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Studies on General and Specific Combining Ability Effects in Onion Using Male Sterile, Maintainer and Restorer Lines and Hybrids

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ABSTRACT

An experiment was conducted on onion variety Hisar-2 in field conditions over two years to identify eight male sterile lines and two maintainer lines using pollen staining test and 24 hybrids obtained from crossing between male sterile and restorer lines. Observations were recorded on five randomly selected plants for height and attributes of bulb yield and quality. Phenotypic coefficient of variation was higher then genotypic coefficient of variation for most of the traits. The line MS 20 was found good general combiner for a greater number of traits. Line MS 34 was found good general combiner (GCA) for number of leaves per plant, average weight of bulb, total bulb yield, marketable yield, moisture content of bulb (%) and dry matter content of bulb (%). Tester Pusa Red figured good general combiner for plant height, diameter of bulb, average weight of bulb, total bulb yield, marketable yield, moisture content of bulb (%), dry matter content of bulb (%) and total soluble solids of bulb (%). Crosses MS 35 x Hisar- 3, MS 37 x Hisar-3, MS 22 x Agrifound Dark Red, MS 40 x Pusa Red and MS 21 x Pusa Red exhibited high Specific Combining Ability (SCA) suggesting the utility of heterosis breeding. Both additive and non-additive gene actions were operative to determine bulb yield and its components and quality parameters, which suggest that selection and heterosis breeding can be practice for improvement of onion.

Keywords: *Allium cepa* L., breeding, male sterility, general combining ability, specific combining ability, hybrid

Introduction

Onion (*Allium cepa* L.), 2n=16, belongs to Alliaceae family and a native of Central Asia, Near-East and Mediterranean regions (Vavilov, 1951), is an important vegetable crop after potato and tomato in the world. Globally, it is grown in mainly Asian countries, Middle-East Europe and North America. In India, the major onion producing states include Maharashtra, Karnataka, Madhya Pradesh, Gujarat, Bihar, Andhra Pradesh, Rajasthan, Haryana, and Tamil Nadu. Onion in production, productivity and area under onion were 26.6 million tonnes with average productivity 1.64 mt/ha from 16.24 million hectare area, respectively was recorded in 2020-21 (Anonymous 2020-21).

Onion crises are subjected to nexus of glut and demand and supply in the market. Therefore, increased production of onion and its availability in all seasons is most important for farmer, consumers and governments alike. One of the ways to increase onion production is to rely on hybrid breeding in onion. In view of timing, size of its flower, the traditional practices of hand emasculation and pollination is cumbersome, not practical and as serious limitation on quantity of hybrid seed production.

Onion breeders follow efficient approaches for selecting and testing parents based on general combining ability (GCA) and specific combining ability (SCA) for producing superior hybrid or varieties. There is a need to develop hybrids in onion having earliness, uniformity in bulb size, longer shelf-life, higher yield and quality.

There are two ways mainly used for identification of male sterility. The most general method is based on morphological examination of flower for impaired development of anthers and second one is microscopic examination wherein, pollen viability test using acetocarmine is conducted (Heslop and Harrison, 1992).

Considering the above facts in view, the present study was conducted on 'Identification of male sterility line, their maintenance and evaluation of male sterile (A line), its maintainer lines (B line) and restorer lines (R line) based on general and specific combining ability estimates.

Materials and Methods

An experiment was conducted at Research Farm of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar, Haryana, India to develop male sterile lines and their maintainers (2018-19). During onion growing winter season the weather condition at Hisar are cooler and chilling temperature prevails in January. Male sterile lines (A lines) were selected from the onion plots of variety Hisar onion -2 by morphological examination and microscopic test for pollen viability using acetocarmine staining (Heslop and Harrison, 1992). Also, these selected male sterile lines and their counterpart male fertile maintainer lines (B lines) selected from the same plots were crossed in A x B manner to maintain the male sterile lines. Also, selfing was carried out to maintain B lines. The line x tester matings were attempted to produce hybrids using male sterile lines (A lines) as lines and restore lines (R lines) as testers namely verities Hisar Onion-3, Pusa Red, and Agri-found Dark Red.

The experimental material was sown in field conditions in two blocks replicated thrice. The first block was allocated to A lines and B lines and the second block was allocated to A line and R line to produce hybrids. Finally, the A, B lines and F_1 hybrids were grown in randomized block design with three replications to evaluate GCA and SCA as per line x tester design.

