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ALIGNMENT OF PHENOTYPIC SELECTION WITH QUANTITATIVELY RECORDED DATA IN F_6 GENERATIONS OF INDETERMINATE TOMATO (*SOLANUM LYCOPERSICUM* L.)

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Abstract

Segregation is the way to explore genetic variability in terms of high yield, disease or cold tolerance. Selection of competitive plants is a decisive step for the plant breeders after hybridization. However, year to year selections and evaluations sometimes are effected by varying environmental conditions. There were about 288 single plant selections from 04 (F_6) generations of indeterminate tomato. Selection pressure was exerted by keeping in view of the yield assessing traits as well as the consumer acceptable fruit shapes i.e.; round, oblong and oval. About 184 single plant selections were made for round fruit, 174 for oblong, 12 for oval shaped fruit morphologies keeping in view of their yield contributing parameters. Phenotypic selections based upon the plant condition i.e.; poor, good, very good, excellent and satisfactory were made and data on the important quantitative traits were also recorded. Out of 997 plants of 184 round single plant selections; 17 plants fell under excellent category while 35 under very good, 260 under good, 100 under satisfactory and 580 under poor category while in the 746 plants belonging to 174 oblong single plant selections; 25 plants fell under excellent category while 20 under very good, 197 under good, 39 under satisfactory and 462 under poor categories. 12 single plant selections of oval fruit morphology comprised of 83 plants. Out of these 84 plants, only 14 plants fell under good, 06 under satisfactory and 63 under poor categories. The mean values were compared with their respective standard error, standard deviation and range values for each of the traits in each of the categories.

A hierarchy was also determined for the mean values in each of the categories described for plant condition in each of the traits justified the alignment of phenotypic selection with the quantitative data.

Key words: *Solanum lycopersicon* L., Growth habit, Indeterminate, Segregation, Phenotypic Selection and F_6 generation.

Introduction

Tomato is one of the important vegetables in Pakistan. It is 2nd most consumed vegetable after potato. In Pakistan, it was grown on an area of 57.87 thousand hectares with a production of 605.07 thousand tonnes (Anon., 2020-21). This domestic tomato yield is very low when compared to the yields of the other countries. The reason behind is the non-availability of the productive tomato germplasm. Only a few varieties are available to the farmers which have also lost their genetic potential as they have been in cultivation since ages. As tomato is not native to our region so the low availability of the germplasm resources has led to narrow down its genetic base.

Nowadays, the world has gone onto the hybrid development. The hybrid seed is selling at a very high price which does not come in the pocket range of all of the farmers of the country. Moreover, hybrids lose their vigour in their second generation. A large number of hybrids in tomato are available in the market; out of which only a few numbers of hybrids have shown significant heterosis. There has been a consistent hurdle in the course of variety or hybrid development in tomato. There are two reasons for this short course of development. One may be related to its place of origin which is primarily different and other may be traced back to the non-availability of productive genetic resources i.e; high yielding, disease/cold tolerance and other quality parameters etc. The short comings can be overcome by the introduction of productive germplasm from various locations but the problem still exists from where the germplasm will be accessed (Rehman *et al*., 2020). In this era of competition, no one can help without getting a mutual benefit. The only way forward in this situation is the self-reliance which will result in self-motivation.

Segregation is the way to explore the genetic variability. There is a chance of getting the best segregants by exploring the genetic variability in terms of high yield, disease or cold tolerance. This principle may increase the germplasm resources for conducting research work in different ways. The development of pure lines or inbreds may proceed to develop a variety for specific objectives or may be used for the development of hybrids. The main benefit will go for the broad genetic base of the germplasm. Selection of best plants after hybridization in the segregating generations from F_2 through F_6 is more decisive step for plant breeders (Singh and Sharma, 2016). Environmental effects also play a significant role in the expression of traits and sometimes superior plant progenies fail to perform the desired significance in the segregating generations (Brown and Caligari, 2008). Precise phenotypic selection from F_2 to F_6 can be followed up by the estimates of means and variance for the traits on which the selection pressure has been exerted by the plant breeder.

