit calyx length (mm)	1.000	1.000	1.000	1.000	0.295	0.28496	0.289	0.195	0.904	0.931	0.087	0.01255	-0.122
Fruit calyx dia. (mm)	1.000	1.000	1.000	1.000	0.22	0.237	0.2291	0.4224	<0.0001	<0.0001	0.7202	0.9593	0.6178
Fruit weight (g)	1.000	1.000	1.000	1.000	1.000	0.614	0.4	0.459	0.219	0.295	0.296	0.39068	-0.102
Fruit volume (cm ³)	1.000	1.000	1.000	1.000	1.000	0.0052	0.0889	0.0477	0.3662	0.2192	0.2178	0.0982	0.6777
Fruit calyx dia. (mm)	1.000	1.000	1.000	1.000	1.000	1.000	0.2231	0.332	0.136	0.261	0.228	0.24722	0.117
Rind weight (g)	1.000	1.000	1.000	1.000	1.000	1.000	0.3586	0.1645	0.5769	0.279	0.347	0.3075	0.6305
Rind thickness (mm)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-0.182	0.169	0.444	0.067	0.35007	-0.232
No. of seeds+aril/fruit	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.4542	0.4888	0.0568	0.7851	0.1418	0.3374
Weight of seeds+aril/fruit (g)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.128	0.118	0.479	0.00469	0.05
Juice (%)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.5988	0.6286	0.0379	0.9848	0.8371
Average aril weight (mg)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.883	-0.164	0.04191	0.025
Average seed weight (mg)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	<0.0001	0.4998	0.8647	0.9166
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-0.007	-0.014	-0.097
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.9773	0.9516	0.6922
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.108	-0.587
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.6583	0.0082
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-0.151
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.5349
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

fruit increased as fruit weight increased and was significant at the 0.01 level (Fig 1D, Fig 1E). The extremely high correlation between fruit diameter, length, volume and weight indicates that weight can be interchangeably used to indicate size. Also, seed + aril number per fruit exhibited a strong linear relationship to fruit size. Thus, the development of a set of fruit characteristics for grading pomegranate fruits destined for different purposes (e.g. fresh fruit versus extracted arils) is probably not necessary. Instead, any of the characteristics loading high on the factor analysis fruit index (fruit volume, fruit weight, fruit length, seed + aril weight/fruit, number of seeds + aril per fruit, rind thickness, rind weight, fruit calyx length and diameter) could serve as a measure. For example, crop breeders, farm managers, and marketing agents could use fruit weight, diameter, or volume as the index of size. In terms of farm management practices, results indicate that methods with the objective of obtaining greater numbers of arils may be beneficial for enhancing fruit size. This is in contrast to managing the size or weight of individual arils. Mean aril weight was poorly correlated with fruit weight ($r = 0.452$) and aril weight remained relatively constant regardless of fruit size. Differences in average aril weight contributed little to fruit size. Larger fruit did not contain larger arils. Thus, increases in fruit size and weight do not appear to be a consequence of enhancement in aril development or enlargement. No significant correlation found between juice percentage and fruit weight (Fig 1F). Small-sized fruits had fewer than 469 arils/fruit; larger fruits had over 500 arils/fruit, and up to 799 in the largest fruit and

no significant relationship were found. Likewise, average aril weight was poorly correlated to fruit weight and volume ($r = 0.003$ and 0.012) (Table 2), indicating that heavier and bigger fruit are not composed of bigger arils. This was also the case for other aril characters including fresh seed and juice percentage. No enhanced enlargement of aril tissues was observed in larger fruits. The relationship between fruit weight and average weight per aril was also not significant at the 0.01 level. However fruit characteristics like rind thickness, rind weight, juice percentage, average aril weight, average seed weight, and fruit calyx length, fruit calyx diameter not shown strong and significant relationship with any of the major contributing characters.

In pomegranate, fruit size was highly correlated with both weight of seeds+ aril (rind thickness and membrane) and number of seeds+aril. An interest in understanding fruit attributes and how size relates to the percent of edible aril weight is pertinent, especially with the onset of mechanical extraction methods (Blasco *et al.* 2009) for marketing pomegranate arils in a ready-to-eat form. The results of this study indicate that although larger fruits contain more arils on a per fruit basis, selecting fruit for size will not improve the percentage of edible yield/fruit. This is in contrast to other fruits such as sweet cherry in which the proportion of pit to flesh changed with size; although both pit and flesh diameter increased in larger fruits, flesh increased proportionally more than pit (Olmstead *et al.* 2007).