Plant Characters

Five randomly selected plants were studied to record observation on plant traits like plant height (cm) and number of leaves per plant and bulb characters like grade wise number and weight of bulbs, both polar and equatorial diameter of the bulb (cm), average bulb weight (g), per plot bulb yield converted to total bulb yield (q/ha), marketable bulb yield (q/ha), bulbs moisture content (%), bulb dry matter content (%), bulb total soluble solids (%).

Statistical analysis

Analysis of variance was conducted for experimental design as described by Panse and Sukhatme (1966) and for general and specific combining ability as described by Arunanchalum (1974).

Results and Discussion

Identification of male sterile lines and them maintainers

Based on morphological examination of anthers (Figure 1a and 1b) 8 male sterile lines (A line) namely MS20, MS21 MS22, MS23, MS34, MS35, MS37and MS40 were isolated from the onion variety Hisar-2 grown in field. These male sterile lines were maintained by crossing with B lines (pollinator 5 and 11) from the same field. From among 95 such crosses above mentioned 8 lines showed 100% sterility. Therefore, the sterility status of these eight lines was further confirmed by microscopic examination for pollen viability test using acetocamine stain (Figure 2a and 2b: A- fertile, B- sterile pollen).

Analysis of variance

Analysis of variance (data not given for brevity) revealed significant difference among lines (A and B) and testers (R lines) for various characters studied in the investigation. This warranted conducting the analysis of variance for combining ability. The analysis showed significant interaction effects among parents and their hybrids which revealed that different combination of A and R lines crossing would result in to different hybrids possessing different traits and thus enable selection for superior hybrids. The lines, testers and hybrids showed significant difference for various characters and therefore, the estimates of components of genetic variance and combining ability were computed.

Components of genetic variance and estimates of genetic parameters

The phenotypic and genotypic variance components were computed to estimate phenotypic (PCV) and genotypic (GCV) coefficients of variation. The results revealed that in general PCV were higher than GCV. This was evident that PCV for number of D grade bulbs (30.95) was highest among studied traits, while it was moderate for marketable bulb yield (18.86) followed by total bulb yield (18.21), number of leaves per plant (16.19), number of B grade bulb (15.99) and polar diameter of bulbs (13.75) whereas all other traits it was low to very low for example PCV for plant height (10.40) was followed by dry matter content of bulb (9.04), total soluble solids of bulb (5.59) and the lowest being for moisture content of bulb (1.02)

The high estimates of heritability were observed in characters like marketable bulb yield (99.73), total bulb yield (99.70), average weight of bulb (94.60), numbers of 'A' grade bulb (94.00), and number of leaves per plant (93.90), plant height (92.50), and diameter of bulb (polar) 91.60. Genetic advance was high for numbers of 'D' grade bulb (53.38) and 'C' grade bulb (46.69).

Combining Ability Analysis

From analysis of variance for combining ability (Table 1) it is evident that the mean sum of squares due to crosses was significant for all ten characters studied. The mean sum of square due to lines (female) was found to be significant for the characters plant height and number of leaves per plant. The mean sum of squares due to testers (male) was significant for plant height and diameter of bulbs (polar). It also revealed that mean sum of squares due to line x tester interaction effect were significant for all the characters studied except bulbs size grades (number of A grade bulb) and diameter of bulb (polar).

Combining ability effects:

General combining ability (GCA) effects of parents

The estimates of GCA effect in favour of male sterile, maintainer, tester lines for various plant and bulb traits are presented in Table 2. Male sterile line MS 20 among eight male sterile lines exhibited good general combining ability for various traits. These included plant traits like plant height and bulb traits like number of 'B' grade bulbs, total bulb yield, marketable bulb yield, bulb moisture content (%) and bulb dry matter content (%). Likewise, the line MS 34 was observed to be good general combiner for bulb traits like average weight of bulb, total bulb yield, marketable bulb yield, bulb moisture content (%) and bulb dry matter content (%) and plant trait like number of leaves per plant. On the same pattern line MS 22 recorded good general combining ability for total soluble solids of bulb (%) whereas, line MS 40 was found to be good combiner for number of 'A' grade bulb, number of 'C' grade bulb, average weight of bulb, and bulb dry matter content (%). Two male sterile lines namely MS 20 and MS 23 figured good general combiner for total soluble solids (TSS) of bulb. Our results were corroborated by earlier studies of Joshi and Tandon (1976), Hosfield et al. (1977), Divakara (2001), and Veeregowda (1988), Sundari (2003), Satyanarayana (2014), Patil and Subramaniam (2020),and Ara and Deb (2021).

