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Physio-morphological variations of pummelo genotype (*Citrus grandis* L. Osbeck)

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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Abstract: The study was conducted to evaluate the physio-morphological variations of 21 pummelo genotype. The experiment was carried out at the existing plantation of Bangladesh Agricultural University Germplasm Centre, Mymensingh, during September 2014 to June 2015. Results showed that different genotype exhibited differently in their physio-morphological features. Genotype Thai Jambura exhibited highest leaf and petiole wing length (16.77 cm and 11.63 cm, respectively), while maximum number of anthers (44.33) were recorded in genotype Green skin. The heaviest and lightest fruits were recorded in genotype Hybrid (1283.33 g) and Accession-52 (300 g). While the maximum weight of non-edible portion (463.33 g), pulp to peel ratio (3.97), thickness of pulp (11.50 cm), amount of juice (366.67 ml), total soluble solids (TSS) (18.67%), number of seeds (114) and weight of seeds (58 g) were found in genotype Hybrid. Correlation coefficient study indicated that leaf length, breadth, petiole wing length, fruit weight, weight of non-edible portion, seed weight, seed number/fruit had positive and highly significant association with leaf breadth, petiole wing breadth, weight of non-edible portion, pulp thickness, total weight of seeds/fruit and number of fruits/plant, respectively. In respect of path analysis, leaf breadth, petiole wing length, fruit weight, average weight of seed, %TSS, seed number/fruit had positive direct effect on fruits/plant indicating its importance as a selection criteria.

1. Introduction

Pummelo (*Citrus grandis* L. Osbeck) belonging to the family Rutaceae, is one of the most distinctive and easily recognized species of the genus citrus (Verdi, 1988). It is one of the most important fruit in Bangladesh because of its taste, aroma and nutrient value. Citrus carry some vitamins like vitamins C, B, A and some minerals like calcium, iron, citric acid etc. The pummelo is an exotic large citrus fruit that is an ancestor of the common grapefruit. In Bangladesh it is locally known as jambura, batabilabu, badami, jamir. The pummelo is significantly larger than the grapefruit. Its flesh is sweet and it has a thick skin and rind. The fruit of the pummelo has a light green colored rind but this gradually becomes mostly yellow when it has fully ripened. The inside of the fruit has a pink color when it is ripe. The pummelo tree thrives well in tropical or near tropical climates. Like other citrus fruits, the pummelo usually ripen in winter. It is an important commercial citrus fruit, grown and available almost everywhere in Bangladesh. The availability of this fruits helping people to overcome the malnutrition problem. There is a special pummelo fruit based diet to treat asthma. Pummelo is a dietary fruit; its caloric value is 25-58 kcal/100 g (Morton, 1987). In Vietnam, the aromatic flowers are used in making perfume. The wood is used for tool handles and firewood while leaves, flowers, fruits, and seeds are sometimes used as herbal medicine to treat cough, fever and gastric disorders (Verheij and Coronel, 1992).

Pummelo grows well everywhere in Bangladesh and is comparatively more tolerate to insects and diseases than other citrus fruits. But the number of trees with good quality fruit is very negligible in comparison to other citrus growing countries of the world. In the year 2015, Bangladesh produces 31,036 metric tons pummelo from 4159.10 hectares of land (BBS, 2015). Although it is one of the most important citrus fruit in Bangladesh, production as well as yield of pummelo fruits is very low due to lack of high yielding and good quality variety. It is reported that a single pummel tree can yield 70-100 fruits/year which is equivalent to 20 tons/ha/year (Verheij and Coronel, 1992). Therefore, selection of high yielding genotype is necessarily important to increase the yield of pummelo in Bangladesh.

Characterization of pummelo using morphological traits will help in the selection of genetically potential genotype for cultivation and also for their exploitation in plant breeding program. Selection of superior genotype from the collected accessions will help in increasing production of pummelo in this country. For improving the production as well as yield of pummelo fruits in this country, Bangladesh Agriculture University - Germplasm Center (BAU-GPC) has already been collected some pummelo genotype from different corner of Bangladesh and also from Thailand, Vietnam, and Malaysia. This experiment has been undertaken to study the physio-morphological characteristics of those pummel accessions to evaluate their relative performance. In plant breeding program, knowledge of the interrelationship among and between yield contributing characters is necessary. Correlation and the path coefficient analysis will provide a true picture of genetic associating among different traits (Bhatt, 1973). Path coefficient analysis specifics the cause and effect and measures their relative importance. Therefore, correlations in combination with the path co-efficient analysis quantify the direct and indirect contribution of one character upon another (Dewey and Lu, 1959). This experiment was therefore, undertaken to study the physio-morphological characteristics of pummelo genotype collected from different parts of the world and to access the interrelationship between yield and yield contributing characters and to select better quality genotype for cultivation in Bangladesh.

2. Materials and Methods

The experiment was conducted at Bangladesh Agricultural University Germplasm Center, Department of Horticulture, Bangladesh Agricultural University, Mymensingh during September 2014 to June 2015. The location of BAU-GPC was medium high land, well drained and slightly acidic soil with pH range from 5.5 to 6.8. The study was conducted in an established orchard where 21 indigenous and exotic pummelo genotype were collected and established (Table 1). The average age of plants were 3-4 years.

