HETEROSIS BREEDING IN SESAME

(*Sesamum indicum* L.)

By

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THESIS

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DECLARATION

I, Gayathri, G., hereby declare that this thesis entitled "**Heterosis breeding in sesame (*Sesamum indicum* L.)**" is a bonafide record of research work done by me during the course of research and this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled "**Heterosis breeding in sesame (*Sesamum indicum* L.)** " is a record of research work done independently by **Smt. Gayathri G.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

ILLUSTRATIONS

APPENDIX

Introduction

INTRODUCTION

Sesame (*Sesamum indicum* L., 2n=2x=26) is the most ancient cultivated oilseed crop (Sengupta and Das, 2003). It is also called Gingelly; *Ellu* in malayalam and *Tila* in sanskrit.

In India sesame seeds are used in religious functions as cited in old Hindu literature (Banerjee and Kole, 2009).The Sanskrit derivation of the word *Taila-Tilasya jata taila* strengthens the view that perhaps the first vegetative oil was from Tila (Sengupta and Das, 2003).

Sesame contains about 50-60 per cent seed oil (Uzun *et al.*, 2002; Arslan *et al.*, 2007), which is of superior quality, nearly matching olive oil (Kapoor, 1990). Sesame oil is highly stable (Brown, 2001) compared to other edible oils, mainly due to the presence of antioxidants (Davidson, 1999) like sesamin, sesaminol, sesamol, sesamolinol and squalene (Mohammed and Awatif, 1998). Sesame oil contains high levels of polyunsaturated fatty acids (Davidson, 1999; Wood, 1999). The oil has a reducing effect on plasma cholesterol and blood pressure (Sankar *et al.*, 2005). Such potential benefits on human life have renewed the interest in this ancient crop (Laurentin and Karlovsky, 2006). In India, it is the third major oilseed crop after groundnut and rapeseed-mustard.

Sesame crop has many agricultural advantages. It is grown on residual soil moisture with low inputs, and is a good crop for rotations with an extensive tap root system (Ashri, 1998). India ranks first in the world in area (about 2.47 m ha annually, 40% of the world) and production (0.74 m tones, 27% of the world) of sesame. But the average productivity of sesame in India (453 kg/ha) is far below the average productivity in China (1,127 kg/ha) and Egypt (1,211 kg/ha). The mean seed yield obtained is low and it is mainly attributed to lack of improved cultivars, low harvest index, susceptibility to biotic and abiotic stresses, seed shattering, indeterminate growth habit and asynchronous capsule ripening.

Reaching an appreciable yield is possible either through increasing the area or by increasing the productivity of the crop. The latter outweighing the former owing to the social and ethical considerations. Hence making the 'Queen of oilseeds' as the king of production lies in the hands of the breeders who nurture the crop. Paradoxically, despite its nutritional value and its historic and cultural importance, research on sesame is scarce. No international CGIAR agency is mandated to study sesame. Sesame was even removed from the original list of under utilized and neglected crops of Biovarsity International (formerly called International Plant Genetic Resources Institute IPGRI; Bedigian, 2003). Yet sesame is a major commodity in many African countries, in much of South West Asia, India, China, Japan, Korea and Mexico.

Research in sesame is seriously overlooked. Hybrid breeding is one of the best methods to increase productivity in sesame. Different studies have indicated that exploitation of hybrid vigour is possible in sesame. Commercial exploitation of hybrid vigour could be achieved through hybrids with high performance *per se* along with SCA for yield and yield attributes. The identification of hybrids is easy in sesame due to the simple inheritance of many of the characters. Though heterosis was reported as early as 1945 by Pal, as of today the commercial exploitation of heterosis is not feasible due to lack of economic means of hybrid seed production.

Hybrids can be produced by hand emasculation and crossing as the success of crossing and seed set are very high in sesame. Due to epipetalous nature, emasculation is relatively easy and a single labourer can handle upto 900 flowers a day. A single crossed capsule may yield upto 64 seeds. These features suggest that production of hybrid seeds by traditional hand emasculation and pollination is possible. Tu (1998) opined that the hybrid seed produced from one acre is sufficient to supply F_1 seeds for 60-80 ha. In recent years, production and cultivation of sesame hybrids on commercial scale is being attempted by means of CGMS and GMS systems (Duhoon *et al.* , 2004).

The evidence for cytoplasmic male sterility in sesame was reported for the first time from India by Prabakaran *et.al.* (1995) when in a wide hybridization

programme *Sesamum malabaricum* was crossed with *Sesamum indicum.* The behaviour of flowers in BC_1 and BC_2 generations indicated that cytoplasmic genic interaction is the basis governing male sterility. The work was continued by Bhuyan (1996) and Kavitha (1998) and advanced up to BC_{12}. But a commercial line is yet to be realized. Wide hybridization can thus be employed to develop male sterile lines for exploitation of hybrid vigour in the most economic way.

The present study entitled 'Heterosis breeding in sesame (*Sesamum indicum* L.)' assumes relevance in this context with the following objectives.

- To collect and evaluate different cultivars of *S.indicum* and *S.malabaricum* for morphological traits and yield attributes.
- To estimate the nature and extent of variability, heritability, genetic advance for seed yield and its component traits
- To find out the change in the strength and direction of association between various economic traits
- To understand direct and indirect effects of various components on yield by path coefficient analysis
- To study the genetic divergence of sesame genotypes
- To attempt interspecific hybridization with *Sesamum malabaricum* as a tool to induce male sterility in sesame
- To identify useful pollen parents and develop hybrids in sesame
- To estimate the magnitude of heterosis in various cross combinations
- To estimate the nature and magnitude of gene action for yield and its components

Review of Literature

2. REVIEW OF LITERATURE

Sesamum indicum is the most ancient oilseed crop and belongs to the order Tubiflorae, family Pedaliaceae. It has earned a poetic label 'Queen of oilseeds' due to high quality polyunsaturated stable fatty acid, which resists oxidative rancidity. It is a good catch crop and grows well in mixed or pure stands, in residual soil mixture. Roots of sesame improve soil structure and water percolation; hence it is ideal for crop rotation also.

The earliest view was that cultivated sesame originated in the Ethiopian region of Africa. But Bedigian (2003) has offered evidence that it originated in the Indian subcontinent. The Sanskrit derivation of the word *Taila- Tilasya jata taila* strengthens the view that perhaps the first vegetable oil was from tila (name of sesame in Sanskrit) which might have been under cultivation (Sengupta and Das, 2003).

Sesame crop has many agricultural advantages including growing on residual soil moisture with low inputs, and a good crop for rotations with an extensive tap root system (Ashri, 1998). Although the potential yields of the cultivars are high, the mean seed yields obtained for the crop are low. This is mainly attributed to lack of improved cultivars, low harvest index, susceptibility to insects, disease and environment, seed shattering, indeterminate growth habit and asynchronous capsule ripening.

Comparing the world's area (74,07,226 ha), production (29,41,290t) and productivity (397kg/ha), India's stand (17,39,000 ha; 6,00,000t and 291kg/ha) is significantly low for productivity. Good ranges of productivity of sesame are recorded in Egypt (1142kg/ha) and China (1185kg/ha)(Ashri,1998). Reaching an appreciable yield potential is possible either through increasing the area or by increasing the productivity of the crop. The latter outweighing the former owing to the social, ethical considerations and hence making the queen of oilseeds the king of production lies in the hands of the breeders who nurture the crop.