Good general combining ability for plant height, polar and equatorial bulb diameter, average bulb weight, total bulb yield, marketable bulb yield, bulb moisture content, bulb diameter and total solids of bulb was recorded for tester Pusa Red among all other testers.

Specific combining ability effects

The data present in table 3 showed that good specific combining ability was exhibited by cross MS 35 x Hisar- 3 for number of 'A' grade bulb, average weight of bulb, total bulb yield, marketable bulb yield and bulb moisture content (%). Likewise, good specific combining ability in cross MS 37 x Hisar-3 was evident for plant height, number of 'A' grade bulb, average weight of bulb, total bulb yield, marketable bulb yield and bulb moisture content (%). Hybrid MS 22 x Agrifound Dark Red revealed good specific combining ability for number of 'A' grad bulb, average weight of bulb, total bulb yield, marketable bulb yield and (%), dry matter content of bulb (%).Whereas, hybrid MS 40 x Pusa Red figured to be good specific combiner for number of leaves per plant, number of 'C' grade bulb, total bulb yield and marketable bulb yield (%). Significant positive specific combining ability for total soluble solids was depicted by hybrid MS 21 x Pusa Red.These results confirm the earlier reports of Netrapal et al. (1986), Aghora and Parhak (1991), Divakara (2001), Sundari (2003), Aghora (1985), Veeregowda (1988),Satyanarayrna (2014), Patil and Subramaniam (2020) and Ara and Deb (2021).

Components of variance for GCA and SCA

The estimates of SCA (specific combining ability) variance were found to be greater than corresponding GCA (general combining ability) variance for all the characters except plant height and diameter of bulbs (polar). The estimated components of variance due to GCA (σ2GCA) were significant for plant height, number of leaves per plant, diameter of bulb (polar) and total soluble solids of bulb, while those due to SCA (σ2SCA) were highly significant in all character studied. The contribution of lines as compared to the testers was found to be more for all the characters except diameter of bulbs (polar).

Line MS 37, MS 20 and tester Hisar 3, Pusa Red were found to be good general combiner for plant height, thus indicating the predominance of additive gene effect. The crosses for SCA effect had shown significance, thus indicating the presence of non-additive gene effects. Two hybrids like MS 37 x Hisar 3 and MS 23 x Agrifound Dark Red exhibited positive and highest significant SCA effect for plant height, thus the character had both additive and non-additive gene effect. The results are in close agreement with the findings of Netrapal et al. (1980, 1986), Aghora (1985), Divakara (2001) Sundari et al. (2003).

Regarding number of leaves per plant, MS 34, MS 35 lines exhibited highest GCA effect and emerged as good combiner. Significantly positive specific combining ability effects exhibited by only one cross combination MS 40 x Agrifound Dark Red. It was generally observed that the parent hybrid having higher number of leaves resulted into higher GCA and SCA effect, respectively. These finding also revealed the fact that best general combiners may not always result in high SCA effects in their respective cross combination. The above findings are in accordance with Netrapal (1980).

Lines MS 23 and MS 40, lines MS22 and MS37 and lines MS 34 and MS 40 exhibited positive and significant high GCA effect for numbers of A, B and C grade bulb, respectively. In case of testers Hisar 3 showed highly positive and significant GCA effect for number of ‘B’ grade bulb and regarded as good combiner, thus indicating the predominance of additive gene effect.

The significant GCA variance and non-significant SCA variance indicated predominance of additive effect. However, the ratio of GCA/SCA indicated there were more of additive effects for equatorial diameter than polar diameter (Table 3). The study of GCA effect revealed that MS 35 among lines and Hisar 3 and Pusa Red among testers in case of polar diameter; line MS 35 and tester Pusa red in case of equatorial diameter, were found to be the best combiners with higher GCA effects. The maximum SCA effects was found in hybrid MS 22 x Hisar 3 for polar diameter; and MS 34 x Hisar 3, MS 21 x Pusa Red and MS 35 x Agrifound Dark Red for equatorial diameter of bulb. From the result it could be concluded that few parent having higher GCA effect contributed towards the increased bulb diameter in the hybrids, which presented higher SCA values. These results are conformity with the findings of Netrapal et al. (1986), Aghora and Parhak (1991), Divakara (2001), Sundari (2003), Aghora (1985), Veeregowda (1988) and Satyanarayrna (2014).