Table 1 - Collected pummelo genotype with their source of origin

Treatment	Pummelo genotype	Sources of origin
T_1	BAU-1	Bangladesh
T_2	BAU-2	,,
T_3	BAU-4	,,
T_4	Hybrid	,,
T_5	Jambura (seeded)	,,
T_6	Mohini	,,
T_7	Green skin	Vietnam
T_8	Malaysian	Malaysia
T_9	Thai jambura	Thailand
T_{10}	Accession-51	Bangladesh
T_{11}	Accession-52	,,
T_{12}	Accession-57	Bangladesh
T_{13}	Accession-58	,,
T_{14}	Accession-59	,,
T_{15}	Accession-62	,,
T_{16}	Accession-63	,,
T_{17}	Accession-76	,,
T_{18}	Accession-87	,,
T_{19}	Accession-93	,,
T_{20}	Accession-101	,,
T_{21}	Accession-103	,,

These 21 genotype were considered as experimental treatments. The experiment was carried out in a randomized complete block design with three replications. Data on different physio-morphological characters of leaves, flowers, fruits and seeds were recorded from sample plants of each genotype following citrus IPGRI descriptor (IPGRI, 1999). Leaf length, breadth, petiole wing length, petiole wing breadth were measured by using measuring scale. Individual fruit weight was recorded by a digital balance and expressed in grams (g). For determination of pulp to peel ratio, fruits were peeled off and weight was taken for separated pulp and peel and expressed in g. Thickness of fruit pulp and peel was measured by using measuring tape after cross-sectioning of the fruits and expressed in centimeter (cm). The pulp vesicles were removed and blended in a blenderin addition with 150 ml of water. Then juice was filtered by a sieve. Except juice the rest of waste materials was considered as non-edible portion and recorded the weight. The amount of juice was measured by measuring cylinder and expressed in milliliter (ml). Total soluble solids (TSS) was determined by Abbe Hand Refractometer. A drop of juice squeezed from the pulp vesicles of fruit then placed on the prism of the refractometer and percent total soluble solids was observed from reading. Temperature correction was made using the method describe by Ranganna (1978).Total number of fruits of each plant was counted during 15 days interval. Thereafter, the average number of fruits per plant was recorded. The total number of seeds per fruit was counted. The total number of seeds, which was obtained from fruits, was weighted in a balance and expressed in g. After counting and weighing the total seeds average weight of seed was determined by the following formula and expressed in g.

$$\text{Average weight of seed (g)} = \frac{\text{weight of seeds (g)}}{\text{total number of seeds}}$$

Estimation of simple correlation coefficient

Association of different characters under the study was analyzed by working out simple correlation coefficient for all the possible pairs of character combination. Simple correlation coefficient (r) among the important characters of pummelo genotype was estimated with the formula stated by Singh and Chaudhary (1985).

Estimation of path coefficient

Path coefficient analysis was done according to the procedure stated by Dewey and Lu (1959) using simple correlation values. In path analysis, correlation coefficient is partitioned into direct and indirect effects of independent variable on the dependent variable. In order to estimate direct and indirect effects of the correlated characters, i.e.X_1, X_2 and X_3, yield Y, a set of simultaneous equations (three equations in the examples) is required to be formulated as shown below:

$$ryx_1 = Pyx_1 + Pyx_2rx_1x_2 + Pyx_3rx_1x_3, ryx_2 = Pyx_1rx_1x_2 + Pyx_2 + Pyx_3, ryx_3 = Pyx_1rx_1x_3 + Pyx_2rx_2x_3 + Pyx_3$$

Where, ‘r’ denotes simple correlation coefficient and ‘P’ denotes path coefficient.

Total correlation, say between x_1 and Y is thus partitioned as followed:

Pyx1 = indirect effect of x1, Pyx2rx1x3 = indirect effect of x1 via x2 only, Pyx3rx1x3 = indirect effect of x1 via x3 only.

After calculating the direct and indirect effect of the characters, residual effect (R) was calculated by using the formula stated by Singh and Chaudhary (1985).

Component of variance

The genotypic and phenotypic variances were calculated according to Johnson *et al*. (1955). Estimation of genotypic and phenotypic coefficient of variation were calculated according to Burton (1952).

Estimation of heritability

Heritability in broad sense can be calculated by using following formula:

$$H^2{}_b\,(\%) = \frac{\text{Genotipic variance}}{\text{Penotypic variance}} \times 100$$

Statistical analysis

Data on different physio-morphological parameters were statistically analyzed to find out the significance of difference among genotype means. The analyses of variances for most of the characters under consideration were performed by *F* variance test. The significance of the difference between treatments means was evaluated by least significance difference test describe by Gomez and Gomez (1984).

3. Results

Morphological features of leaves

As regard to leaf length it was observed that leaf length varied significantly among the genotype. The longest value was observed in genotype Thai Jambura (16.77 cm) and minimum value in genotype

BAU-2 (7.67 cm) (Fig. 1). It was revealed that the leaf breadth of the plant also varied significantly and ranged from 5.00 to 11.63 cm (Table 2). The genotype Thai Jambura showed the highest leaf breadth (11.63 cm) and the lowest leaf breadth (5 cm) was observed in Accession-62 (Table 2). It was revealed that the petiole wing length of the leaf varied significantly and ranged from 1.23 to 3.60 cm (Table 2). The genotype Thai Jambura showed the highest petiole wing length (3.60 cm) and the lowest petiole wing length (1.23 cm) was observed in Accession-62 (Table 2). Petiole wing breadth of pummelo genotype varied significantly. The genotype Thai Jambura showed the highest petiole wing breadth (4.17 cm) and the lowest petiole wing breadth (0.90 cm) was observed in Accession-63 (Table 2).