Although efforts have been made for yield improvement by developing non shattering, pest and disease resistant varieties, significant increase in yield to compete with other oilseed crops has not yet been realized.

Heterosis breeding works in sesame is relatively easy due to the following factors- ease of crossing, a single pollination giving many seeds, greater genetic variability, possibility of growing more than one generation in a year, relative ease of interspecific crosses and the possibilities of growing a large population in a unit of land. (Ashri, 1998)

Khidir and Osman (1970) and Chaudhary *et al.* (1977) reported that the three major yield components in sesame are i) number of capsules per plant, ii) 1000 seed weight and iii) plant height. These can be used as selection criteria while breeding for high yield.

Bayder (2005) reported a systematic approach to breed for ideal plant type of sesame with respect to capsules per axil, number of seeds per capsule and branching habit through pedigree selection after crossing genotypes with contrasting characters and raising upto F_5 generation.

Many studies have indicated that exploitation of hybrid vigour is possible in sesame. It is possible to develop hybrids through hand emasculation and pollination. Tu (1998) calculated that one ha of hybrid seed producing field could supply sufficient F_1 seeds for 60-80 ha. He estimated that in China F_1 hybrids could be produced economically by using GMS lines and manually rouging out the male fertile plants. Though the hybrid vigour of certain F_1 hybrids encouraged producing F_1 hybrids commercially, lack of stably expressing CGMS line is a major constraint. Success in any breeding programme depends largely on the choice of parental materials, for which a clear understanding of the contributing component characters, breeding and selection methods, nature of combining ability and gene action and heterosis is highly essential.

The available literature on seed yield and selected component characters in sesame are reviewed under the following headings

1. Variability
2. Heritability and genetic advance
3. Correlation
4. Path analysis
5. Divergence studies
6. Heterosis
7. Combining ability
8. Gene action
9. Interspecific hybridization

2.1. Variability

Genetic variability present in the base population is essential for successful crop improvement by plant breeding methods. Genetic variability existing in a crop is of great importance since greater the diversity, wider the scope for selection. The extent of variability of a character is measured by different statistics namely phenotypic variance, genotypic variance, phenotypic coefficient of variation and genotypic coefficient of variation. Such findings of different workers on sesame are briefed below.

2.1.1 Number of days to flowering

High range of variability was reported for number of days to flowering by Yadava *et al.* (1980). Shadakshari *et al.* (1995) observed low PCV and GCV for days to flowering. High estimates of PCV and GCV were recorded for days to flowering by Parameshwarappa *et al.* (2009).

2.1.2 Plant height

A wide range of variability was observed for this trait. High values of PCV and GCV were reported by several workers (Pathak and Dixit, 1992; Krishnaiah *et al.*, 2002b; Mukhekar *et al.*, 2002; Babu *et al.*, 2004; Velu and Shunmugavalli, 2005; Banerjee and Kole, 2006; Parameshwarappa *et al.*, 2009; Mandal *et al.*, (2010b).

2.1.3 Number of branches per plant

Several authors working on diverse genetic material in sesame which included varieties, accessions, crosses, F_2 and F_3 materials as well as advanced breeding lines recorded high PCV and GCV for number of branches per plant (Rai *et al.*, 1981; Shadakshari, 1984; Bakheit and Mahdy, 1988; Pathak and Dixit, 1992; Reddy *et al.*, 1993; Shadakshari *et al.*, 1995; Biswas and Akbar, 1995; Begum and Dasgupta, 2003; Solanki and Gupta, 2004; Banerjee and Kole,2006; Prasad *et al.*, 2007; Parameshwarappa *et al.*, 2009; Mandal *et al.*, 2010b).

2.1.4 Number of capsules per plant

High PCV and GCV values were noticed by Solanki and Paliwal (1981), Shadakshari (1984), Shadakshari *et al.*(1995), Patil and Sheriff (1996), Shunmugavalli and Vanniarajan (1998), Begum and Dasgupta (2003), Sengupta and Datta (2004), Solanki and Gupta (2004), Narain *et al.*(2004), Babu *et al.* (2004), Ganesan (2005), Velu and Shunmugavalli (2005), Banerjee and Kole (2006), Parameshwarappa *et al.* (2009), Mandal *et al.* (2010a) and Mandal *et al.* (2010b) for the character number of capsules per plant.

2.1.5 Capsule length

Capsule length recorded low values of PCV and GCV in various studies as reported by Pathak and Dixit (1986), Chandrasekhara and Reddy (1993 a), Shadakshari *et al.* (1995) and Singh and Singh (2004). However, Paramasivam and Prasad (1981) and Reddy *et al.* (2001) reported high PCV and GCV values for capsule length.

2.1.6 Test weight (1000 seed weight)

Babu *et al.* (2004) reported a narrow range of variability for this character.

2.1.7. Seed yield per plant

This character recorded high values of PCV and GCV for different sets of sesame population like varieties accessions, F_1, F_2 , F_3 generations and advanced breeding lines as opined by Janardhanan *et al.* (1981), Shadakshari (1984), Govindarasu *et al.*, (1990), John *et al.* (1993), Bhombe *et al.* (1994), Shadakshari *et al.* (1995), Biswas and Akbar (1995), Singh *et al.* (1997), Shunmugavalli and Vanniarajan (1998), Mukhekar *et al.* (2002), Sankar and Kumar (2003a), Babu *et al.* (2004), Begum and Dasgupta (2003) and Solanki and Gupta (2004).

2.1.8. Oil content

Low PCV and GCV values were realized for oil content by Chandrasekhara and Reddy (1993 a) and Shadakshari *et al.* (1995).

2.2. Heritability and genetic advance

Heritability of a particular trait is the extent to which the variability for that trait is transferred to the progeny and genetic advance is the measure of the expected improvement of a trait under a selection process. Heritability coupled with genotypic coefficient of variation would give a more reliable index of selection value (Burton, 1952). The genetic advance as percent of mean together with high heritability is advantageous for selection because of the nature of additive gene action for the trait. The reports of earlier works are enlisted here adopting the ratings suggested by Johnson *et al.* (1955).

Character	Heritability	Genetic advance	Reference
Number of days to flowering	High	High	Chavan and Chopde (1982) Pathak and Dixit (1992) Bhombe *et al.* (1994) Biswas and Akbar (1995)
	High	Low	Kandaswamy *et al.* (1990)
Plant height	High	High	Sivaprakash (1982) Pathak and Dixit (1992) Krishnaiah *et al.* (2002 b) Mukhekar *et al.* (2002)

			Begum and Dasgupta (2003) Saravanan *et al.* (2003) Sengupta and Dutta (2004) Solanki and Gupta (2004) Mothilal (2006) Prasad *et al.* (2007) Parameshwarappa *et al.* (2009)
	High	Moderate	Saravanan *et al.* (2000) Babu *et al.* (2005) Ganesan (2005)
	Moderate	High	Banerjee and Kole (2006)
Number of branches per plant	High	High	Rai *et al.* (1981) Shadakshari (1984) Kandaswamy (1985) Pathak and Dixit (1992) Solanki and Gupta (2003) Solanki and Gupta (2004) Mothilal (2006) Parameshwarappa *et al.* (2009)
	High	Moderate	Saravanan *et al* (2000)
	High	Low	Shadakshari *et al* (1995)
	Moderate	High	Banerjee and Kole (2006)
Number of capsules per plant	High	High	Chavan and Chopde (1982) Shadakshari (1984) Kandaswamy *et al.* (1990) Bhombe *et al.* (1994) Shadakshari *et al.* (1995) Patil and Sheriff (1996) Shunmugavalli and Vanniarajan (1998) Begum and Dasgupta (2003) Solanki and Gupta (2003) Narain *et al.* (2004) Singh and Singh (2004) Babu *et al.* (2005) Ganesan (2005) Mothilal (2006) Parameshwarappa *et al.* (2009)
	High	Moderate	Saravanan *et al.* (2000)
	Moderate	High	Banerjee and Kole (2006)
	Moderate	Moderate	Solanki and Paliwal (1981)
	Low	Low	Kandaswamy *et al.* (1990)
Capsule length	High	High	Reddy *et al.* (2001)