Since the correlation coefficients may not provide complete information on the relationship between different traits and not to provide benefits according to several multivariate statistical analysis to understand the deep structure of data, factor analysis was used to establish relationship between fruit and aril characteristics (Table 3 and 4). The analysis identified 13 factors out of which only



Fig 2 Relationships among 13 fruit and aril traits in pomegranate cv Dholka shown by a 2D scatter for first two factors

Table 3 Eigen values and proportion of variance explained by the 13 factor with respect to fruit and aril traits of pomegranate

Eigenvalues of the correlation matrix			
Eigenvalue	Difference	Proportion	Cumulative
6.156	3.901	0.473	0.473
2.255	0.796	0.173	0.647
1.459	0.069	0.112	0.759
1.389	0.727	0.106	0.866
0.661	0.194	0.050	0.917
0.466	0.141	0.035	0.953
0.324	0.159	0.025	0.978
0.165	0.118	0.012	0.990
0.047	0.006	0.003	0.994
0.040	0.018	0.003	0.997
0.022	0.012	0.001	0.999
0.009	0.008	0.0007	0.999
0.001		0.0001	1.000

Table 4 Factor loadings of 13 fruit and aril traits on four principal factors

Factor	Factor1	Factor2	Factor3	Factor4	Community
Fruit diameter (mm)	0.97883	- 0.11947	0.06660	- 0.08218	0.98385
Fruit length (mm)	0.98440	- 0.13109	0.00788	- 0.02358	0.96124
Fruit weight (g)	0.98057	- 0.15873	- 0.02917	- 0.06143	0.9805
Fruit volume (cm ³)	0.96971	- 0.10214	0.02505	- 0.11380	0.88825
Fruit calyx length (mm)	0.44357	0.69757	0.09776	0.31974	0.79562
Fruit calyx dia. (mm)	0.37621	0.54872	0.28115	0.42518	0.7489
Rind weight (g)	0.40706	0.28157	- 0.64473	0.28066	0.87501
Rind thickness (mm)	0.22943	0.51407	0.69519	- 0.16619	0.89282
No. of seeds+aril/fruit	0.90417	- 0.28824	0.05209	0.01146	0.95119
Weight of seeds+aril/fruit (g)	0.96294	- 0.14312	- 0.07706	- 0.03028	0.97973
Juice (%)	0.08750	0.72944	0.05073	- 0.59497	0.90197
Average aril weight (mg)	0.08761	0.50990	- 0.41277	0.42289	0.61894
Average seed weight (mg)	- 0.10508	- 0.40150	0.53286	0.66473	0.94613

four were extracted which together explained 86.62% of the variance among the entries. The first factor with Eigen value of 6.15 accounted for 47.36% of the variance and was mostly correlated with characters as fruit diameter, fruit length, fruit weight, fruit volume, no. of seeds+aril and weight of seeds+aril per fruit. First factor indicated to fruit diameter, fruit length, fruit weight, fruit volume, no. of seeds+aril per fruit and weight of seeds+aril per fruit could call this factor weight factor because these main characters are effective in fruit weight (Fig 2). The second factor that accounted for 17.35% of the total variance was mainly loaded by average aril weight, fruit calyx length and diameter and juice percentage. The third factor that accounted for 11.22% of the total variance was mainly described by rind thickness. The fourth factor was loaded by average fresh seed weight and it accounted for just 10.69% of the total variance. The results shows that even within a single genotype, same-aged fruits grown under similar cultural conditions can show marked differences in size. This indicates that any studies evaluating pomegranate fruit characteristics such as size, volume, and weight should take precautions so that fruit samples are sufficiently large to compensate for large fruit-to-fruit variation. This is in contrast to characteristics such as percent juice, ratio of aril to whole fruit weight, and mean aril size, which exhibit less variability within a genotype and could thus be accurately assessed with smaller sample numbers.

From the present study it was concluded that fruit length, fruit volume, fruit weight, number of seeds+ aril per fruit and seeds+ aril weight per fruit are closely correlated, any single character can be used as a common indicator of fruit size. The number of arils per fruit was highly correlated with fruit size with larger fruit containing greater numbers of arils. This is in contrast to average aril weight, which had no significant relationship to fruit size. Limitations in final fruit size could result from poor ovule development, insufficient pollination, or inadequate fertilization. Crop production

strategies aimed at increasing aril numbers may be a means for obtaining larger fruit in pomegranate.

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