Morphological features of flowers

In case of number of petals per flower it was observed that petals varied significantly genotype to genotype. The maximum number of petals was found in genotype Hybrid (6) and minimum value (4) in genotype BAU-2, BAU-4, Mohini, Accession-59, 63, 93 and 103 (Table 2). Similarly, calyx number was also found significantly varied among the genotype. The height number of calyx was observed in genotype Hybrid (6) and lowest number (4) in genotype BAU-2, BAU-4, Mohini, Accession-51, 59, 63, 93 and 103 (Table 2). However, number of anthers/flower significantly varied among 21 pummelo genotype and ranged from 22.67 to 44.33. The maximum value was recorded in genotype Green skin (44.33) and the minimum value in Accession-76 (22.67) (Table 2).

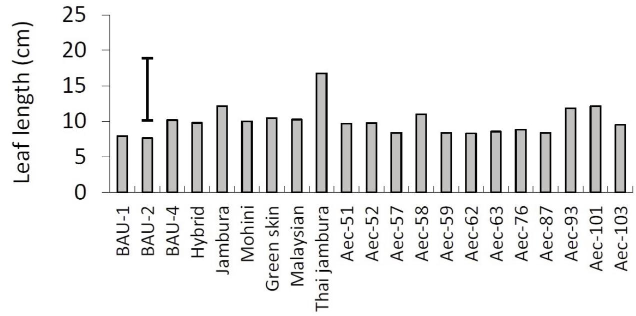

Fig. 1 - Leaf length of 21 pummelo genotype. Vertical bar indicates LSD at 1% level of probability.

Physio-morphological features of fruits

Individual fruit weight varied significantly among the genotype and it ranged from 300 to 1283.33 g. Fruit with the heaviest weight (1283.33 g) was observed in genotype Hybrid and the lowest (300 g)

Table 2 - Leaf breadth, petiole wing length, petiole wing breadth, number of petals, calyx, anthers per flowers of 21 pummelo genotype

Genotype	Leaf breadth (cm)	Petiole wing length (cm)	Petiole wing breadth (cm)	No. of petals/flower	No. of calyx/flower	No. of anthers/flower
BAU-1	5.70	2.00	1.60	5.00	5.00	42.00
BAU-2	5.83	2.00	1.50	4.00	4.00	35.67
BAU-4	5.93	2.83	2.87	4.00	4.00	39.00
Hybrid	5.93	1.67	0.93	6.00	6.00	32.33
Jambura (Seeded)	6.23	3.33	2.33	5.00	5.00	32.33
Mohini	6.17	2.17	1.67	4.00	4.00	38.00
Green skin	5.93	2.50	1.73	5.00	5.00	44.33
Malaysian	5.63	1.73	1.17	5.00	5.00	43.00
Thai jambura	11.63	3.6	4.17	5.00	5.00	41.33
Accession-51	5.90	1.33	1.17	4.00	4.00	34.33
Accession-52	5.17	2.70	2.23	5.00	5.00	42.67
Accession-57	5.80	2.40	1.40	5.00	5.00	32.33
Accession-58	8.17	1.67	1.50	5.00	5.00	41.00
Accession-59	5.80	2.40	1.40	4.00	4.00	43.67
Accession-62	5.00	1.23	1.10	5.00	5.00	31.33
Accession-63	5.63	1.40	0.90	4.00	4.00	33.33
Accession-76	5.17	2.40	2.50	5.00	5.00	22.67
Accession-87	6.27	2.73	3.33	5.00	5.00	43.67
Accession-93	7.13	2.10	2.00	4.00	4.00	35.33
Accession-101	7.07	2.00	1.47	5.00	5.00	37.67
Accession-103	5.43	1.83	1.33	4.00	4.00	29.00
$LSD_{0.01}$	0.69	0.62	0.76	0.78	0.78	6.07
Level of significance	**	**	**	**	**	**

** = Significant at 1% level of probability.

fruit was recorded in Accession-52 (Table 3). In respect of non-edible portion weight, statistically significant variations were noticed among the genotype. The maximum weight of non-edible portion (463.33 g) was obtained from the genotype Hybrid. On the other hand, the minimum weight of non-edible portion (100 g) was recorded from the genotype Accession-52 (Table 3). Pulp to peel ratio of fruits varied significantly among the 21 pummelo genotype. The amount of pulp to peel ratio was highest in genotype Hybrid and lowest in Accession-87 (Fig. 2).

Among the genotype thickness of fruit pulp differed significantly and ranged from 6.50 to 11.50 cm (Table 3). The pulp of the fruits of genotype BAU-1 and BAU-2 was the thickest (11.50 cm) followed by the Hybrid genotype (11.37 cm) and Thai Jambura (11.00 cm) and the thinnest (6.33 cm) pulp was observed in Accession-51 (Table 3). The thickness of peel also differed significantly among the genotype. The peel of the genotype Jambura (seeded) and Accession-93 was thickest (2.17 cm) and the thinnest (1.00 cm) peel was observed in genotype Accession-76 and Accession-103 (Table 3). In terms of juice content of fruits it was noticed that pummelo genotype varied significantly. The highest amount of juice (366.67 ml) was measured in genotype BAU-1 and

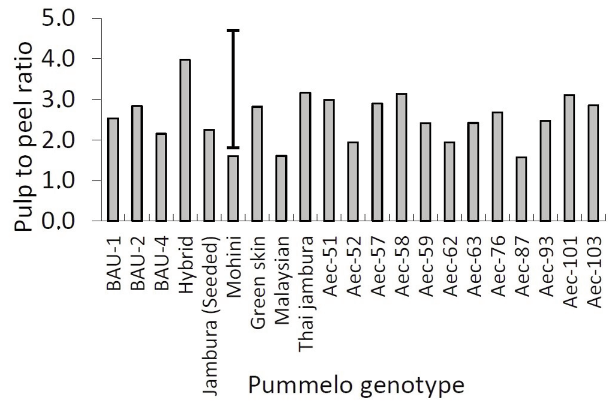

Fig. 2 - Pulp to peel ratio of 21 pummelo genotype. Vertical bar indicates LSD at 1% level of probability.