	High	Low	Solanki and Paliwal (1981) Shadakshari *et al.* (1995)
	Low	Low	Chandraprakash (1983) Pathak and Dixit (1986) Chandrasekhara and Reddy (1993a)
Number of locules per capsule	High	High	Shadhakshari *et al.* (1995)
1000 seed weight	High	High	Solanki and Paliwal (1981) Biswas and Akbar (1995) Mukhekar *et al.* (2002) Begum and Dasgupta (2003) Solanki and Gupta (2004) Babu *et al.* (2005)
	High	Moderate	Ganesan (2005)
	Low	High	Chandraprakash (1983)
	Low	Low	Babu *et al.* (2004)
Seed yield per plant	High	High	Govindarasu *et al.* (1990) Kandaswamy *et al.* (1990) Shadakshari *et al.* (1995) John *et al.* (1993) Bhombe *et al.* (1994) Patil and Sheriff (1996) Singh *et al.* (1997) Shunmugavalli and Vanniarajan (1998) Mukhekar *et al.* (2002) Begum and Dasgupta (2003) Solanki and Gupta (2003) Babu *et al.* (2004) Narain *et al.* (2004) Singh and Singh (2004) Solanki and Gupta (2004) Babu *et al.* (2005) Parameshwarappa *et al.* (2009)
	High	Moderate	Saravanan *et al.* (2000)
	High	Low	Mothilal (2006)
	Moderate	High	Banerjee and Kole (2006)
	Low	Low	Chandraprakash (1983)
Oil content	High	High	Babu *et al.* (2005) Mandal *et al.* (2010 b)

	High	Low	Shadakshari *et al.* (1995)

2.3. Correlation studies

Yield being a quantitative character, is dependent upon a number of component characters. A knowledge of association between yield and yield components will serve to make simultaneous selection for more characters.

Correlation studies pave way to know the association between highly heritable characters with the most economic character, the yield. Many authors have computed genotypic and phenotypic correlation coefficients to bring out the relationship of different traits with yield. The extent of environmental influence can also be known through the analysis. The review on correlation in sesame is presented below.

Character	**Direction of association**	**Reference**
Number of days to flowering	Positive	Shadakshari (1984) Mukhekar *et al.*(2002) Manjunatha *et al.(* 2008) Alake *et al.*(2010)
	Negative	Raghuvanshi *et al.*(2003) Solanki and Gupta (2003)
Plant height	Positive	Ramkrishnan and Soundarapandian (1990) Babu and Shivasubramanian, (1992) Biswas and Akbar (1995) Thiyagarajan and Ramanathan (1995) Mukhekar *et al.*(2002) Yingzhong and Yishou (2002) Begum and Dasgupta, (2003) Raghuvanshi *et al.* (2003) Sankar and Kumar (2003b) Solanki and Gupta (2003) Mothilal *et al.* (2004) Sengupta and Dutta (2004) Banerjee and Kole (2006) Mothilal (2006) Parimala and Mathur (2006) Zeinali *et al.* (2006)
		Sumathi *et al.* (2007) Thiagu *et al.* (2007) Sumathi *et al*, (2009) Das *et al.* (2010) Sarwar and Hussain (2010)

	Negative	Deshmukh and Chavan (1990)
Number of branches per plant	Positive	Reddy and Ramachandriah(1990) Reddy and Haripriya (1991) Biswas and Akbar (1995) Chaudhary (1995) Patil and Sheriff (1996) Manivannan (1998) Arulmozhi *et al.* (2001) Begum and Dasgupta (2003) Sankar and Kumar (2003b0 Laurentin *et al.* (2004) Mothilal *et al.* (2004) Sengupta and Dutta (2004) Banerjee and Kole (2006) Mothilal (2006) Mothilal and Manoharan (2006) Parimala and Mathur (2006) Prasad *et al.* (2007) Parameshwarappa *et al.* (2009) Sumathi *et al.* (2009) Sarwar and Hussain (2010)
	Negative	Raghuvanshi *et al.* (2003) Zeinali *et al.* (2006)
Number of capsules per plant	Positive	Deshmukh and Chavan (1990) Kandaswamy *et al.* (1990) Ramkrishnan and Soundarapandian (1990) Reddy and Ramachandriah (1990) Reddy and Haripriya (1991) Pathak and Dixit (1992) Chaudhary (1995) Mishra *et al.* (1995) Patil and Sheriff (1996) Manivannan (1998) Arulmozhi *et al.* (2001) Uzun and Cagirgan, (2001) Yingzhong and Yishou (2002) Begum and Dasgupta (2003) Raghuvansi *et al.* (2003) Sankar and Kumar (2003b) Mothilal *et al.* (2004) Narain *et al.* (2004) Sengupta and Dutta (2004) Mothilal (2006) Mothilal and Manoharan (2006) Parimala and Mathur (2006) Zeinali *et al.* (2006) Prasad *et al.* (2007) Sumathi *et al.* (2007) Thiagu *et al.* (2007) Sumathi *et al.* (2009) Alake *et al.* (2010)

		Das *et al.* (2010) Sarwar and Hussain (2010)
Capsule length	Positive	Godawat and Gupta (1986) Pathak and Dixit, (1992) Vanishri *et al.* (1994) Thiyagarajan and Ramanathan (1995) Patil and Sheriff (1996) Begum and Dasgupta (2003) Sankar and Kumar (2003) Sengupta and Dutta (2004b) Parameshwarappa *et al.* (2009)
1000 seed weight	Positive	Vanishri *et al.* (1994) Biswas and Akber (1995) Thiyagarajan and Ramanathan (1995) Patil and Sheriff (1996) Mukhekar *et al.* (2002) Raghuvansi *et al.* (2003) Sankar and Kumar (2003b) Mothilal *et al.* (2004) Mothilal and Manoharan (2006) Zeinali *et al.* (2006)
	Negative	Rong and Wu (1989) Begum and Dasgupta (2003) Parimala and Mathur (2006)
Oil content	Positive	Shadakshari (1984) Vanishri *et al.* (1994) Thiyagarajan and Ramanathan (1995)
	Negative	Vadhwani *et al.* (1992) Backiyarani *et al.*(1999)

2.4.Path analysis

The attainment of characteristic form and function in crop plants depends upon a chain of interrelated events which are sequential in time. Seed yield is an example of such integration and its expression is dependant upon action and integration of various components. As Grafius (1956) suggested, there may not be genes for yield per se but there are genes for various yield components.

Association between quantitative characters statistically determined by Pearson's correlation coefficient (r) has been quite useful as basis for selection. The

basic concept of correlation was elaborated and discussed by Fisher (1918) and Wright (1921) for plant breeding programmes.