The main hurdle in the progression of research in the indeterminate tomato types is the availability of productive germplasm resources. Exploitation of genetic variability is the ultimate source of generating variability in the indeterminate tomato. Creation of variability will open the window for research in various perspectives. The stable productive lines keeping in view of their economic traits may either be progressed for general cultivation as adaptable variety or may be used as inbreds for hybrid development. Hybrids lose their vigour in their second generation. A large number of hybrids in tomato are available in the market; out of which only a few numbers of hybrids have shown significant heterosis. It means potential also lies in the varieties/lines which can be explored. Study of the segregating generations can not only result in the development of the stable tomato lines but will last to broaden the scope of genetic variability which can be exploited for hybrid development.

Presently, the available germplasm resources for indeterminate tomato are very limited. So, the development and addition of new lines of indeterminate tomato may increase the chances for developmental research at the indigenous level which will ultimately not only strengthen the knowledge of national scientists working on tomato but the products of research will also benefit the farming community at large. By keeping a reference of this principle, the segregating generations of 288 single plant selections of 04 crosses in F_6 generation of indeterminate tomato were also planted in the field. Selection pressure was exerted on the best plants by keeping in view of the yielding traits as well as the consumer acceptable fruit shapes i.e; round, oblong and oval.

Materials and Methods

The present studies pertaining to genetic variability in indeterminate tomato were conducted at the Vegetable Crops Research Programme, Horticultural Research Institute, National Agricultural Research Centre, Islamabad during 2019-20.

Plant material: The plant material used under the study comprised of the single plant selections of the segregating generations in F_6. The details of the plant materials under study is given in (Table 1).

Nursery sowing, transplantation and planting geometry: The nursery of 288 single plant selections from 04 (F_6) generations of indeterminate tomato was sown on 15 cm raised beds on the 16th of October, 2019. The raised beds were manually ploughed and upper surface of 2-3 cm was top dressed with compost and FYM in the ratio 1:1. Each single plant selection was sown on separate 1.5 cm deep furrow/row and a thin layer of media (FYM: Compost) in a ratio of 1:1 was placed on the seed. The beds were irrigated with hand shower so as to moisten the seed sown without disturbing its orientation.

The seedling beds were covered with plastic sheet at night in order to maintain the temperature at night. Manual weeding and hoeing of nursery beds was also done to accelerate the seedling emergence process. The seedlings were emerged by the second week of November, 2019. The day and night temperatures of tunnel were retained at 30 ± 3°C and 23 ± 3°C respectively. The seedlings were transplanted under plastic tunnel on 12th of December, 2019 with plant to plant and row to row distances 50 cm and 1 meter respectively.

Farm yard manure @ 30,000 kg $ha^{-1}$and NPK @ 150:75:75 $kg.ha^{-1}$ was applied. Whole of P and half of N & K were applied at soil preparation and remaining half of Nitrogen & potash was applied in five equal doses at two weeks interval after one month of transplanting. Insecticides (Permethrin or Cypermetherin mixed with Chloropyrephos were applied to control the attack of sucking and chewing insects (*Heliothis* sp.). The plants were staked under the plastic tunnel with jute treads. In the next step, all of the plants were tagged by mentioning the individual numbers. The pruning of plants was also done to maintain plant vigorsity.

Field evaluation at maturity: At maturity, the data on the main morphologically identified traits i.e; plant height, number of clusters per plant, number of fruits per cluster and number of fruits per plant was recorded as per official descriptor of FSC&RD. However, for the other traits like fruit shape, pubescence and plant condition etc; a qualitative grading system based upon visual ratings was adopted (Nawab *et al*., 2011 & Nawab *et al*., 2014). The detail is given in (Table 2).

Table 1. Resource plant material for study
(288) Single plant selections of 04 cross combinations (F_6)

S. No.	Plant material	Single plant selections	Source	Design
1.	NTT-04-08	110	Locally developed	Non-replicated
2.	NTT-06-08	10	Locally developed	Non-replicated
3.	NTT-07-08	116	Locally developed	Non-replicated
4.	NARC-Sahil	52	Locally developed	Non-replicated

Table 2. Qualitative grading system based upon visual ratings.