Hybrid followed by BAU-2 (350 ml) and Thai Jambura (336.67 ml) while the lowest (90 ml) found in Accession-52 (Table 3).

Total soluble solids (TSS) contents of fruits was significantly different in different pummelo genotype. The highest TSS was recorded in genotype Hybrid (18.67% Brix) followed by Accession-62 (18.23% Brix), Accession-63 and Accession-87 (17.33% Brix) and the lowest TSS was observed in genotype Mohini (13.5% Brix) (Fig. 3).

Table 3 - Fruit weight, weight of non-edible portion, thickness of pulp, peel, average weight of seed/ fruit, amount of juice/fruit and number of fruits/plant of 21 pummelo genotype

Genotype	Fruit weight (g)	Non-edible portion weight (g/fruit)	Pulp thickness (cm)	Peel thickness (cm)	Juice amount (ml/fruit)	Number of fruits/plant	Seed weight average (g)
BAU-1	1160.00	450.00	11.50	2.03	366.67	20.16	0.50
BAU-2	1250.00	426.67	11.50	1.83	350.00	17.38	0.48
BAU-4	1060.00	266.67	10.17	1.83	143.33	33.33	0.47
Hybrid	1283.33	463.33	11.37	1.80	366.67	29.56	0.51
Jambura (Seeded)	696.67	290.00	8.97	2.17	233.33	47.16	0.24
Mohini	543.33	206.67	7.33	1.57	101.67	35.00	0.08
Green skin	866.67	243.33	10.50	1.30	223.33	10.00	0.33
Malaysian	1020.00	290.00	10.83	1.67	206.67	25.86	0.43
Thai jambura	1013.33	346.67	11.00	1.50	336.67	31.16	0.29
Accession-51	516. 67	233.33	6.33	1.83	130.00	14.16	0.55
Accession-52	300.00	100.00	6.50	1.33	90.00	14.53	0.58
Accession-57	906.67	380.00	9.50	2.00	200.00	15.60	0.39
Accession-58	490.00	236.67	7.33	1.33	140.00	11.36	0.06
Accession-59	696.67	276.67	8.67	1.50	206.67	13.53	0.65
Accession-62	613.33	306.67	8.17	2.00	123.33	9.20	0.42
Accession-63	760.00	323.33	9.33	1.83	233.33	10.58	0.47
Accession-76	640.00	136.67	9.73	1.00	193.33	12.24	0.45
Accession-87	720.00	276.67	8.50	1.17	170.00	12.73	0.47
Accession-93	876.67	310.00	9.50	2.17	216.67	24.00	0.58
Accession-101	776.67	333.33	9.21	1.93	150.00	27.53	0.42
Accession-103	816.67	236.67	9.90	1.00	156.67	23.33	0.39
$LSD_{0.01}$	80.19	64.57	1.77	0.48	63.96	1.81	0.11
Level of significance	**	**	**	**	**	**	**

** = Significant at 1% level of probability.

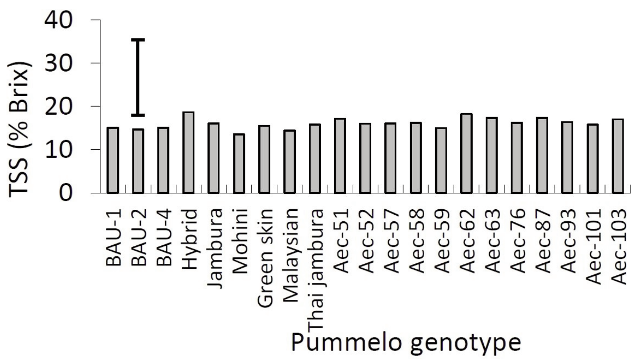

Fig. 3 - Total soluble solids (TSS) of pummelo genotype. Vertical bar indicates LSD value at 1% level of probability.

The number of fruits/plant varied significantly and ranged from 9.20 to 47.16 with the mean value of 20.88. Among the genotype Jambura (seeded) bears the maximum number of fruits (47.16) followed by Mohini (35.00) and BAU-4 (33.33) whereas Accession-62 (9.20) bears the minimum number of fruits (Table 3). In respect of number of seeds/fruit it was observed that different genotype differed significantly. The maximum number of seeds per fruit was recorded in the genotype Hybrid (114) followed by Seeded Jambura (110), BAU-4 (108.67) whereas the minimum number of seeds was found in Accession-58 (10) (Fig. 4).