MS 34 and MS 40 among lines and tester Pusa Red emerged as best combiners for the average weight of bulb producing higher significant GCA effects, thus indicating the predominance of additive gene effect. While MS 35 x Hisar 3, MS 22 x Agrifound Dark Red, MS 37 x Hisar 3 and MS 23 x Agrifound Dark Red exhibited the maximum SCA effects. From these results it could be inferred that the parents having good combining ability produced heterotic hybrids with higher SCA values. Results were confirmative with Joshi and Tandon (1976), Hosfield et al. (1977), Divakara (2001), and Veeregowda (1988), Sundari (2003) and Satyanarayana (2014).

Conclusions

Thus our results revealed that the onion genotypes studied in the present investigation exhibited significant variation for different traits as corroborated by high estimates of PCA and GCA. High heritability coupled with significant variation suggested that selection would be effective for improvement of different traits associated with bulb yield and quality in onion. The analysis of variance of combining ability for line x tester design revealed significant differences among female (A and B lines) and male lines (testers/restorers) and significant interaction among parents and hybrids. Which indicated that both non additive gene effects and heterosis are involved in determining bulb yield potential. The analysis for component of variance suggested presence of additive as well as non-additive gene effects suggesting there by that the hybrids may be used for population improvement programme or direct use as hybrids. From general and specific combining ability analysis of parents and hybrids it appeared that lines; MS 20, MS 22, MS 23, MS 34 and MS 40 good general combiner for a number of traits associated with bulb yield and quality. Likewise, among testers Pusa Red figured good general combiner for number of traits contributing to bulb yield and quality. A few F_1 hybrids namely MS 35 x Hisar- 3, MS 37 x Hisar-3, MS 22 x Agrifound Dark Red, MS 40 x Pusa Red and MS 21 x Pusa Red appeared good specific combiner for a number of traits associated with total bulb yield as well as marketable bulb yield. These crosses involved parents with high GCA or average GCA indicating that both additive as well as non-additive gene effects are implied in good level of SCA. Therefore, these crosses may be effectively used in onion breeding programme either for developing improved population like composite or single cross hybrids for sustainable onion production.

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Table 1. Analysis of variance in respect of 10 characters for combining ability .

Sr. No.	Source		Replication	Crosses	Lines	Tester	Line x Tester	Error
	Degrees of freedom		**2**	**23**	**7**	**2**	**14**	**46**
1	Plant height (cm)		23.944	46.268**	59.434*	177.671**	20.914**	7.988
2	Number of leaves per plant		0.268	2.339**	4.568*	0.429	1.498**	0.361
3	Bulbs size grades (number and weight basis)	A (>70g)	8.222	165.608**	235.918	47.263	150.216	6.888
		B (40-70g)	96.055*	256.222**	233.396	130.722	285.563**	21.823
		C (<40g)	19.430	174.490**	206.880	29.347	179.029**	12.271
		D (D and B)	16.666	38.704**	35.458	20.166	42.976**	8.724
4	Diameter of bulbs (cm)	Polar	0.134	0.769**	0.365	5.898**	0.238	0.131
		Equatorial	0.151	0.527**	0.592	0.613	0.483**	0.061
5	Average weight of bulb (g)		0.152	99.198**	100.209	69.783	104.078**	6.805
6	Total bulb yield (q/ha)		16.917	3387.430**	4030.530	3351.732	3070.979**	17.552
7	Marketable bulb yield (q/ha)		5.826	3506.483**	4194.627	3476.916	3166.635**	14.565
8	Moisture content of bulb (%)		0.018	4.054**	4.597	1.852	4.097**	0.278
9	Dry matter content of bulb (%)		0.018	4.054**	4.597	1.852	4.097**	0.278
10	Total soluble solids of bulb (%)		0.350	1.228**	1.858	1.806	0.829***	0.242

*, **P ≤ 0.05 and 0.01, respectively

Table 2. Estimates of general combining ability (GCA) effects for 10 characters in onion.

