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Quantification of gynoecious and monoecious populations for horticultural traits in bitter gourd (*Momordica charantia* L.)

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Abstract
The current study used eight bitter gourd (*Momordica charantia* L.) populations (333 Sib, 323, 144 Sib, 244, 166 Sib, 2144, 2145, and 2116) descended from gynoecious lines segregating for monoecious and gynoecious plants and two checks (Pusa Hybrid and Pusa Do Mausami). The segregation study found that key recessive genes govern gynoecious base derived populations. Fruit yield per plant was higher in three populations (gynoecious 323, monoecious 323, and gynoecious 333) than check (Pusa Do Mausami), but lower than in the Pusa Hybrid. The yields of both gynoecious populations were higher than those of the monoecious group. Because the fruit size and shape of both populations are of acceptable quality, gynoecious base populations can be commercially exploited. Both populations' monoecious plants (323 and 333) produced pistillate flowers at lower nodes than staminate flowers, and staminate flowers developed 20-30 days after pistillate flowers. This is one of the most useful visual observations made throughout the study, which might be used for hybrid seed production if inbred populations produced from such populations are employed as female parents. The significant positive correlation of vine length with number of fruits/plant and fruit yield which provide ample scope to produce more flowering nodes and fruits in biter gourd. The cross combination 333 x PDM (50%)and 333 x MC-83, 2116 x DVBTG-2 and 2145 x DVBTG-2 are found best cross combination having 33 fruit set, which can be used as hybrids and parents can be utilized in development of trait specific cross combinations considering yield and number of fruits/plant.

Keywords: Bitter gourd, monoecious, gynoecism, cross combinations, segregation, yield

Introduction
Bitter gourd (*Momordica charantia* L.) is widely farmed throughout the country and is well known for its nutritional, therapeutic (anti-diabetic), and curative characteristics. Bitter gourd was recently named one of the "Five Foods That Will Save the World" by Reader's Digest UK, with basmati rice, mung bean, disease-resistant banana, and drought-resistant maize. Its tender green fruits have captured a prominent position among fresh vegetables. It is now an export oriented vegetable which is generally marketed in fresh but sometimes in dehydrated or osmo-drying form. Occurrence and distribution of both wild and cultivated forms of bitter gourd indicates its rich diversity in India. The predominant sex form in bitter gourd is monoecious; however, gynoecious sex form (only female flower bearing plant) has been reported from India, Japan and China (Ram *et al*., 2006; Ram *et al*., 2002; Shukla *et al*., 2014) [5, 4, 7]. There are several agronomical practices which are responsible for fruit quality and seed yield like training system in bitter gourd (Singh *et al*., 2014) [8]. The success of breeding procedure is determined by the useful gene combinations organized in the form of good combining lines and isolation of valuable germplasm. Some lines produce outstanding progenies on crossing with others, while others may look equally desirable, but may not produce good progenies on crossing. There is a great scope for the improvement of this crop through hybridization and use of gynoecious population in exploitation of heterosis (Moharana *et al*., 2022) [3]. Therefore, the present study was undertaken to develop high yielding hybrids (F_{1s}) having valuable horticultural attributes *viz*. earliness, uniformity, good quality, high yield, resistance to diseases and adaptability to wider environmental conditions.

Materials and Methods
The experiment was conducted at ICAR-Indian Institute of Vegetable Research, Varanasi (U.P.), India. The experimental materials consisted of 8 populations (333 Sib, 323, 144 Sib,

244, 166 Sib, 2144, 2145 and 2116) derived from gynoecious lines and two checks (Pusa Hybrid and Pusa Do Mausami). The seeds of 9 segregating population derived from the gynoecious plants along with checks were sown in plastic bags (12 cm x 6 cm size) filled with equal proportion of soil, sand and well decomposed FYM. The field was well manured with rotten FYM@ 15 tons per hectare 20 days before seed sowing. The 30 days old seedlings were transplanted in the main field keeping row-to-row and plant-to-plant 1.50 m x 0.50 m, respectively. The recommended cultural practices and plant protection measures were applied to raise the healthy crop. Quantitative observations on nine important horticultural characters i.e. days to germination, days to anthesis, 1stpistillate flower node, vine length (cm), no. of fruits/ plant, fruit length (cm), days to horticultural maturity, days to physiological maturity (days after planting) and fruit yield/ plant were recorded on five randomly selected plants from each row. The recorded data were averaged and subjected to statistical analysis using Chi-square test (X^2) for testing the discrepancies between observed and expected value of frequencies of gynoecious and monoecious plants.