Fruit shape	**Round**	**Oblong**	**Oval**
Rating	1	2	3
Pubescence	**Sparse**	**Medium**	**Dense**
Rating	1	2	3

Plant condition	**Poor**	**Good**	**Very Good**	**Excellent**	**Satisfactory**
Rating	1	2	3	4	5

Procedure for studying segregating generations: For studying the segregating generations; pedigree method was followed as outlined by Poelman and Sleper (1995). Single plant selections were progressed in progeny to row fashion. Selection of best plants was made keeping in view of yield attributing traits and fruit shape. Four segregating generations in F_6 were progressed to the succeeding generations following self-pollination.

Statistical data analysis: Recorded data were averaged and analyzed for simple/ descriptive statistics including mean, standard error, standard deviation and range using computer software MS EXCEL, Windows 2003 (Ghafoor *et al*., 2003; Elahi *et al*., 2017) to estimate the genetic diversity present in the single plant selections of varying segregating generations.

Results and Discussion

Study of filial/ segregating generations: The segregating generations are the means to exploit genetic variability which is the main objective of the present study. The 04 segregating generations in F_6 were studied and selection pressure was exerted on their yield contributing traits by keeping in view of their fruit shape (Visa *et al*., 2014). Yield and fruit shape in tomato are very important criteria from consumer preference point of view. Four fruit shapes have been commercially accepted by the consumers in tomato i.e.; round, oblong, oval and pear shaped. The present study also taken into account the desirables fruit shapes along with the yield contributing traits. Qualitative grading system was adopted for the traits like fruit shape, pubescence and plant condition. The plant condition of the segregating populations from the breeder's eye was evaluated as a selection criterion (excellent, very good, good, satisfactory and poor). However, the data from each of the plant was collected. Pedigree method of selection was preferred over the bulk selection method which is though laborious in handling but is easy to trace back the phylogenetic record.

Single plant selections from F_6 generations: The progeny of about 288 single plant selections of 04 cross combinations in F_6 was evaluated not only for their yield contributing traits but also for other physical parameters like fruit shape. Since, the progenies in F_6 had attained a desired level of homogeneity (Nawab *et al*., 2019) so, the whole of the selected plants were grouped mainly into three groups based upon their fruit shapes depending upon their encouraging yield traits. Fruit shape in tomato is very important from the consumer preference point of view (Ahmad *et al*., 2019; Anjum *et al*., 2020). Normally, three fruit shapes viz; round, oblong and oval are commonly preferred by the farming community. keeping in view of the consumer preference in terms of fruit shapes. In all the four cross combinations in F_6 the plants were therefore grouped in round, oblong and oval fruit shapes.

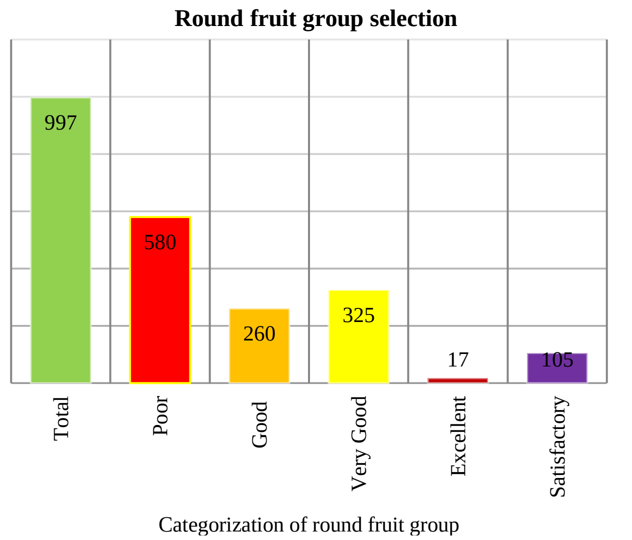

Fig. 1. Categorization of round fruit group plants on the basis of their performance.