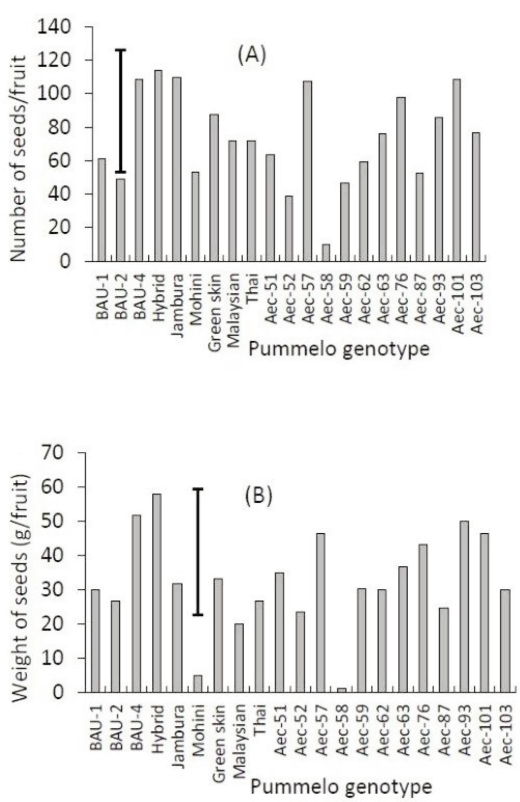

Fig. 4 - Number of seeds per fruit (A) and weight of seeds per fruit (B) of pummelo genotype. Vertical bars indicates LSD at 1% level of probability.

Like number of seeds, seed weight/fruit was also differed significantly from genotype to other genotype. The maximum weight of seeds/fruit was found in the genotype Hybrid (58 g) followed by BAU-4 (51.67 g), Accession-93 (50.00 g) whereas the minimum weight of seeds was found in the Accession-58 (1.00 g) (Fig. 5). Average weight of seed differed significantly ranging from 0.06 to 0.65 g with the mean value of 0.42 g. The heaviest average weight of seed (0.65 g) was found from the Accession-59 whereas Accession-58 gave the lowest average seed weight (0.06 g) (Table 3).

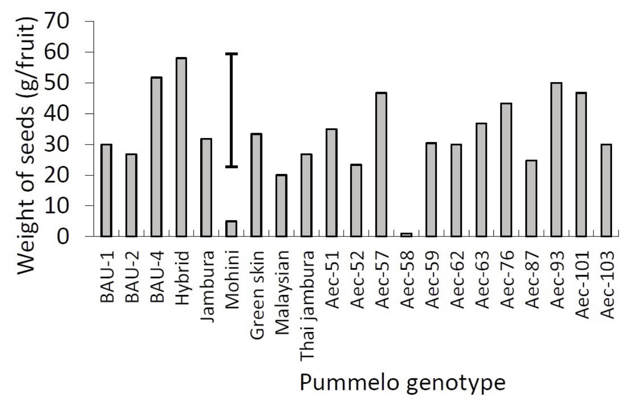

Fig. 5 - Weight of seeds per fruit of pummelo genotype. Vertical bar indicates LSD at 1% level of probability.

Correlation coefficient

Estimation of simple correlation coefficient was made among some important fruit producing characters of 21 pummelo genotype. The values of 'r' and the characters correlated are presented in Table 4. It was observed that leaf length had highly significant positive correlation with leaf breadth (r= 0.853**) and significant positive association with petiole wing length (0.519*) and petiole wing breadth (0.544*). It had also significant negative correlation with number of fruits/plant (-0.464*) (Table 4). Leaf breadth had highly significant positive correlation with wing breadth (0.584**) and significant positive correlation with wing length (0.450*). On the other hand, this character had negative correlation with %TSS, number of seeds, weight of seed and average weight of seed (Table 4). Correlation coefficient revealed that petiole wing length had highly positive significant correlation with petiole wing breadth (0.846**) and number of fruits/plant (0.773**). On the other hand, this character had negative correlation with weight of non-edible portion, pulp to peel ratio, average weight of seed and %TSS (Table 4). It was observed that wing breadth had positive correlation with number of anthers, thickness of pulp, total soluble solids, number of seeds/fruit and number of fruits/plant. On the other hand, this character had negative correlation with weight of fruit, weight of non-edible portion, pulp to peel ratio, average weight of seed and weight of seeds/fruit (Table 4). It was observed that number of anther had simply positive correlation with weight of fruit and weight of non-edible portion. This character had highly negative significant correlation with number of fruits/plant (-0.686**) and had negative significant correlation with number of seeds/fruit (-0.455*) (Table 4).

Correlation coefficient revealed that weight of fruit had highly positive significant correlation with weight of non-edible portion (0.818**) and thickness of pulp (0.930**). On the other hand, this character had negative significant correlation with %TSS (-0.487*) (Table 4). It was observed that weight of non-edible portion had highly positive significant correlation with thickness of pulp (0.671**) and number of fruits/plant (0.655**). On the other hand, this character had only negative correlation with %TSS (Table 4). Correlation coefficient revealed that pulp to peel ratio had simply positive correlation with thickness of pulp, %TSS, number of seeds and weight of seed/fruit. This character had negative correlation with average weight of seed and number of fruits/plant (Table 4). It was observed that thickness of pulp had significant positive correlation with number of seeds/fruit (0.440*) and had significant negative correlation with %TSS (-0.452*) (Table 4). Correlation coefficient revealed that average weight of seed had highly positive significant correlation with weight of seeds/fruit (0.588**) and number of fruits/plant (0.605**). This character had simply positive association with number of seeds/fruit (Table 4). It was observed that TSS had highly positive significant correlation with number of fruits/plant (0.823**) and had simply negative association with number of seeds/fruit (Table 4). Correlation coefficient revealed that number of seeds/fruit had highly positive significant with total weight of seed (0.822**) and had highly negative significant with number of fruits/plant (Table 4).