Results and Discussion

In 333 sib mated populations, 56 plants were grown, 11 of which were gynoecious and 45 of which were monoecious. In each of the eight populations, the X2 for goodness of fit was used. In 323 selfed populations, 23 plants were gynoecious and 69 plants were monoecious, with the X2 for goodness of fit being non-significant (table 1). The monoecious and gynoecious populations *viz*., 323 and 333 expressed sufficient morphological variations for all the traits under study. Significant variation of 323 monoecious populations for days to germination (8-13 days with average of 10.50 days) but in gynoecious population it was 8-12 with average of 10.00 days. The monoecious populations for days to anthesis ranged 42-48 days with the average value of 44.20 days while gynoecious populations ranged from 40-47 days with the average value of 48.9 days after seed sowing. Emergence of 1st pistillate flower node in 323 monoecious populations appeared on 5th to 13th node and average value was 8.7 while in gynoecious populations it was 5th to 7.5th node with average of 6th node. Over all, vine length varied from 60-160 cm in 323 monoecious populations which ranged from 68-153 cm with average of 91.90 cm while in gynoecious populations ranged from 67-160 cm with average of 127.7 cm. In monoecious populations for number of fruits/plant ranged from 10-16 days with the average of 13 monoecious populations ranged from 4-11 days with average of 7.24, while in gynoecious populations it was7-16 days with the average of 11.94. Fruit length varied in monoecious populations from 8-16 cm with average of 12.80 cm while in gynoecious populations it ranged from 10-16 cm with average of 12.50 cm. In monoecious population's horticultural maturity varied from 55-62 days after seeding with average of 58.3 days while in gynoecious populations it was 54-60 days with average of 58 days. In monoecious populations of 323 for fruit yield/plant varied from 300.0-900.0 g with average of 580.7 g while in gynoecious populations it was550.0-960.0 g with average of 736.67 g. In monoecious populations of 333 for fruit yield/plant varied from 240.0-750.0 g with average of 446.16 g while in gynoecious populations it varied from 400.0-900.0 g with average of 754 g. among the checks, Pusa Hybrid yield 990.0 g and Pusa do Mausami yield 540.0 g per plant (table 2 and 3). Similar findings are also reported in monoecious genotypes by Singh *et al*. (2014) [8].

In monoecious populations of 323, days to anthesis had significant positive correlation with horticultural maturity and physiological maturity. Vine length had significant positive correlation with number of fruits/plant and fruit yield. The number of fruits/plant had significant positive correlation with fruit yield/plant (table 4). The findings revealed that morphological analyses define the genetic diversity of Indian bitter gourd (Singh *et al*., 2014) [8]. Similarly, in gynoecious populations of 323, days to anthesis had significant positive correlation with horticultural maturity and physiological maturity. Vine length also expressed significant positive correlation with number of fruits/plant and fruit yield/plant. The number of fruits/plant had significant positive correlation with fruit yield/plant (table 4). In gynoecious population days to anthesis had significant positive correlation with horticultural maturity and physiological maturity. Similarly, Vine length also had significant positive correlation with number of fruits/plant and fruit yield/plant (table 4). In monoecious population days to anthesis had significant positive correlation with horticultural maturity and physiological maturity. Similarly, Vine length also had significant positive correlation with number of fruits/plant and fruit yield/plant (table 5). The cause and effect analysis of yield in off-season bitter gourd reported by Ram, *et al*. (2006) [4] also expressed the same trend. In gynoecious populations of 333 days to germination had significant positive correlation with days to anthesis, 1st pistillate flower node, horticultural maturity and physiological maturity. Like all the other populations, days to anthesis had significant positive correlation with horticultural maturity and physiological maturity. Vine length also had significant positive correlation with number of fruits/plant and fruit yield/plant (table 5). Genetic architecture and association analysis also revealed the same trend in bitter gourd landraces (Singh *et al*., 2014) [8].