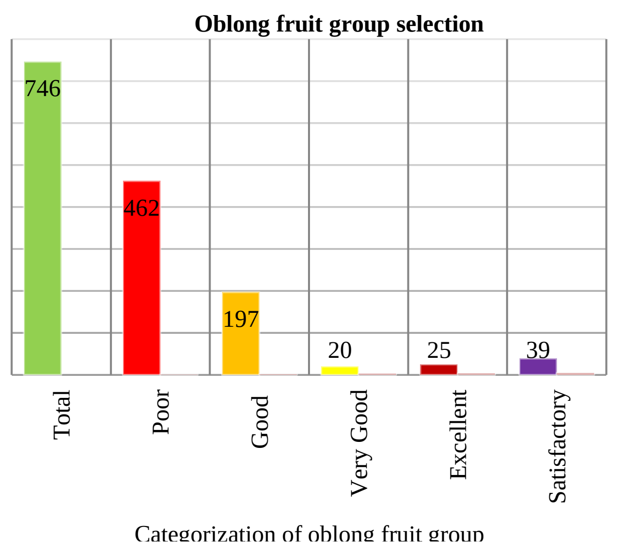

Fig. 2. Categorization of oblong fruit group plants on the basis of their performance.

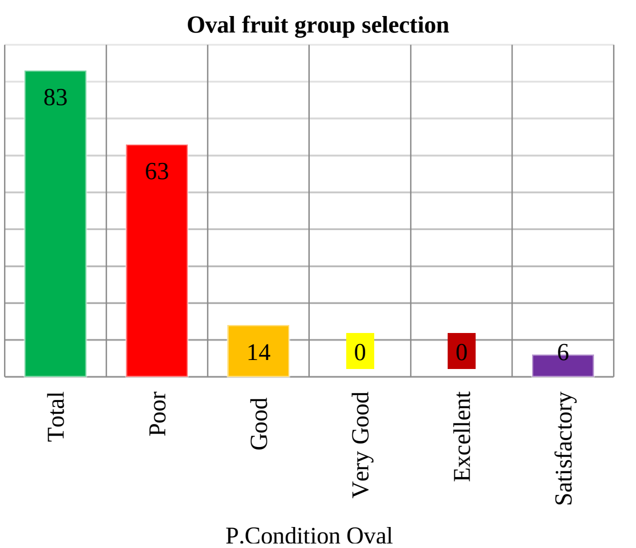

Fig. 3. Categorization of oval fruit group plants on the basis of their performance.

a) Round fruit group selection: There were about 997 plants studied under this round fruit shape group. The data on yield contributing traits on each of the plant was recorded. Selection of best/ideal plants was made on the basis of the physically observed yield attributes. According to the plant performance the plants both agronomical and with disease perspective were further grouped into five categories viz; poor, good, very good, excellent and satisfactory. The selection criteria were applied to the group of plants belonging to good, very good and excellent. Out of 997 plants; 17 plants fell under excellent category while 35 under very good, 260 under good, 100 under satisfactory and 580 under poor category as shown in (Fig. 1).