Path coefficient analysis is important for partitioning the genotypic correlation coefficient into direct and indirect effects of component characters. A path coefficient is simply a standardized partial regression coefficient and as such it measures the direct influence of one variable upon another (Dewey and Lu, 1959). From this we can estimate the actual contribution of an attribute and its influence through other characters. A review of the work done in path coefficient analysis in sesame is presented below.

2.4.1. Direct effects of component traits on seed yield per plant in sesame

Component trait	Direction of effects	References
Number of days to flowering	Positive	Pathak and Dixit (1986) Mishra *et al.* (1995) Patil and Sheriff (1996) Siddiqui *et al.* (1998) Solanki and Gupta (2003) Manjunatha *et al.* (2008)
	Negative	Siddiqui *et al.* (2005) Raghuvamshi (2007) Rao (2007) Manjunatha *et al.* (2008)
Plant height	Positive	Reddy *et al.* (1984) Pathak and Dixit (1986) Thiyagarajan and Ramanathan (1995) Subbalakshmi (1996) Siddiqui *et al.* (1998) Uzun and Cagirgan (2001) Mothilal (2005) Siddiqui *et al.* (2005) Vidhyavathi *et al.* (2005) Raghuvamshi (2007) Manjunatha *et al.* (2008) Suvarna *et al.* (2008) Parameshwarappa *et al.* (2009)
	Negative	Gupta and Chopra (1984) Sengupta and Dutta (2004) Rao (2007)

Number of branches per plant	Positive	Pathak and Dixit (1992) Subramanian and Subramanian (1994) Tak (1997) Alam *et al* .(1999) Backiyarani *et al.* (1999) Arulmozhi *et al.* (2001) Bhuyan and Sharma (2004) Laurentin *et al.* (2004) Mothilal *et al.* (2004) Sengupta and Datta (2004) Solanki and Gupta (2004) Mothilal (2005) Banerjee and Kole (2006) Mothilal and Manoharan (2006) Prasad *et al.* (2007) Raghuvamshi (2007) Manjunatha *et al.* (2008) Suvarna *et al.* (2008) Gangarde *et al.* (2009) Sarwar and Hussain (2010)
	Negative	Reddy *et al.* (1984) Patil and Sheriff (1996)
Number of capsules per plant	Positive	Reddy and Haripriya (1992) Vadhwani *et al.* (1992) Chandrasekhara and Reddy (1993 b) Subramanian and Subramanian (1994) Vanishri *et al.* (1994) Mishra *et al.* (1995) Patil and Sheriff (1996) Thiyagarajan and Ramanathan (1995) Tak (1997) Manivannan (1998) Alam *et al.* (1999) Tomar *et al.* (1999) Arulmozhi *et al.* (2001) Yingzhong and Yishou (2002) Begum and Dasgupta (2003) Sankar and Kumar (2003) Solanki and Gupta (2003) Bhuyan and Sharma (2004) Mothilal *et al.* (2004) Narain *et al.* (2004)

		Sengupta and Datta (2004) Mothilal (2005) Vidhyavathi *et al.* (2005) Banerjee and Kole (2006) Mothilal and Manoharan (2006) Parimala and Mathur (2006) Prasad *et al.* (2007) Raghuvamshi (2007) Rao (2007) Sumathi *et al.* (2007) Manjunatha *et al.* (2008) Suvarna *et al.* (2008) Parameshwarappa *et al.* (2009) Das *et al.*(2010) Sarwar and Hussain (2010)
Capsule length	Positive	Pathak and Dixit (1986)
1000 seed weight	Positive	Pathak and Dixit (1986) Bhele *et al.* (1987) Rong and Wu (1989) Li and Zhang (1991) Subramanian and Subramanian (1994) Thiyagarajan and Ramanathan (1995) Patil and Sheriff (1996) Subbalakshmi (1996) Tomar *et al.* (1999) Arulmozhi *et al.* (2001) Solanki and Gupta (2003) Laurentin *et al.* (2004) Sengupta and Datta (2004) Mothilal (2005) Rao (2007) Manjunatha *et al.* (2008) Suvarna *et al.* (2008) Gangarde *et al.* (2009) Parameshwarappa *et al.* (2009)
Oil content	Positive	Thiyagarajan and Ramanathan (1995) Solanki and Gupta (2003)

2.4.2. Indirect effects of component traits on seed yield per plant

Component trait	Trait through which indirect effect is expressed	Direction of effects	Reference
Plant height	Number of branches per plant	Positive	Sengupta and Datta (2004)
	Number of capsules per plant	Positive	Sankar and Kumar (2003b) Sengupta and Datta (2004) Parimala and Mathur (2006)

Number of branches per plant	Plant height	Negative	Sengupta and Datta (2004)
	Number of capsules per plant	Positive	Sankar and Kumar (2003) Laurentin *et al.* (2004) Sengupta and Datta (2004) Parimala and Mathur (2006)
Number of capsules per plant	Number of days to flowering	Positive	Sumathi *et al.* (2007)
	Plant height	Positive	Sumathi *et al.* (2007)
		Negative	Sengupta and Datta (2004)
	Number of branches per plant	Positive	Sengupta and Datta (2004) Sumathi *et al.* (2007)
	Capsule length	Positive	Sengupta and Datta (2004)
	Oil content	Positive	Sumathi *et al.* (2007)
Capsule length	Plant height	Negative	Sengupta and Datta (2004)
	Number of branches per plant	Positive	Sengupta and Datta (2004)
	Number of capsules per plant	Positive	Sankar and Kumar (2003) Sengupta and Datta (2004) Parimala and Mathur (2006)
Oil content	Number of branches per plant	Negative	Laurentin *et al.* (2004)
	Number of capsules per plant	Positive	Sankar and Kumar (2003) Parimala and Mathur (2006)

2.4. Genetic divergence

Genetic diversity plays an important role in plant breeding because hybrids between genotypes of diverse nature generally display greater heterosis and produce more recombinants than those between closely related parents.

Mahalanobis (1928) developed the concept of D^2 statistics for a measure of group distance based on multiple characters. Rao (1952) suggested the application of this technique for assessing genetic diversity in plant breeding. Selecting the parents for breeding programmes is crucial because, the success of such programmes depends

on the segregants of hybrid derivatives when the aim is to improve the quantitative character. Selection of parents in hybridization programme based on Mahalanobis D^2 statistics is more reliable as the requisite knowledge of parents with respect to many characters is available prior to crossing. Nair and Mukherjee (1960) were the pioneers to use D^2 statistics as a measure of genetic divergence in the classification of teak.

Trehan *et al.* (1974) grouped 52 sesame accessions into 17 clusters based on D^2 statistics and observed that plant height and days to flowering contributed greatly to genetic diversity. 40 genotypes of sesame were grouped into six clusters by Thangavelu and Rajasekharan (1983). They found that oil content followed by days to maturity showed maximum divergence.

According to Dhamu *et al.* (1984), number of capsules per plant contributed to genetic divergence. Divergence studies of Kulkarni (1985), Jinxiong *et al.* (1995) and Ganesh and Thangavelu (1995) revealed that there was no relation between geographical origin and genetic diversity.

Manivannan and Nadarajan (1996) grouped 52 genotypes into six clusters and found that plant height, number of branches, seed yield and capsules per plant contributed to diversity.