During the study, using 4 gynoecious lines *viz*., 333, 323, 2116 and 2145 with 5 monoecious male plants i.e. Pusa Do Mausami, DVBTG-1, DVBTG-2, MC-84 and MC-43several cross combinations were developed. On the gynoecious line 333, the maximum fruit setting was recorded in the cross 333 x Pusa Do Mausami (50%) followed by 333 x MC-43 (33%). Other cross combinations like 333 x DVBTG-1, 333 x DVBTG-2 and 333 x MC-84 set only 25% fruits per plant, which can be useful in exploitation of heterosis in gynoecious base lines describe in Moharana *et al*., 2022) [3]. Other cross combinations like 323 x Pusa Do Mausami (20%) followed by 323 x MC-43 (18.20%). In gynoecious line 2116, the maximum fruit set was observed in combination 2116 x DVBTG-2 (33%). Similarly, when 2145 gynoecious line was crossed with DVBTG-2 fruit setting was also equal i.e.33% (table 6). In general, the monoecious combinations also exhibited superior performance over all other accessions, which are similar to the findings of Bhardwaj and Singh, 2022 [1, 2].

Table 1: Segregating pattern of gynoecious and monoecious populations

Populations	Sex forms			Total plants	X^2
		Gynoecious	Monoecious		
333 sib	O	11.00	45.00	56	0.856
	E	14.00	42.00		
323 (x)	O	23.00	69.00	92	-
	E	23.00	69.00		
144 sib	O	5.00	26.00	31	1.3
	E	7.75	23.25		
244 (x)	O	6.00	31.00	37	1.52
	E	9.25	27.75		
166 sib	O	3.00	11.00	14	0.1
	E	3.50	10.5		
2116 (x)	O	5.00	16.00	21	0.02
	E	5.25	15.75		
2144 (x)	O	11.00	12.00	23	5.39
	E	5.75	17.25		
2145 (x)	O	6.00	29.00	35	1.15
	E	8.75	26.25		
Pooled	O	70.00	239.00	309	0.91
	E	77.25	231.75		

O=Observed; E= Expected77.25; Sib= Sib mated plants and (x) = Selfed plants

Table 2: Morphological observation on Monoecious and Gynoecious plants of the population 323

Plant No.	Days to germination	Days to anthesis	1st Pistillate flower node	Vine length (cm)	No. of fruits/plant	Fruit length (cm)	Days to horticultural maturity (days after planting)	Days to physiological maturity (days after planting)	Fruit yield/plant
Monoecious Plants									
2	8.0	43.0	7.3	98.0	11.0	12.0	57.0	71.0	670.0
3	10.0	44.0	7.5	120.0	12.0	13.0	58.0	72.0	700.0
4	9.0	42.0	11.2	80.0	10.0	11.0	57.0	73.0	600.0
5	12.0	46.0	9.7	70.0	8.0	13.0	60.0	75.0	500.0
7	11.0	45.0	11.0	75.0	7.0	14.0	58.0	73.0	400.0
8	13.0	48.0	10.0	68.0	5.0	13.0	62.0	75.0	300.0
9	12.0	45.0	10.3	98.0	10.0	15.0	59.0	78.0	600.0
10	10.0	42.0	50.	69.0	9.0	16.0	55.0	73.0	530.0
11	9.0	46.0	6.0	75.0	12.0	15.0	60.0	75.0	630.
12	10.0	44.0	13.0	135.0	14.0	14.0	58.0	73.0	840.0
20	11.0	44.0	6.5	153.0	16.0	8.0	59.0	73.0	910.0
21	9.0	43.0	6.5	102.0	11.0	12.0	59.0	72.0	620.0
22	12.0	45.0	10.5	75.0	9.0	13.0	58.0	75.0	470.0
23	13.0	42.0	7.5	68.0	5.0	10.0	56.0	73.0	300.0
Mean	10.5	44.2	8.7	91.9	9.9	12.8	58.3	78.9	580.7
Gynoecious plants									
1	9.0	42.0	5.0	134.0	14.0	14.0	57.0	72.0	860.0
6	8.0	40.0	7.0	150.0	16.0	11.0	54.0	71.0	960.0
13	9.0	45.0	5.8	144.0	15.0	12.0	59.0	74.0	800.0
14	9.0	41.0	6.5	138.0	12.0	11.0	56.0	70.0	690.0
15	10.0	44.0	7.5	160.0	16.0	16.0	59.0	71.0	890.0
16	11.0	45.0	6.5	96.0	10.0	16.0	58.0	73.0	600.0
17	9.0	46.0	5.5	120.0	11.0	13.0	60.0	72.0	590.
18	8.0	45.0	5.5	67.0	10.0	9.0	59.0	74.0	550.0
19	12.0	47.0	5.0	140.0	13.0	10.0	60.0	78.0	690.0
Mean	9.5	48.9	6.0	127.7	13.0	12.5	58.0	72.8	736.67
Pusa Hybrid ©	10.0	44.0	7.2	150.0	16.0	15.0	58.0	74.0	990.0
Pusa Do Mausami ©	10.0	47.0	10.3	75.0	9.0	13.0	60.0	76.0	540.0