The mean performance, values of standard error, standard deviation and range of round fruit shaped plants for various morphological traits in F_6 for each of the category is presented in Table 3 (Umar *et al*., 2014) which depicted that the selection and categorization of plants on phenotypic basis coincides with the average quantitative performance. The mean values were compared with their respective standard error, standard deviation and range values for each of the traits in each of the category (Ghafoor *et al*., 2005). In all of the traits, the standard error values remained less in comparison to their means which clearly indicated that plants in each group had reached a desired level of homogeneity (Ghafoor and Ahmad, 2005). For plant height there was not much variability observed among the groups. However, higher level of variability was studied for plant height as evident from the high values of standard deviation. Selection could be made from the first three top categories with good plant condition. Mean maximum number of clusters per plant was recorded for excellent (8.2) followed by very good (6.86) and good (6.01) categories. The range and standard deviation values for this trait indicated a considerable amount of variability which was utilized in the selection of best plants. The range of average number of fruits per cluster in the selective classes i.e.; excellent, very good and good, remained from 3.4 to 3.06 where, also a considerable level of variability helped in the selection process with respect to the overall plant condition. The same pattern was followed for number of fruits per plant. Mean maximum number of fruits per plant were recorded as 27.9 with the range of 7 to 64 fruits in the excellent category of plants followed by a mean of 21.97 fruits with range from 5 to 57 in the very good category, 17.93 of mean number of fruits with a range of from 1 to 79 fruits in good category. However, in the satisfactory and poor category the mean number of fruits was low as 16.5 and 11.39 respectively. Number of clusters per plant and number of fruits per plant are very important traits from breeding point of view (Rehman *et al*., 2000). The plants in the whole round fruit shape generations were categorized on the basis of these two main traits. A hierarchy for each of the traits was also observed for the mean values in each of these categories described for plant condition which justified the phenotypic selection based upon quantitative data. It was noticed from the Table 3 that the values of standard deviation were found decreasing from the excellent to the poor category which meant that maximum variability and probability of ideal plants was associated to the magnitude of variability among the plant population as evident from the mean values assigned to each of the categories (Table 3). Single plant selections by accumulatively considering the yield contributing traits along with the plant condition could be affective from breeding point of view for desirable gene fixation. There was no variability observed for fruit shape which indicated as evident from the standard deviation of each of the category; confirming all plants belonged to round fruit shape group and selection had confined the variability to round fruit shape in F_6. In the whole group, sparse and medium hairiness was reported as reflected from the (Table 3).

b) Oblong fruit group selection: On the basis of the physical plant performance; the plants under oblong fruit shape category were further grouped into five categories viz; poor, good, very good, excellent and satisfactory. Out of 746 plants; 25 plants fell under excellent category while 20 under very good, 197 under good, 39 under satisfactory and 462 under poor categories as shown in (Fig. 2).

Table 3. Mean performance of round fruit shaped plants for various morphological traits in F_6.

Category		Plant height (cm)	No. of clusters/plant	Av. No. of fruits/cluster	No. of fruits/ plant	Fruit shape	Pube-scence	P. Cond.
Excellent	Mean	182.2	8.2	3.4	27.9	1.0	1.6	4.0
	SE	5.9	1.07	0.32	3.65	0.00	0.12	0.00
	SD	24.2	4.40	1.31	15.06	0.00	0.48	0.0
	Range	120-210	3-19	1.8-6.2	7-64	1-1	1-2	4-4
Very good	Mean	181.57	6.86	3.22	21.97	1.00	1.66	3.00
	SE	5.23	0.51	0.24	2.21	0.00	0.08	0.00
	SD	30.92	3.0	1.43	13.05	0.00	0.47	0.00
	Range	130-240	3-15	1.2-7.1	5-57	1-1	1-2	3-3
Good	Mean	181.84	6.01	3.06	17.93	1.00	1.70	2.0
	SE	2.0	0.15	0.12	0.72	0.00	0.09	0.00
	SD	31.59	2.34	1.87	11.56	0.00	1.37	0.00
	Range	100-250	2-16	1-13.1	1-79	1-1	1-2	2-2
Satisfactory	Mean	180	6.0	2.6	16.5	1.0	1.7	5.0
	SE	3.9	0.26	0.12	1.05	0.00	0.05	0.00
	SD	37.82	2.56	1.21	10.32	0.00	0.47	0.00
	Range	100-250	1-14	1-8	1-51	1-1	1-2	5-5
Poor	Mean	174	4.30	2.47	11.39	1.00	1.54	1.00
	SE	1.6	0.08	0.05	0.50	0.00	0.02	0.00
	SD	36.65	1.95	1.15	11.57	0.00	0.50	0.00
	Range	3.1-270	1-13	1-11.2	1-150	1-1	1-2	1-1

Fruit shape: Round (1), Oblong (2), Oval (3); Pubescence: Sparse (1), Medium (2), Dense (3); Plant condition: Poor (1), Good (2), Very Good (3), Excellent (4), Satisfactory (5)

Table 4. Mean performance of oblong fruit shaped plants for various morphological traits in F_6.