Genotypes	Plant Height (cm)	Number of Leaves Per Plant	Bulbs Size Grades (Number and Weight Basis)				Diameter of Bulbs (cm)		Average Weight of Bulb (g)	Total Bulb Yield (q/ha)	Marketable Bulb Yield (q/ha)	Moisture Content of Bulb (%)	Dry Matter Content of Bulb (%)	Total Soluble Solids of Bulb (%)
			A (>70g)	B (40-70g)	C (<40g)	D (D and B)	Polar	Equatorial						
LINES														
MS20	3.19**	-0.31	2.79*	4.66**	-8.63**	1.04	0.05	-0.03	0.09	40.42**	37.93**	-0.64**	0.64**	0.14
MS21	-0.56	-0.66**	2.79*	-2.66	-2.97*	2.59*	0.05	0.12	0.78	-7.15**	-8.36**	-0.07	0.07	-0.02
MS22	-1.53	-0.17	-4.09**	5.22**	0.69	-1.84	-0.15	-0.31**	-1.69	-16.94**	-6.08**	0.43*	-0.43*	0.64**
MS23	-3.89**	-0.10	5.23**	-4.55**	-0.19	-0.51	0.01	0.09	1.35	2.71	7.73**	-0.18	0.18	0.48**
MS34	1.71	1.25**	2.12*	-3.00	2.25	-1.40	-0.25*	-0.14	5.20**	18.22**	24.18**	-0.95**	0.95**	0.24
MS35	-0.54	0.90**	-7.43**	-2.77	7.80**	2.37*	0.32*	0.53**	-4.22**	-27.47**	-23.38**	0.93**	-0.93**	-0.41*
MS37	3.42**	-0.76**	-7.31**	8.00**	-1.75	0.59	0.20	-0.10	-4.41**	-8.16**	-13.52**	0.97**	-0.97**	-0.58**
MS40	-1.80	-0.15	4.90**	-4.88**	2.80*	-2.84**	0.23	-0.17*	2.89**	-1.64	-18.49**	-0.49**	0.49**	-0.48**
CD 5% GCA	1.89	0.40	2.11	3.13	2.35	1.98	0.24	0.17	1.75	2.81	2.56	0.35	0.35	0.33
TESTERS														
Hisar 3	1.29*	0.15	-0.73	2.69**	-1.06	-0.19	0.36**	0.01	-1.42*	-8.88**	-2.11**	0.25*	-0.25*	-0.09
Pusa Red	1.83**	-0.12	1.22	-1.30	-0.06	0.90	0.20**	0.16**	1.89**	13.41**	12.95**	-0.30**	0.30**	0.31**
Agrifound Dark Red	-3.13**	-0.03	-0.48	-1.38	1.13		-0.57**	-0.16**	-0.47	-4.53**	-10.84**	0.05	-0.05	-0.22*
CD 5% GCA	1.16	0.25	1.29	1.91	1.44	1.21	0.15	0.10	1.07	1.72	1.57	0.22	0.22	0.20

*, ** P ≤ 0.05 and 0.01, respectively

Table 3. Estimates of specific combining ability (SCA) effects for 10 characters in onion.