Swain and Dikshit (1997) observed that clustering was not based on genetic diversity. Among the characters studied, oil content contributed maximum total divergence (44.90%) followed by seed weight (10.6%), capsule length (8.9%) and days to flowering (7.1%).

Ninety five sesame genotypes were grouped into five clusters by Johnjoel *et al* (1998) and according to them 1000 seed weight, seed yield, days to maturity, oil content, days to first flowering and days to 50% flowering were the major factors of differentiation.

Dikshit and Swain (2000) grouped 11 parents into six clusters by multivariate analysis of divergence and found that seed oil content contributed maximum towards total divergence.

50 indigenous and exotic germplasm lines of sesame were clustered by Navale *et al.* (2001) into six sets which revealed that geographical origin and genetic diversity were not related.

An analysis was done to cluster 50 genotypes of sesame by Manivannan and Ganesan (2000) and their studies revealed that plant height, branches per plant and 1000 seed weight contributed maximum to genetic divergence.

Gupta *et al.* (2001) grouped 50 accessions into six clusters and found that there was no relationship between geographical origin and genetic diversity.

According to Solanki and Gupta (2002), number of capsules per plant contributed maximum to genetic divergence followed by seed yield per plant.

Ujjainkar *et al.* (2002) grouped 50 genotypes of sesame into 11 clusters and opined that test weight, plant height and days to 50% flowering led to maximum divergence.

Sixty two genotypes of sesame were clustered into 13 groups by Sudhakar (2003). In this study it was found that number of capsules per plant, number of seeds per capsules, days to maturity and days to 50% flowering were the major contributors to genetic divergence. Least contributors included plant height and seed yield per plant.

Adopting Tocher's procedure, Anuradha and Reddy (2005) grouped 71 genotypes into six diverse clusters. Days to maturity had the highest contribution towards genetic divergence followed by 1000 seed weight, seeds per capsule and capsule length.

Raghuwanshi and Duhoon (2005) evaluated 100 indigenous and exotic lines of sesame to assess diversity using D^2 analysis. The study revealed that oil content and days to 50% flowering had the highest contribution to divergence followed by 1000 seed weight, seed yield, plant height, number of capsules per plant, days to maturity

and number of branches per plant. They also observed that exotic lines did not show much diversity among them and indigenous lines were richest in terms of existing genetic diversity.

Velusami *et al.* (2008) studied twenty five genotypes of sesame and grouped them into eight clusters. Seed yield followed by 1000 seed weight contributed towards diversity.

Sixty four sesame genotypes were evaluated and grouped into nine clusters based on nine characters (Parameshwarappa *et al.*, 2010). 1000 seed weight contributed highest to divergence (38.26%) followed by number of capsules per plant (28.50%) and seed yield per plant (19.42 %).

2.5.Heterosis

Heterosis refers to the superiority of F1 hybrid over both its parents in yield and other yield component traits. The three estimates of heterosis viz. relative heterosis, heterobeltiosis and standard heterosis measure the F_1 superiority over mid parent, better parent and standard check (Fonseca and Patterson, 1968)

Heterosis for different traits in sesame

Character	Standard Heterosis	Heterobeltiosis	Reference
Number of days to flowering	-12.5 to 20.15	-11.76 to 26.17	Sajjanar (1994)
	-27.77 to 40.78	-28.57 to 35.51	Fatteh *et al.* (1995)
	-20.26 to 11.99	-26.76 to 6.52	Devaraj (1996)
	-7.32 to 12.95	-2.94 to 23.97	Ragiba and Reddy (2000b)
	-5.94 to 5.36	-2.88 to 10.28	Saravanan and Nadarajan (2002)
	-	-16.13 to 6.00	Krishnaiah *et* al. (2003c)
	-12.62 to 15.57	-12.52 to 13.86	Mathapati (2003)
Plant height	69.86	59.56	Gupta (1980)
	-13.26 to 9.26	-19.07 to9.26	Shrivas and Singh (1981)
	-24.62 to 30.25	-15.71 to 59.08	Sajjanar (1994)
	-11.91 to 18.58	-3.43 to 30.66	Fatteh *et al.* (1995)
	-31.21 to 50.23	-17.77 to 11.36	Subbalakshmi (1996)
	-	-3.43 to 39.20	Devaraj (1996)
	-14.1 to 28.1	-26.7 to 21.4	Manoharan *et al.* (1997)
	-15 to 73	-22.0 to 60.0	Alarmelu and Ramanathan (1998)
	20.12 to 35.79	2.97 to 33.87	Padmavathi (1999)

	-	36.7 per cent	Solanki and Gupta (2000)
	-27.22 to 35.22	-31.28 to 30.73	Ragiba and Reddy (2000b)
	-22.8 to 10.7	-24.7 to 4.7	Jayaprakash and Sivasubramanian (2000)
	-6.18 to 31.11	-10.02 to 22.24	Saravanan and Nadarajan (2002)
	-	-42.78 to 35.70	Krishnaiah *et al.* (2003c)
	-	-14.13 to 29.25	Mathapati (2003)
	-9.26 to 8.91	-15.84 to 8.67	Mothilal *et al.* (2004)
Number of branches per plant	-	36.34	Shrivas and Singh (1981)
	-	84.76	Sharma and Chauhan (1983)
	-	25	Krishnaswamy and Appadurai (1984)
	-24.6 to 30.25	-15.71 to 59.08	Fatteh *et al.* (1995)
	-60.75 to 65.85	-68.18 to 54.14	Alarmelu and Ramanathan (1998)
	-20.7 to 19.1	-39.3 to 12.4	Padmavathi (1999)
	-36 to 20.9	-40.7 to 6.1	Jayaprakash and Sivasubramanian (2000)
	30.07 to 89.03	25.68 to 70.35	Solanki and Gupta (2000)
	-	62.5	Ragiba and Reddy (2000b)
	30.14 to 96.75	-40.16 to 92.5	Saravanan and Nadarajan (2002)
	-	-32.50 to 58.62	Mathapati (2003)
	-	-17.16 to104.92	Krishnaiah *et al.* (2003c)
	-22.89 to 25.3	-27.45 to 14.29	Mothilal *et al.* (2004)
Number of capsules per plant	158.68	131.96	Sajjanar (1994)
	-	-7.10 to 190.90	Anandkumar (1995)
	-	-40.05 to 92.5	Fatteh *et al.* (1995)
	73.62 to103.36	47.04 to 65.95	Devaraj (1996)
	-57.76to108.14	-59.72 to 88.65	Mishra and Yadav (1996)
	-44.9 to 51.8	-23.67 to 31.55	Subbalakshmi (1996)
	-40.5 to 98.1	-44.9 to 51.8	Manoharan *et al.* (1997)
	-35 to 61	-41 to 52	Ray and Sen (1998)
	-	71.4	Alarmelu and Ramanathan (1998)
	-58.59 to 68.14	-44.19 to 57.69	Padmavathi (1999)
	-33.80 to 69.90	-38.20 to 61.40	Solanki and Gupta (2000)
	-37.98 to 63.39	-42.95 to 35.56	Jayaprakash and Sivasubramanian (2000)
	-53 to 54.34	-57.80 to 51.31	Ragiba and Reddy (2000b)
	-9.17 to 90.86	-16.37 to 84.97	Saravanan and Nadarajan (2002)
	-	-23.99 to113.79	Mathapati (2003)
	-31.79 to 33.53	-41.28 to 18.52	Mothilal *et al* .(2004)
Capsule length	-17.73 to 10.31-	-24.91 to10.08	Fatteh *et al* . (1995)
	23 to 57	-29.00 to39.00	Alarmelu and Ramanathan (1998)
	-31.35 to 24.55	-37.64 to20.25	Devaraj (1996)
	5.54 to 29.40	0.40 to 22.12	Padmavathi (1999)
	-	-15.13 to11.00	Krishnaiah *et al.* (2003c)
	-15.43 to 16.61	-18.53 to14.90	Mathapati (2003)
1000 seed weight	-	0.18 to 56.66	Murthy *et al.* (1975)
	-	50.66	Paramasivan *et al.* (1982)
	27.54	25.21	Sharma and Chauhan (1983)
	-	7.22	Dora and Kamala (1986)
	-	-22.39 to34.86	Fatteh *et al.* (1995)
	-14.42 to 23.14	-17.56 to19.52	Mishra and Yadav (1996)
	-11.90 to 25.70	-18.40 to16.50	Manoharan *et al.* (1997)
	-6 to 26	-21.00 to24.00	Alarmelu and Ramanathan (1998)