Category		Plant height (cm)	No. of clusters/plant	Av. No. of fruits/cluster	No. of fruits/ plant	Fruit shape	Pube-scence	P. Cond.
Excellent	Mean	189	5.8	4.0	23.8	2.0	1.5	4.0
	SE	6.0	0.4	0.4	2.9	0.0	0.1	0.0
	SD	30.08	2.22	1.90	14.38	0.00	0.50	0.0
	Range	130-250	3-12	1.0-8.3	3-50	2-2	1-2	4-4
Very good	Mean	181	6.4	3.1	19.6	2.0	1.5	3.0
	SE	5.2	0.7	0.4	2.9	0.0	0.1	0.0
	SD	23.24	3.0	1.6	13.1	0.0	0.5	0.0
	Range	130-210	3-14	1.0-7.5	3.0-60	2-2	1-2	3-3
Good	Mean	188	5.3	3.2	16.9	2.0	1.2	2.0
	SE	2.5	0.13	0.10	0.70	0.00	0.03	0.00
	SD	34.65	1.81	1.47	9.89	0.00	0.43	0.00
	Range	56-250	2-11	1.0-10.7	2.0-67	2-2	1-2	2-2
Satisfactory	Mean	190.7	5.4	3.1	16.5	2.0	1.3	5.0
	SE	3.9	0.28	0.23	1.59	0.00	0.07	0.00
	SD	24.30	1.7	1.4	9.9	0.0	0.5	0.0
	Range	130-240	2-12	1.6-7.4	6-52	2-2	1-2	5-5
Poor	Mean	177	3.7	2.5	10.0	2.0	1.1	1.0
	SE	5.0	0.1	0.1	0.4	0.0	0.0	0.0
	SD	105.63	1.67	1.37	8.23	0.00	0.34	0.00
	Range	36-270	1-14	1-13.2	1-69	2-2	1-2	1-1

Fruit shape: Round (1), Oblong (2), Oval (3); Pubescence: Sparse (1), Medium (2), Dense (3); Plant condition: Poor (1), Good (2), Very Good (3), Excellent (4), Satisfactory (5)

Table 5. Mean performance of oval fruit shaped plants for various morphological traits in F_6.

Category		Plant height (cm)	No. of clusters/plant	Av. No. of fruits/cluster	No. of fruits/ plant	Fruit shape	Pube-scence	P. Cond.
Excellent	Mean	180.5	4.4	2.5	10.6	3.0	1.0	2.0
	SE	12.2	0.4	0.2	1.2	0.0	0.0	0.0
	SD	45.5	1.55	0.74	4.64	0.0	0.0	0.0
	Range	130-310	1-7	1.6-4.0	4-21	3-3	1-1	2-2
Very good	Mean	191	4.2	2.7	11.0	3.0	1.0	5.0
	SE	14.26	0.7	0.4	2.1	0.0	0.0	0.0
	SD	34.9	1.8	0.9	5.3	0.0	0.0	0.0
	Range	165-240	2-7	1.5-4.0	3-19	3-3	1-1	5-5
Good	Mean	178	3.2	2.2	7.4	3.0	1.0	1.0
	SE	5.6	0.2	0.1	0.7	0.0	0.0	0.0
	SD	44.54	1.84	0.77	5.29	0.0	0.0	0.0
	Range	85-300	1-13	1.0-4.5	1-30	3-3	1-1	5-5
Satisfactory	Mean							
	SE							
	SD							
	Range							
Poor	Mean							
	SE							
	SD							
	Range							

Fruit shape: Round (1), Oblong (2), Oval (3); Pubescence: Sparse (1), Medium (2), Dense (3); Plant condition: Poor (1), Good (2), Very Good (3), Excellent (4), Satisfactory (5)