Genotypes	Plant Height (cm)	Number of Leaves Per Plant	Bulbs Size Grades (Number and Weight Basis)				Diameter of Bulbs (cm)		Average Weight of Bulb (g)	Total Bulb Yield (q/ha)	Marketable Bulb Yield (q/ha)	Moisture Content of Bulb (%)	Dry Matter Content of Bulb (%)	Total Soluble Solids of Bulb (%)
			A (>70g)	B (40-70g)	C (<40g)	D (D and B)	Polar	Equatorial						
CROSSES														
MS 20 x Hisar 3	-0.32	0.53	4.62*	-7.25**	2.84	-0.08	-0.26	-0.13	0.33	12.18**	4.89*	0.32	0.32	0.43
MS 20 x Pusa Red	0.08	0.09	5.33**	-1.25	-3.48	-0.66	-0.07	0.03	2.17	7.30**	8.78**	-0.11	-0.11	-0.14
MS 20 x Agrifound Dark Red	0.24	-0.63	-9.96**	8.50**	0.63	0.75	0.33	0.10	-2.50	-19.48**	-13.68**	-0.21	-0.21	-0.29
MS 21 x Hisar 3	2.77	0.65	-0.37	10.41**	-7.15**	-2.63	-0.02	-0.26	-1.00	-2.86	-1.88	-0.24	-0.24	-0.82**
MS 21 Pusa Red	-2.13	-1.22**	0.66	0.75	-1.15	-0.55	0.24	0.49**	-1.69	-6.07*	-5.45*	-0.26	-0.26	1.15**
MS 21 x Agrifound Dark Red	-0.64	0.56	-0.29	-11.16**	8.30**	3.19	-0.22	-0.23	2.69	8.93**	7.33**	0.50	0.50	-0.33
MS 22 x Hisar 3	-2.06	0.032	-2.48	7.86**	-4.15*	-1.19	0.45*	0.13	0.15	7.94**	4.73*	-0.01	-0.01	0.02
MS 22 x Pusa Red	-0.57	0.46	-9.11**	-0.80	7.51**	2.55	-0.19	-0.09	-4.72**	-23.16**	-26.23**	-0.87**	-0.87**	-0.04
MS 22x Agrifound Dark Red	2.63	-0.69	11.59**	-7.05	-3.36	-1.36	-0.25	-0.04	4.57**	15.22*	21.50**	0.87**	0.87**	0.02
MS 23 x Hisar 3	-3.79*	-0.18	-10.15**	-1.02	3.73	7.47**	-0.25	-0.43**	-4.99**	-18.08**	-35.77**	-1.03**	-1.03**	0.33
MS 23 x Pusa Red	0.44	-0.28	7.22**	-9.03**	2.40	-0.44	0.11	-0.40**	1.65	1.58	-0.11	0.41	0.41	-0.37
MS 23 x Agrifound Dark Red	3.36*	0.46	2.93	10.05**	-6.13**	-7.02**	0.15	0.03	3.34*	16.50**	35.88**	0.63*	0.63*	0.048
MS 34 x Hisar 3	-1.94	-0.06	-4.04	-2.58	4.29*	2.36	0.34	0.78**	-5.39**	-23.80**	-30.44**	-1.12**	-1.12**	0.62*
MS 34 x Pusa Red	0.96	0.54	-2.00	8.08**	-6.70	0.77	-0.01	-0.55**	2.49	7.55**	2.77	0.58	0.58	-0.279
MS 34 x Agrifound Dark Red	0.98	-0.48	6.04**	-5.50*	2.41	-3.13	-0.33	-0.24	2.90	16.25***	27.66**	0.53	0.53	-0.344
MS 35 x Hisar 3	1.68	-0.35	5.84**	-3.13	1.40	-4.08*	0.01	0.01	11.98**	60.51**	58.05**	-2.36**	-2.36**	-0.096
MS 35 x Pusa Red	0.05	-0.32	-2.44	14.19**	-12.59**	1.00	0.12	-0.47**	-4.68**	-37.98**	-36.38**	0.56**	0.56**	-0.031
MS 35 x Agrifound Dark Red	-1.73	0.66	-3.40	-11.05**	11.19**	3.08	-0.13	0.45**	-7.29**	-22.54**	-21.66**	1.50**	1.50**	0.127
MS 37 x Hisar 3	3.68*	0.321	5.06**	-3.25	-1.70	-0.63	-0.139	0.048	4.44**	5.264*	12.40**	-0.85**	-0.85**	-0.023
MS 37 x Pusa Red	0.95	-0.283	-0.88	-2.91	6.29**	-2.88	-0.159	0.156	2.46	36.33**	16.61**	-0.57	-0.57	-0.151
MS 37x Agrifound Dark Red	-4.63**	-0.04	-4.18*	6.16*	-4.58*	3.52*	0.29	-0.20	-6.89**	-41.59**	-29.02**	-1.42**	-1.42**	0.17
MS 40 x Hisar 3	-0.03	-0.96**	1.51	-1.02	0.73	-1.19	-0.11	-0.15	-5.52**	-41.15**	-11.97**	1.14**	-1.14**	-0.45
MS 40 x Pusa Red	0.24	1.01**	1.22	-9.02**	7.73**	0.22	-0.04	0.03	2.31	14.45**	39.99**	-0.54	0.54	-0.13
MS 40 x Agrifound Dark Red	-0.21	-0.05	-2.73	10.05**	-8.47**	0.97	0.15	0.13	3.21	26.70**	-28.02**	-0.60	0.60	0.59*