Table 3: Morphological observation Monoecious and Gynoecious plants of the population 333

Plant No.	Days to germination	Days to anthesis	1st Pistillate flower node	Vine length (cm)	No. of fruits/ plant	Fruit length (cm)	Days to horticultural maturity (days after planting)	Days to physiological maturity (days after planting)	Fruit yield/ plant
Monoecious plants									
1	9.0	42.0	7.0	98.0	10.0	12.0	54.0	69.0	600.0
5	10.0	47.0	7.0	97.0	8.0	16.0	60.0	74.0	490.0
6	9.0	45.0	10.6	59.0	7.0	15.0	57.0	73.0	400.0
7	11.0	48.0	7.0	62.0	9.0	13.0	60.0	78.0	540.0
9	12.0	45.0	6.0	88.0	11.0	11.0	59.0	74.0	750.0
10	14.0	49.0	5.0	69.0	9.0	14.0	61.0	76.0	690.0
14	11.0	45.0	8.0	67.0	8.0	14.0	59.0	76.0	500.0
17	9.0	45.0	4.5	68.0	5.0	11.0	58.0	74.0	290.0
19	12.0	46.0	7.25	59.0	5.0	14.0	58.0	74.0	250.0
21	9.0	44.0	8.0	60.0	5.0	9.0	58.0	73.0	240.0
23	11.0	43.0	6.0	67.0	7.0	8.0	59.0	73.0	400.0
24	14.0	49.0	5.0	60.0	4.0	14.0	62.0	78.0	300.0
28	9.0	43.0	11.5	64.0	6.0	12.0	58.0	74.0	350.0
Mean	10.77	45.47	7.15	70.62	7.24	12.54	58.7	74.31	446.16
Gynoecious plants									
2	10.0	44.0	7.5	145.0	14.0	14.0	57.0	72.0	900.0
3	9.0	44.0	5.5	125.0	13.0	13.0	58.0	73.0	870.0
4	8.0	40.0	10.3	105.0	13.0	14.0	56.0	73.0	850.0
8	13.0	48.0	7.0	140.0	12.0	12.0	62.0	77.0	820.0
11	9.0	50.0	8.0	130.0	11.0	12.0	63.0	79.0	750.0
12	11.0	48.0	8.0	98.0	9.0	11.0	60.0	77.0	700.0
13	13.0	50.0	6.2	115.0	11.0	13.0	63.0	77.0	800.0
15	9.0	48.0	6.0	135.0	14.0	15.0	60.0	75.0	900.0
16	9.0	45.0	10.5	98.0	7.0	9.0	57.0	73.0	400.0
18	8.0	47.0	4.5	92.0	10.0	13.0	60.0	76.0	500.0
20	14.0	46.0	7.5	145.0	16.0	12.0	60.0	76.0	980.0
22	13.0	48.0	7.33	89.0	10.0	13.0	60.0	76.0	450.0
25	9.0	44.0	10.0	135.0	16.0	10.0	59.0	75.0	900.0
26	7.0	46.0	11.5	125.0	14.0	16.0	60.0	74.0	790.0
27	11.0	46.0	6.5	90.0	9.0	14.0	59.0	73.0	700.0
Mean	10.2	46.27	7.77	117.8	11.94	12.74	59.6	75.07	754.0
Pusa Hybrid ©	12.0	47.0	9.0	140.0	13.0	14.0	61.0	77.0	890.0
Pusa Do Mausami ©	8.0	45.0	9.5	105.0	7.0	12.0	60.0	75.0	540.0

Table 4: Correlation analysis in Monoecious and Gynoecious derived population of 323