	-	44.90	Solanki and Gupta (2000)
	-57.24 to 47.42	-97.11 to41.64	Ragiba and Reddy (2000b)
	-29.87 to 42.72	-29.87 to35.30	Saravanan and Nadarajan (2002)
	-	-12.14 to 4.64	Krishnaiah *et al* . (2003c)
	-	-39.97 to12.15	Mathapati (2003)
	-9.87 to 15.75	-15.50 to13.20	Mothilal *et al.*(2004)
Oil content	-7.46 to 11.11	-	Murthy *et al.* (1975)
	-	44.22	Sharma and Chauhan (1983)
	-	27.70	Dora and Kamala (1986)
	-5.55 to 5.96	-9.75 to 2.41	Sajjanar (1994)
	-5.75 to 5.35	-722 to 5.06	Fatteh *et al.* (1995)
	-5.60 to 10.04	-10.13 to 9.86	Devaraj (1996)
	-	-8.97 to 1.89	Subbalakshmi (1996)
	46.22 to 178.50	23.12 to165.24	Padmavathi (1999)
	-	110.7	Solanki and Gupta (2000)
	-92.26 to 137.8	-42.37to146.98	Jayaprakash and Sivasubramanian (2000)
	-39.2 to 80.3	-84.90 to 69.20	Ragiba and Reddy (2000b)
	-16.18 to 0.13	-20.08 to 0.01	Saravanan and Nadarajan (2002)
	-5.58 to 4.28	4.28	Mathapati (2003)

2.6. Combining ability

The combining ability analysis gives useful information regarding selection of parents in terms of performance of their hybrids. Further it elucidates the nature and magnitude of various types of gene action involved in the expression of quantitative traits (Dhillon, 1975). Sprague and Tatum (1942) defined the term general combining ability (GCA) as the performance of a line or population in several hybrid combinations and specific combining ability (SCA) was used to designate those effects in specific combinations which significantly departed from what could be expected on the basis of average performance of the lines involved. GCA is due to additive genetic effects and SCA is due to dominance deviation and epistatic interactions.

Rojas and Sprague (1952) examined combining ability over years in corn and found that SCA was constantly greater that GCA and concluded that SCA not only involved dominance and epistasis but a considerable amount of genotype and environmental interactions. Griffings(1956) expressed that GCA involved both additive and additive x additive interaction.

Kempthorne (1957) precisely defined GCA and SCA in terms of covariance of half sibs (HS) and full sibs (FS) in a random mating population where GCA variance is Cov.HS and SCA variance is CovFS-2 Cov HS.

There are several techniques for the evaluation of varieties or strains in terms of their genetic makeup, of these, line x tester technique (Kempthorne, 1957) is one which is commonly used. The line x tester technique is a good approach for screening the germplasm on the basis of GCA and SCA variance and effects. It also enable us to understand the nature of gene action involved in the expression of various quantitative traits. This technique measures the GCA and SCA variances and effects and the genetic components of variance (σ^2 A and σ^2D). It however fails to detect and estimate epistatic interactions. The combining ability effects for different traits in sesame are reviewed below.

Combining ability effects for different traits in sesame (*Sesamum indicum* L.)

Character	GCA effects	Reference
Number of days to flowering	Positive GCA effects	Sajjanar (1994) Thakare *et al.* (1998) Ragiba and Reddy (2000 a) Mathapati (2003) Vidhyavathi *et al* .(2005)
	Negative GCA effects	Devaraj (1996) Ramesh *et al* . (1998) Krishnaiah *et al.* (2003)
Plant height	Positive GCA effects	Ramesh *et al* . (1998) Kavitha *et al.* (1999) Padmavathi (1999) Ragiba and Reddy (2000 a) Manivannan and Ganesan (2001)
	Negative GCA effects	Backiyarani *et al* .(1997) Thakare *et al.* (1999) Krishnaiah *et al* . (2003) Mathapati (2003) Mothilal and Manoharan (2004) Vidhyavathi *et al.* (2005) Singh *et al.* (2007)

Number of branches per plant	Positive GCA effects	Pawar *et al.* (1990) Backiyarani *et al.* (1997) Ramesh *et al.* (1998) Das and Gupta (1999) Ragiba and Reddy (2000a) Manivannan and Ganesan (2001)
	Negative GCA effects	Krishnaiah *et al.* (2003) Mathapati (2003) Mothilal *et al.* (2004) Vidhyavathi *et al.* (2005) Singh *et al.* (2007)
Number of capsules per plant	Positive GCA effects	Sajjanar (1994) Mishra and Yadav (1996) Devaraj (1996) Backiyarani *et al.* (1997) Ramesh *et al.* (1998) Thakare *et al.* (1999) Kavitha *et al.* (1999) Das and Gupta (1999) Ragiba and Reddy (2001a) Mathapati (2003) Singh et al. (2007)
	Negative GCA effects	Mothilal *et al.* (2004) Vidhyavathi *et al.* (2005)
Capsule length	Positive GCA effects	Devaraj (1996) Ramesh *et al.* (1998) Krishnaiah *et al.* (2002a) Mathapati (2003) Singh *et al.* (2007)
1000 seed weight	Positive GCA effects	Thakare *et al.* (1999) Krishnaiah *et al.* (2003)
	Negative GCA effects	Ramesh *et al.* (1998) Kavitha *et al.* (1999) Das and Gupta (1999) Ragiba and Reddy (2001a) Mathapati (2003) Vidhyavathi *et al.* (2005)

Seed yield per plant	Positive GCA effects	Murthy (1975) Gupta (1981) Chaudhari and Shah(1984) Anandkumar and Sreerangasamy (1987) Sajjanar (1994) Fatteh *et al.* (1995) Devaraj (1996) Backiyarani *et al.* (1997) Ramesh *et al.* (1998) Thakare *et al.* (1999) Kavita *et al.* (1999) Das and Gupta (1999) Ragiba and Reddy (2000a) Manivaran and Ganesan (2001) Krishnaiah *et al.* (2003) Vidhyavathi *et al.* (2005) Singh *et al.*(2007)
	Negative GCA effects	Mothilal *et al.* (2004)
Oil content	Positive GCA effects	Sajjanar (1994) Fatteh *et al.* (1995) Thiyagarajan and Ramanathan (1995) Devaraj (1996) Backiyarani *et al.* (1997) Ramesh *et al.* (1998) Thakare *et al.* (1999) Kavita *et al.* (1999) Das and Gupta (1999) Mathapati (2003)