*, **, *** $P \leq 0.05$, 0.01 and 0.001, respectively

Figure 1a and 1b: (Original) 1a: A- Fertile anthers 1b: B- Sterile anthers

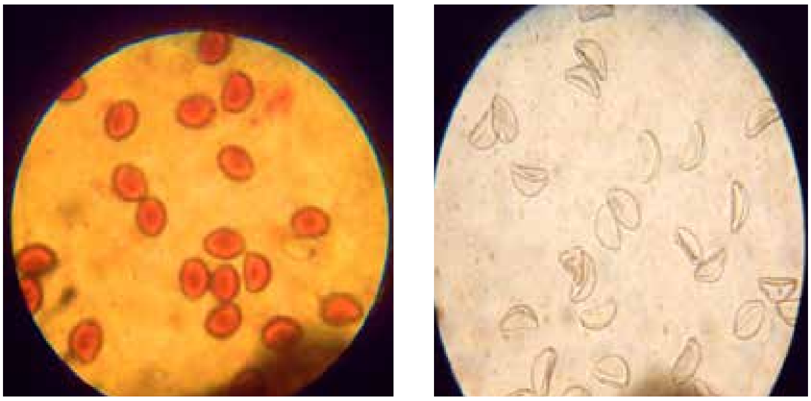

Figure 2a and 2b: (Original) 2a: A- Fertile pollen 2b: B- Sterile pollen

References

Aghora TS, (1985). The heterosis and combining ability studies in onion (*Alium cepa* L.) using line × tester analysis. M.Sc. Thesis, University of Agricultural Sciences, Dharwad, India

Aghora TS and Pathak CS, (1991). The heterosis and combining ability studies in onion (*Allium cepa* L.) using line × tester analysis. Vegetable Science, 18:53-58

Anonymous, (2020-21). Department of Agriculture & Farmer Welfare, (2020-21). Area and production of horticulture crops. www/https//pib.gov.in (Accessed 09 July 2022)

Ara R and Deb AC, (2021). Combining ability and gene action of four seed yield contributing characters in onion (*Allium cepa* L.). IJCS, 9(1): 01-07, doi:10.22271/chemi.2021.v9.i1a.11189

Arunachalam V, (1974). The fallacy behind the use of a modified line × tester design. Indian Journal of Genetics, 34: 280-287

Divarkar DS, (2001). Heterosis and combining ability studies for bulb yield, its components and quality parameters in onion. M. Sc. (Agri) Thesis, University of Agricultural Sciences, Dharwad

Heslop and Harrison JS, (1992). Cytological techniques to assess pollen quality, In: M. Cresti and A. Tiezzi (eds.). Sexual plant reproduction. Springer, p. 41-48. Verlag, Berlin

Hosfield GL, Vest G and Peterson CE, (1977). Heterosis and combining ability in diallel cross of onions. Journal of American Society for Horticultural Science, 102: 355-360

Joshi HC and Tandon JP, (1976). Heterosis for yield and its genetic basis in onion. Indian Journal of Agriculture Science, 46(2): 88- 92

Netrapal and Singh N, (1986). Diallel analysis for maturity, yield and its contributing characters in onion. South Indian Horticulture, 34(6): 391-394

Patil DG and Subramaniam VR, (2020). Combining ability analysis for yield and processing qualities in white onion (*Allium cepa* L.). Current Agriculture Research; 8(1):18-24, doi:10.12944/CARJ.8.1.04

Satyanarayana P, (2014). Heterosis and combining ability studies for yield and quality traits in onion (*Allium cepa* L.). M.Sc. (Vegetable crop) Thesis, Punjab Agricultural University, Ludhiana

Sundari NS, Netrapal and Narendra S, (2003). Line × tester analysis of combining ability in onion. Indian Journal of Horticulture, 60(4):356-62

Vavilov NI, (1951). The origin, variation, immunity and breeding of cultivated plants. Chronica Botanica, Waltham, Mass, New York, USA. Stechert- Hafner, 364 pp

Veeregowda, (1988). Studies on the genetics of yield and quality characters in bulb and seed crop of onion (*Allium cepa* L.). Ph.D. Thesis, University of Agriculture Science, Bangalore, India