Plant No.	Days to germination	Days to anthesis	1st Pistillate flower node	Vine length (cm)	No. of fruits/ plant	Fruit length (cm)	Days to horticultural maturity (days after planting)	Days to physiological maturity (days after planting)	Fruit yield/ plant
Monoecious Plants									
1	1.00	0.438	0.287	-0.278	-0.575	-0.092	0.283	0.573*	-0.575*
2		1.00	0.290	-0.159	-0.192	0.281	0.890**	0.590*	-0.232
3			1.00	0.004	-0.156	0.099	0.206	0.305	-0.099
4				1.00	0.857**	-0.386	0.042	-0.283	0.882**
5					1.00	-0.176	-0.009	-0.226	0.985**
6						1.00	0.016	0.386	-0.187
7							1.00	0.473	-0.043
8								1.00	-0.254
Gynoecious Plants									
1	1.00	0.572	-0.119	0.142	-0.117	0.307	0.469	0.585	-0.189
2		1.00	-0.457	-0.338	-0.418	0.009	0.950**	0.747*	-0.6.9
3			1.00	0.343	0.338	0.415	-0.437	0.629	0.422
4				1.00	0.864**	0.225	-0.254	-0.218	0.800**
5					1.00	0.145	-0.339	-0.197	0.956**
6						1.00	0.075	-0.378	0.219
7							1.00	0.602	-0.545
8								1.00	-0.338

*Significant at P=0.05 and **Significant at P=0.01

Table 5: Correlation analysis in Monoecious derived population of 333

Plant No.	Days to germination	Days to anthesis	1st Pistillate flower node	Vine length (cm)	No. of fruits/ plant	Fruit length (cm)	Days to horticultural maturity (days after planting)	Days to physiological maturity (days after planting)	Fruit yield/ plant
Monoecious Plant									
1	1.00	0.426	-0.345	0.086	-0.047	-0.218	0.416	0.387	0.070
2		1.00	-0.422	-0.017	-0.314	-0.043	0.902**	0.790**	-0.218
3			1.00	0.059	0.129	-0.167	-0.335	-0.239	0.003
4				1.00	0.798**	0.090	0.163	0.065	0.805**
5					1.00	0.304	-0.057	-0.105	0.843**
6						1.00	0.007	-0.246	0.307
7							1.00	0.882**	0.034
8								1.00	-0.063
Gynoecious Plant									
1	1.00	0.732**	-0.561*	-0.158	0.056	0.246	0.738**	0.635*	0.290
2		1.00	-0.438	-0.221	-0.075	0.582*	0.819**	0.815**	0.132
3			1.00	-0.205	-0.064	0.015	-0.406	-0.242	-0.210
4				1.00	0.659*	0.098	-0.297	-0.496	0.606*
5					1.00	0.072	-0.177	-0.194	0.952**
6						1.00	0.248	0.198	-0.163
7							1.00	0.881**	0.042
8								1.00	-0.018

*Significant at P=0.05 and **Significant at P=0.01

Table 6: Performance of cross combination (F_{1s}) developed using gynoecious line on fruit set

Cross combination	No. of buds pollinated	No. of fruit set	Fruit set (%)
333 x PDM	18	9	50
333 x DVBTG-1	16	4	25
333 x DVBTG-2	8	2	25
333 x MC-84	24	6	25
333 x MC-83	21	7	33
323 x PDM	25	5	20
323 x DVBTG-1	24	4	16.67
323 x DVBTG-2	16	2	12.50
323 x MC-84	18	3	16.67
323 x MC-83	11	2	18.12
2116 x PDM	24	6	25
2116 x DVBTG-1	10	2	20
2116 x DVBTG-2	12	4	33
2116 x MC-84	16	2	12.5
2116 x MC-83	24	3	16.5
2145 x PDM	8	2	25
2145 x DVBTG-1	12	3	25
2145 x DVBTG-2	9	3	33
2145 x MC-84	18	3	16.67
2145 x MC-83	5	1	20

Conclusion

Genetic architecture of monoecious and gynoecious populations in bitter gourd defined the trait specific path in selection of suitable genotypes. The breeding efficacy and improvement in this crop is based on now use new sex mechanism i.e. gynoecism. Derived progenies can lead firstly in fixing and characterizing of trait and secondly development of high yielding hybrids. The cross combination 333 x PDM (50%) and 333 x MC-83, 2116 x DVBTG-2 and 2145 x DVBTG-2 are next best cross combination having 33 fruit set, which can be used as hybrids and parents can be utilized in development of trait specific cross combinations considering yield and number of fruits/plant.

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