Path coefficient analysis

A path coefficient is simply a standardized partial regression coefficient and as such measures of the influence of one variable upon another permits separation of correlation coefficient into components of

Table 4 - Correlation coefficient between fruits per plant and fruit producing characters in pummelo genotype

Traits	Leaf breadth (cm)	Petiole wing length (cm)	Petiole wing breadth (cm)	Number of anthers/ flower	Weight of fruit (g)	Weight of non-edible portion (g/fruit)	Pulp to peel ratio	Thickness of pulp (cm)	Average weight of seed (g/fruit)	TSS (% Brix)	Number of seeds/ fruit	Weight of seeds (g/fruit)	No. of fruits/ plant
Leaf length (cm)	0.853**	0.519*	0.544*	0.176	0.011	-0.043	0.236	0.071	-0.393	-0.093	0.18	-0.052	-0.464*
Leaf breadth (cm)		0.450*	0.584**	0.292	0.121	0.169	0.301	0.132	-0.39	-0.151	-0.097	-0.18	0.192
Petiole wing length (cm)			0.846**	0.259	0.045	-0.15	-0.102	0.151	-0.095	-0.161	0.231	0.069	0.773**
Petiole wing breadth (cm)				0.227	-0.002	-0.208	-0.128	0.082	-0.099	0.014	0.051	-0.018	0.121
Number of anthers/flower					0.021	0.024	-0.334	-0.035	-0.01	-0.242	-0.455*	-0.414	-0.686**
Weight of fruit (g)						0.818**	0.195	0.930**	0.143	-0.487*	0.413	0.387	0.208
Weight of non-edible portion (g/fruit)							0.195	0.671**	0.1	-0.298	0.26	0.308	0.655**
Pulp to peel ratio								0.235	-0.059	0.079	0.162	0.234	-0.106
Thickness of pulp (cm)									0.094	-0.452*	0.440*	0.351	0.056
Average wt. of seed (g/fruit)										0.306	0.152	0.588**	0.605**
TSS (% Brix)											-0.114	0.139	0.823**
Number of seeds/fruit												0.822**	-0.754**
Weight of seeds (g/fruit)													-0.822**

* = indicates 5% level of significance (using mean values).
** = indicate 1% level of significance (using mean values).

direct and indirect effects. The simple correlation values were used to compute the path coefficient analysis. Direct and indirect effects of different characters on fruits per plant have been presented in Table 5.

4. Discussion and Conclusions

The physio-morphological features of 21 pummelo genotype were found significantly different among each other. The variations were observed in leaves, flowers, fruits and seeds of all genotype. A wide variation of morphological characters of trees, leaves, fruits and seeds were identified among the pummelo clones (Paudyal and Haq, 2008). Hossain (1983) noticed varied leaf length, breadth, wing length and breadth of citrus. However, minor differences were observed between genotypic (4.043 cm) and phenotypic (4.542 cm) variance as well as genotypic (20.10%) and phenotypic (21.30%) coefficient of variation indicating minimum environmental effect upon the expression of this character. Heritability in broad sense (H^2b) was also calculated and it was moderately high as 89.01% (Table 6). In case of leaf breadth,

Table 5 - Path coefficient between fruits per plant and fruit producing characters in pummelo genotype

Traits	Leaf length (cm)	Leaf breadth (cm)	Petiole wing length (cm)	Petiole wing breadth (cm)	Number of anthers/ flower	Weight of fruit (g)	Weight of non-edible portion (g/fruit)	Pulp to peel ratio	Thickness of pulp (cm)	Average weight of seeds (g/fruit)	TSS (% Brix)	Number of seeds/ fruit	Weight of seeds (g/fruit)	Number of fruits/ plant
Leaf length (cm)	**-0.660**	0.312	0.613	-0.940	-0.044	0.032	0.069	-0.091	-0.135	-0.366	-0.062	0.647	0.161	-0.464*
Leaf breadth (cm)	-0.270	**0.650**	0.531	-0.101	-0.073	0.350	-0.272	-0.116	-0.253	-0.363	-0.100	-0.349	0.558	0.192
Petiole wing length (cm)	-0.380	0.640	**0.180**	-0.146	-0.065	0.130	0.242	0.039	-0.289	-0.088	-0.107	0.831	-0.214	0.773**
Petiole wing breadth (cm)	-0.145	0.213	0.999	**-0.173**	-0.057	-0.006	0.335	0.049	-0.157	-0.092	0.009	0.184	0.056	0.121
Number of anthers/flower	-0.468	0.107	0.306	-0.392	**-0.252**	0.061	-0.038	0.128	0.066	-0.009	-0.160	-0.163	0.128	-0.686**
Weight of fruit (g)	-0.029	0.441	0.053	0.004	-0.005	**0.289**	-0.132	-0.075	-0.177	0.133	-0.322	0.149	-0.120	0.208
Weight of non-edible portion (g/fruit)	0.114	0.616	-0.177	0.359	-0.006	0.237	**-0.161**	-0.075	-0.128	0.093	-0.197	0.935	-0.955	0.655**
Pulp to peel ratio	-0.628	0.109	-0.121	0.229	0.084	0.564	-0.314	**-0.385**	-0.449	-0.055	0.052	0.583	-0.726	-0.106
Thickness of pulp (cm)	-0.188	0.481	0.178	-0.141	0.009	0.269	-0.108	-0.090	**-0.191**	0.087	-0.299	0.157	-0.108	0.056
Average weight of seeds (g/fruit)	0.105	-0.142	-0.112	0.171	0.003	0.414	-0.161	0.023	-0.179	**0.930**	0.193	-0.457	-0.182	0.605**
TSS (% Brix)	0.247	-0.551	-0.190	-0.024	0.061	-0.141	0.480	-0.030	0.864	0.285	**0.663**	-0.410	-0.431	0.823**
Number of seeds/fruit	-0.479	-0.354	0.473	-0.088	0.114	0.119	-0.418	-0.062	-0.842	0.752	-0.075	**0.361**	-0.255	-0.754**
Weight of seeds (g/fruit)	0.138	-0.656	0.082	0.031	0.104	0.112	-0.496	-0.090	-0.671	0.546	0.092	0.296	**-0.310**	-0.822**

Residual effetct: 0.1579, Bold and underlined direct effect.