2.7. Gene action

The magnitude and direction of GCA and SCA elucidates the kind of gene action for a particular trait. Depending on the nature and extent of fixable and non fixable genetic proportion, suitable breeding procedure is suggested for the improvement of the character. The nature of gene action for different characters is reviewed here

Character	Nature of gene action	Reference
Number of days to flowering	Additive	Gaikwad *et al.* (2009)
	Non additive	Babu *et al* . (2004) Yamanura and Nadaf (2009) Mandal *et al* . (2010b)

Plant height	Additive	Gupta (1981) Balsane *et al* . (1991) Singh *et al* . (1993) Backiyarani *et al.* (1997) Padmavathi (1999) Krishnaiah *et al* . (2003) Singh *et al* . (2007) Gaikwad *et al* . (2009) Parameshwarappa andSalimath (2010)
	Non additive	Dora and Kamala (1987) Khorgade *et al.* (1989) Mishra and Yadav (1996) Kavita *et al* . (1999) Sumathi and Kalaimani (2000) Ragiba and Reddy (2000a) Arulmozhi *et al* . (2001) Manivannan and Ganesan (2001) Mathapati (2003) Mothilal *et al* . (2004) Vidhyavathi *et al* . (2005) Yamanura and Nadaf (2009) Bangar *et al* . (2010)
	Both	Chavan *et al.* (1981) Babu *et al.* (2004a) Singh *et al.* (2007) Banerjee and Kole (2009)
Number of branches per plant	Additive	Murthy (1975) Gupta (1981) Chaudhari (1984) Pawar *et al.* (1990) Fatteh *et al.* (1995) Kavitha *et al.* (1999) Das and Gupta (1999) Singh *et al.* (2007) Gaikwad *et al* (2009) Parameshwarappa and Salimath (2010)
	Non additive	Dora and Kamala (1986) Goyal and SudhirKumar (1991) Padmavathi (1999) Manivannan and Ganesan(2001) Arulmozhi *et al* . (2001) Krishnaiah *et al* . (2003) Mathapati (2003) Mothilal *et al.* (2004) Babu *et al.* (2004) Vidhyavathi *et al* . (2005) Bangar *et al* . (2010) Mandal *et al* . (2010b)
	Both	Khorgade *et al.* (1989)

		Kadu *et al* . (1992) Singh *et al* . (2007) Banerjee and Kole (2009)
Number of capsules per plant	Additive	Murthy (1975) Kotecha and Yermanos (1978) Gupta (1981) Shrivas and Singh (1981) Chaudhari (1984) Khorgade *et al* . (1989) Fatteh *et al* . (1995) Backiyarani *et al* . (1997) Kavita *et al* . (1999) Das and Gupta (1999) Singh *et al*. (2007) Gaikwad *et al*. (2009) Parameshwarappa and Salimath (2010)
	Non additive	Goyal and Sudhir Kumar (1991) Mishra and Yadav (1996) Kamala (1998) Sumathi and Kalaimani (2000) Ragiba and Reddy (2000a) Manivannan and Ganesan (2001) Arulmozhi *et al*. (2001) Krishnaiah *et al*. (2003) Mothilal *et al*. (2004) Vidhyavathi *et al*. (2005) Yamanura and Nadaf (2009) Bangar *et al*. (2010) Mandal *et al*. (2010b)
	Both	Chandraprakash (1987) Kadu *et al*. (1992) Mathapati (2003) Singh *et al*. (2007) Banerjee and Kole (2009)
Capsule length	Additive	Kotecha and Yermanos (1978) Krishnaiah *et al*. (2003) Singh *et al*. (2007)
	Non additive	Chandraprakash (1983) Narkhede and SudhirKumar (1991) Devaraj (1996) Padmavathi (1999) Mathapati (2003) Gaikwad *et al*. (2009) Yamanura and Nadaf (2009)
	Both	Khorgade *et al*. (1988) Fatteh *et al*. (1995) Singh *et al*. (2007)

1000 seed weight	Additive	Singh *et al.* (1983) Mishra and Yadav (1996) Kamala (1998) Mothilal *et al.* (2004) Babu *et al.* (2004) Vidhyavathi *et al.* (2005) Singh *et al.* (2007) Gaikwad *et al* .(2009) Yamanura and Nadaf (2009) Parameshwarappa and Salimath (2010)
	Non additive	Arulmozhi *et al.* (2001)
	Both	Geetha and Subramanian (1992) Kadu *et al.* (1992) Thakare *et al.* (1999) Singh *et al.* (2007) Banerjee and Kole (2009)
Seed yield per plant	Additive	Gaikwad *et al.* (2009) Parameshwarappa and Salimath (2010)
	Non additive	Sumathi and Kalaimani (2000) Arulmozhi *et al.* (2001) Babu *et al.* (2004) Yamanura and Nadaf (2009) Bangar *et al.* (2010) Mandal *et al.* (2010a)
	Both	Banerjee and Kole (2009)
Oil content	Additive	Goyal and Sudhirkumar (1991) Fatteh *et al.* (1995) Backiyarani *et al.* (1997) Vidhyavathi *et al.* (2005)
	Non additive	Devaraj (1996) Kavitha *et al.* (1999) Mathapati (2003) Babu *et al.* (2004) Yamanura and Nadaf (2009) Bangar *et al.* (2010) Mandal *et al.* (2010a)
	Both	Singh *et al.* (1983) Khorgade *et al.* (1989) Das and Gupta (1999)

2.8. Interspecific hybridization

The first and foremost approach by a plant breeder is to look for divergence in a crop and to exploit this variability to breed a homogenous, homozygous variety adapted to local conditions. All breeding programmes except introduction, essentially involve crossing between desired parents to obtain viable recombinants. Crossing between the selected parents either wild or cultivated form the basic step of a breeding programme bringing the genome of two parents together to manifest a required phenotype. The economic feasibility of hybrid sesame is mainly dependent on the availability of stable CGMS lines, identification of suitable restorers and heterotic expression to surpass the yield level of locally available cultivar besides reasonable degree of outcrossings to produce F_1 seeds in bulk quantities at minimum cost. Successful exploitation of heterosis breeding in a predominantly self pollinated crop like sesame depends primarily on the development of stable male sterility. Thus the sesame breeder is left with a choice of creating male sterility either through biological, physiological or chemical means.

Successful utilization of wild species in breeding has redefined ideotypes, and led to the introduction of new resistance genes into major agricultural crops like rice, wheat, cotton, etc. Crop improvement in sesame through an infusion of germplasm from wild relatives has also been reported from the 1940's (Ramanujam, 1942, 1944). Wild species of *Sesamum* found in South India are potential sources of resistance to biotic stresses. Some wild accessions have been located in water scarce rocky areas while others thrive in water logged marshy areas. This creates the potential for using the weedy and wild forms of *Sesamum* as germplasm donors in breeding programs (Prabakaran, 1996; Ram *et al.* , 2006).

Prevalence of wild forms of a cultivated species need not guarantee success in germplasm enhancement scheme. A prerequisite for it is a successful hybridization with the cultivated taxon. Earlier attempts to introgress useful genes from wild relatives into sesame have been less successful due to low crossability in the interspecific crosses (Ramanathan, 1950; Amrithadevarathnam, 1965; Subramanian, 1972; Subramanian and Chandrasekharan, 1977 and Prabakaran *et al.,* 1995). Many

wild species of *Sesamum* including *S.malabaricum* contain chemical inhibitors and consequently the seeds are difficult to germinate (Bedigian, 2003).