The mean, standard deviation, standard error and range values (Ahmad *et al*., 2017) of oblong fruit shaped plants for various morphological traits in F_6 for each of the category is presented in Table 4. The quantitative data of yield contributing traits was also found in line with the selection and categorization of plants done on their phenotypic performance. The mean values were compared with their respective standard error, standard deviation and range values for each of the traits in each of the category (Anjum *et al*., 2020). In all of the traits, the standard error values remained less in comparison to their means which clearly indicated that plants in each group had reached a desired level of homogeneity. The range and standard deviation values clearly indicated the presence of variability. For plant height and number of fruits per plant; a higher level of variance was observed following number of clusters per plant and average number of fruits of fruits per plant. The range of mean plant height (177 to 189 cm) was recorded for all of the categorical classes which gave an indication that most of the plants in each of the categories have indeterminate type of growth habit and selection could be successful by considering the other yield attributes and plant condition. The range of difference for number of clusters per plant and average number of fruits per cluster in excellent (3-12; 1.0-8.3), very good (3-14; 1.0-7.5), good (2-11; 1.0-10.7), satisfactory (2-12; 1.6-7.4) and poor (1-14; 1.0-13.2) was due to the variable differences among the plants present in each of the category as evident from the values of their variance. The ideal plants for these two traits existed in the top three categories in relation to their plant condition. The variability in the categories of satisfactory and poor was not qualified due to the physical plant condition and the quantitative data. The maximum mean value for number of fruits per plant was recorded for plants falling under excellent category (23.8) followed by very good (19.6), good (16.9), satisfactory (16.5) and poor (10.0) which indicated the presence of ideal plants with respect to this trait in the first three top categories. Selection of the best plants was made on the basis of the physical condition in relation to the number of fruits per plant. From the Table 4, it was concluded that the plants falling under excellent, very good and good categories had fruits in a range from 3-67. But the selection pressure was exerted on those plants with good number of fruits per plant and plant condition (Ahmad *et al*., 2018). There was no variability observed for fruit shape in the varying cross combinations followed under oblong fruit category which indicated that all the plants belonged to oblong fruit shape group and selection has confined the variability to oblong fruit shape in F_6. Sparse to medium hairiness was reported as reflected from the (Table 4). Single plant selections with respect to the yield contributing traits along with the plant condition could be affective in advancing the breeding cycles for attaining a level of homozygosity and gene fixation.

c) Oval fruit group selection: Plant performance under oval fruit shape category was further grouped into three categories viz; poor, good and satisfactory. Out of 83 plants; 14 plants fell under good category, 06 under satisfactory and 63 under poor categories as shown in (Fig. 3).

The mean, standard deviation, standard error and range values (Nawab *et al*., 2013; Shankar *et al*., 2013) of oval fruit shaped plants for various morphological traits in F_6 is presented in (Table 5). The mean values were compared with their respective standard error values for each of the traits in each of the category. In all of the traits, the standard error values remained less in comparison to their means which clearly indicated that plants in each group had reached a desired level of homogeneity. Three distinct categories were observed under oval group selections. The plants belonged to the good category were selected. For plant height there was considerable variability observed among the groups which might be due to genetics or due to varying environmental factors. However, for the traits like number of clusters per plant and average number of fruits other traits, the variability was found negligible which meant that plants in each of categories were not much different. Maximum mean number of fruits per plant (10.6 ± 1.2) with range from 4 to 21 and sparse hairiness were reported for the selective good category of the progenies of single plant selections.

Conclusions

There were about 288 single plant selections from 04 (F_6) generations of indeterminate tomato planted in the field during 2019-20. Selection pressure was exerted on the best plants by keeping in view of the yielding traits as well as the consumer acceptable fruit shapes i.e.; round, oblong and oval. Phenotypic selections based upon the plant condition i.e.; poor, good, very good, excellent and satisfactory were made and data on the important quantitative traits were also recorded. A hierarchy in each of the traits was also observed for the mean values in each of the categories described for plant condition which justifiably align the phenotypic selection based upon quantitative data. About 174 single plant selections were made for oblong fruit, 184 for round, 12 for oval shaped fruit morphologies keeping in view of their yield contributing parameters.

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