Table 6 - Genotypic variance, phenotypic variance, genotypic coefficient of variation, phenotypic coefficient of variation and per cent heritability of fruit producing characters of 21 pummelo genotype

Traits	Genotypic variance	Phenotypic variance	Genotypic CV	Phenotypic CV	Heritability (%)
Leaf length (cm)	4.043	4.542	20.10	21.30	89.01
Leaf breadth (cm)	2.004	2.103	22.61	23.16	95.29
Petiole wing length (cm)	0.362	0.441	27.46	30.30	82.09
Petiole wing breadth (cm)	0.651	0.771	44.25	48.16	84.44
Number of anthers/flower	30.870	38.432	15.06	16.80	80.32
Weight of fruit (g)	66033.637	67396.887	31.73	32.06	97.98
Weight of non-edible portion (g/fruit)	8092.547	8976.507	30.80	32.44	90.15
Pulp to peel ratio	0.350	0.406	23.28	25.08	86.20
Thickness of pulp (cm)	2.218	2.884	15.97	18.21	76.91
Average weight of seed (g/fruit)	0.021	0.024	35.01	37.40	87.67
TSS (% Brix)	1.436	1.890	7.47	8.56	75.98
Number of seeds/fruit	754.160	804.840	37.21	38.44	93.70
Weight of seeds (g/fruit)	195.793	209.793	43.17	44.69	93.33
Number of fruits/plant	103.963	104.635	48.84	49.00	99.36

petiole wing length and petiole wing breadth little differences were observed between genotypic (2.004 cm, 0.362 cm, 0.651 cm) and phenotypic variances (2.103 cm, 0.441 cm, 0.771 cm) as well as genotypic (22.61%, 27.46%, 44.25%) and phenotypic coefficient of variation (23.16%, 30.30%, 48.16%) indicating minimum environmental effect upon the expression of these characters. Heritability in broad sense (H^2b) was also calculated and it was high as 95.29%, 82.09%, 84.44% (Table 6). Flower characters of different pummelo genotype were also varied significantly in this experiment. Hoque (2015) reported that petals number of pummelo genotype ranged from 4 to 4.5. Considerable differences were observed between genotypic (30.870) and phenotypic (38.432) variance as well as genotypic (15.06%) and phenotypic (16.80%) coefficient of variation indicating considerable environmental effect upon the expression of this character. H^2b was also calculated and it was very high as 80.32% (Table 6).

Regarding fruit weight, it was found that fruit weight varied significantly among the pummelo genotype. Rahman *et al*. (2003) reported that fruit weight of local pummelo accessions varied from 718.33 g to 2160 g. While Hays (1966) noticed that the pummelo fruit is larger than the other important commercial citrus species, somewhat weighing more than 1 kg. Purseglove (1968) also observed that the fruit of pummelo is large to very large. The weight of pummelo fruit were ranged from 250 to 1218.75 g (Hossain, 1983). In Bangladesh, weight of fruit varied from 396 to 1418 g. This variation might be due to genetical, physiological, nutritional or environmental influences. The genotypic and phenotypic variances of weight of fruits were 66033.637 g and 67396.887 g, respectively. The genotypic coefficient of variation (31.73%) was lower than phenotypic coefficient of variation (32.06%), which indicated more influence of environment on the performance of particular trait. H^2b was also calculated and it was 97.98% which was high.

The genotypic and phenotypic variances of weight of non-edible portion were 8092.547 g and 8976.507 g, respectively. The genotypic coefficient of variation (30.80%) was lower than phenotypic coefficient of variation (32.44%), which indicated more influence of environment on the performance of particular trait. Heritability in broad sense (H^2b) was also calculated and it was 90.15%, which was moderately high. The genotypic and phenotypic variances of ratio of pulp and peel were 0.350 and 0.406, respectively. The genotypic coefficient of variation (23.28%) was lower than the phenotypic coefficient of variation (25.08%), which indicated more influence of environment on the performance of particular trait. H^2b was also calculated and it was 86.20%, which was very high.

The genotypic and phenotypic variances of thickness of pulp were 2.218 cm and 2.884 cm, respectively. The genotypic coefficient of variation (15.97%) was lower than the phenotypic coefficient of variation (18.21%), which indicated more influence of environment on the performance of particular trait. H^2b was calculated and it was 76.91%, which was very high. TSS content significantly varied among the genotype. But little differences were observed between genotypic (1.436%) and phenotypic (1.890%) variances as well as genotypic (7.47%) and phenotypic (8.56%) coefficient of variation indicating low environmental influence on this trait. H^2b was calculated and it was 75.98% which was high. The number of fruits/plant varied significantly among the genotype. Verheij and Coronel (1992) reported that a single tree can yield 70-100 fruits/year. The genotypic and phenotypic variances of thickness of number of fruits/plant were 103.963 and 104.635, respectively. The genotypic coefficient of variation (48.84%) was lower than the phenotypic coefficient of variation (49.00%), which indicated more influence of environment on the performance of particular trait. H^2b was also calculated and it was 99.36% which was very high.

Maximum number of seeds/fruit was observed in Hybrid (114) among the studied genotype and minimum seed number was found in Accession-58. Hossain (1983) reported that the number of seeds in pummelo fruits varied from 8 to 94/fruit and also he found both seedless and seeded genotype. The genotypic and phenotypic variances of number of seeds/fruit were 754.160 and 804.840, respectively. The genotypic coefficient of variation (37.21%) was lower than the phenotypic coefficient of variation (38.44%), which indicated more influence of environment on the performance of particular trait. H^2b was also calculated and it was 93.70% which was very high. The genotypic and phenotypic variances of total weight of seeds were 195.793 g and 209.793 g, respectively. The genotypic coefficient of variation (43.17%) was lower than the phenotypic coefficient of variation (44.69%), which indicated more influence of environment on the performance of particular trait. H^2b was also calculated and it was 93.33%, which was very high.

Correlation coefficient revealed that leaf breadth, petiole wing length and breadth will be increased with the increase of leaf length. On the other hand, this trait had negatively associated with weight of non-edible portion, average weight of seeds/fruit, %TSS and weight of seeds/fruit. This indicate that petiole wing length and breadth will be increased with the increase of leaf breadth. On the other hand, this trait had negatively associated with TSS, number of seeds/fruit and total weight of seeds/fruit. Correlation coefficient revealed that petiole wing breadth and number of fruits/plant will be increased with the increase of petiole wing length. Correlation coefficient revealed that weight of non-edible portion and thickness of pulp will be increased with the increase of fruit weight. This indicate that thickness of pulp and number of fruits/plant will be increased with the increase of weight of non-edible portion. On the other hand, this trait had negatively associated with %TSS. It was observed that Correlation coefficient revealed that thickness of pulp indicates that number of seeds/fruit will be increased with the increase of thickness of pulp. Correlation coefficient revealed that average weight of seed/fruit indicates total weight of seeds and number of fruits/plant will be increased with the increase of average weight of seed.

Correlation coefficient revealed that %TSS indicates number of fruits/plant will be increased with the increase of %TSS. Correlation coefficient revealed that number of seeds/fruit indicates weight of seeds/fruit will be increased with the increase of number of seeds/fruit. Leaf length showed low direct negative effect (-0.66) on fruits/plant whereas it also contributed indirect positive effect via leaf breadth, petiole wing length, fruit weight, weight of non-edible portion, number of seeds/fruit and weight of seeds/fruit. Leaf breadth contributed low direct positive effect (0.65) on fruits/plant. This trait had also indirect positive effect on wing length, fruit weight, weight of seeds/fruit and number of fruits/plant. Petiole wing length showed low direct positive effect (0.18) on fruits/plant whereas it also contributed indirect positive effect on fruits/plant via leaf breadth, fruit weight, weight of non-edible portion, pulp to peel ratio and number of seeds/fruit.

Petiole wing breadth contributed low direct negative effect (-0.173) on fruits/plant. This trait had also indirect positive effect on number of fruits/plant via leaf breadth, petiole wing length, weight of non-edible portion, pulp to peel ratio, %TSS, number of seeds/fruit and weight of seeds per fruit. Number of anthers/flower showed low direct negative effect (-0.252) on fruits/plant. This trait had also indirect positive effect on leaf length, wing length, weight of fruit, pulp to peel ratio, thickness of pulp and weight of seeds/fruit. Fruit weight showed low positive effect (0.289) on fruits/plant whereas it also contributed indirect positive effect on number of fruits/plant via leaf length, leaf breadth, wing length, average weight of seed and number of seeds/fruit. Weight of non-edible portion contributed direct negative effect (-0.161) on fruits/plant. This trait had also indirect positive effect on number of fruits/plant via leaf length, leaf breadth, petiole wing breadth, weight of fruit, average weight of seed and number of seeds/fruit.

Pulp to peel ratio showed direct negative effect (-0.385) on fruits/plant whereas it also contributed indirect positive effect via leaf breadth, petiole wing breadth, number of anthers/flower, weight of fruit, %TSS and number of seeds/fruit. Thickness of pulp contributed direct negative effect (-0.191) on fruits/plant. This trait had also indirect positive effect on number of fruits/plant via leaf breadth, petiole wing length, weight of fruit, number of anthers, average weight of seeds and number of seeds/fruit. Average weight of seeds/fruit showed direct positive effect (0.93) on fruits/plant whereas it also contributed indirect positive effect on fruits/plant via leaf length, petiole wing breadth, number of anthers/flower, fruit weight, pulp to peel ratio and TSS. TSS showed direct positive effect (0.663) on fruits/plant. This trait had also indirect positive effect on number of fruits/plant via leaf length, number of anthers/flower, weight of non-edible portion, thickness of pulp and mean weight of single seed. Number of seeds/fruit contributed direct positive effect (0.361) on fruits/plant whereas it also contributed indirect effect via petiole wing length, number of anthers/flower, weight of fruit and average weight of seeds/fruit. Weight of seeds/fruit showed direct negative effect (-0.31) on fruits/plant. This trait had also indirect positive effect via leaf length, petiole wing length, petiole wing breadth, number of anthers/flower, weight of fruit, average weight of seeds/fruit, TSS (%) and number of seeds/fruit.

It was noticed that a wide variations existed among the pummelo genotype and these variability could be useful for varietal improvement of pummelo in Bangladesh. It appeared from the study that grouping of the genotype differed based on morphological traits. In respect on different traits genotype hybrid was found potential followed by BAU-1.

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