Sesamum malabaricum is found on uncultivated laterite hill tops in wild state, occurs in the region of Malabar to Bombay and Central provinces. This wild variety possesses a unique character to withstand heavy rainfall (Annapurna *et al.*, 2008). It has been found gregariously in wild state and described as wild variety. The plant is often seen in waste ground and along railroad tracks in South India. The habit of the taxon vary considerably. *S. malabaricum* has been observed growing as a slender, unbranched weed under 30cm height, among coconut trees on very dry sandy soils at CPCRI, Kayamkulam (Bedigian, 2003). On the other hand, it grows as a robust roadside weed, with a thick stem, reaching a height of 2m with profuse branching in rich loam of fallow fields (Bedigian, 2003).

John *et al.* (1950) crossed three *S. indicum* genotypes with a wild variety collected from the hills of Malabar which was named as *Sesamum malabaricum*, to evolve economically useful strains. One economic selection from F_3 progenies was found to be the best and is now a popular variety called TMV-3.

Amirthadevarathinam (1965) and Sundaram (1968) obtained shriveled and inviable seeds when *S.indicum* and *S.malabaricum* were crossed. The studies attempted by Prabakaran *et al.* (1995) with direct and reciprocal crosses of *S. indicum* and *S. malabaricum* revealed that the cytoplasm of *S. malabaricum* on interaction with the genome of *S. indicum* induces male sterility. The studies resulted in identification of four male sterile lines each from *S.indicum* cv. CO-1, TMV-3, TMV-4 and TMV-6. Nevertheless, the percentage of capsule and seed setting by selfing, cross pollination and open pollination indicated an increase in the extent of male sterility and female fertility by every backcross.

The work was continued by Bhuyan (1996) who reported that the occurrence of sterile plants and degree of pollen fertility increased by each backcross generation in the crosses. The anthers of the male sterile plants were reduced in size. The expression of male sterility was stable in summer and rainy season while in post rainy season, decrease in pollen sterility percentage was observed. Cytological examination

revealed breakdown of the process of microsporogenesis after tetrad formation. *In vivo* pollen germination from fertile plants revealed normal germination and tube growth.

Kavitha (1998) who continued the work succeeded in establishing four sets as CMS-T3, CMS-T4, CMS-T6 and CMS-C1 utilising *S. indicum* cv TMV-3, TMV-4, TMV-6 and CO-1 respectively as nuclear donor. She also observed that the backcross progenies in BC_8 to BC_{12} generations closely resembled the cultivated species for most of the qualitative characters except for profuse branching and shrivelled anthers. Her study also revealed the absence of GxE interaction in the expression of pollen sterility.

Direct and reciprocal crosses of *S. indicum* cv. Tilak and OS.2 with *S. malabaricum* was attempted by Vighneswaran (2001) and obtained good capsule and seed set with reciprocal crosses compared to direct crosses. Two backcross generation progenies exhibited more attributes of the recurrent parent.

Bhuyan and Sharma (2004) obtained 36 hybrid combinations by crossing three *S. malabaricum* cytoplasm induced male sterile lines with 12 *S indicum* cultivars of diverse origin. Significant positive heterobeltiosis was shown by some crosses for number of capsules per plant, seed yield per plant and oil content. This study showed the availability of sufficient hybrid vigour in several hybrids with respect to seed yield for taking up a profitable hybrid breeding programme.

Kulkarni (2006) attempted embryo rescue in interspecific crosses of *S. indicum* with *S. occidentale* and *S. radiatum* 9- 12 days after pollination as the hybrid seeds obtained were abnormal and shrivelled due to embryo degeneration. Shrivelled seeds failed to germinate even with 200ppm GA_3 treatment.

Materials and Methods

3. MATERIALS AND METHODS

The present investigations were conducted in the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara, Kerala Agricultural University. Field trials were laid out at the garden lands of the Department of Plant Breeding and Genetics during 2008-2010 where the soil is predominantly clayey loam. The experimental site is situated at an altitude of 58m above mean sea level. All cultural operations were carried out as per the Package of Practices recommendations of the KAU 2007.

The total study was divided into the following three experiments.

Experiment I

Genetic variability and diversity studies was done to study the relative contribution of different plant characters to total divergence using Mahalanobis D^2 statistics.

Experiment II

Intervarietal hybridization was undertaken to study the combining ability variances and effects .The mating design used was line x tester mating design. This will help in identifying the best general combiners and heterotic crosses.

Experiment III

Interspecific hybridization with *S. malabaricum* for development of male sterile lines.

3.1. Experiment I Genetic variability and diversity studies

3.1.1 Experimental material

The material used in this study comprised of 40 genotypes including seven varieties from Kerala Agricultural University, seven varieties from Tamil Nadu

Agricultural University, 20 cultures of varietal traits obtained from AICRP on Oilseeds functioning at ORARS, Kayamkulam under KAU and 20 cultures from NBPGR, Regional Centre, Vellanikkara which were maintained under Medium Term Storage at the centre. List of accessions and varieties are given in the Table 1.

3.1.2. Layout

Seeds of the 40 genotypes were sown during October. 2007 in randomized block design with three replications. A spacing of 45 cm between rows and 20 cm between plants was adopted. Observations were recorded in ten randomly tagged plants in each genotype for nine quantitative characters namely number of days to flowering, plant height, number of branches per plant, number of capsules per plant, capsule length, locules per capsule, 1000 seed weight, seed yield per plant and oil content.

3.1.3. Collection of *Sesamum malabaricum*

Seeds of *Sesamum malabaricum* were collected from NBPGR Regional Station, Vellanikkara (accession 1) and ARS, Vridhachalam (accession 2) during October 2007 and were sown in earthern pots (90cm x 45cm) filled with potting mixture (sand, soil, vermicompost, in the ratio 1:1:1). The pots were irrigated regularly. Seeds of accession 1 failed to germinate even after three months of regular irrigation. Four seeds from accession 2 germinated six weeks after sowing. They were assessed for their morphological characteristics and were used for crossing with the fourteen released varieties of *S. indicum* .

Two crosses (*S. malabaricum* x CO-1 and *S. malabaricum* x KYM-1) produced one capsule each with seeds . The capsules were collected on maturity and seeds used to raise the F_1 generation.

Since majority of the intespecific crosses did not set seed,the seeds of accession 2 were sown again to effect crossing with the remaining varieties. But they failed to germinate even after 3 months of sowing. Hence viability was tested using tetrazolium test and the seeds were found to be viable. As the seeds were viable,

Table 1 List of *Sesamum indicum* genotypes in base collection (Experiment I)

Sl No:	Genotype	Source
1.	KYM – 1	ORARS, Kayamkulam
2.	Soma	ORARS, Kayamkulam
3.	Surya	ORARS, Kayamkulam
4.	Tilak	ORARS, Kayamkulam
5.	Tilatara	ORARS, Kayamkulam
6.	Tilarani	ORARS, Kayamkulam
7.	CO-1	TNAU, Coimbatore
8.	SVPR-1	CRS,Srivilliputhur
9.	VRI-1	RRS, Vridhachalam
10	VRI-2	RRS, Vridhachalam
11.	TMV-3	RRS, Vridhachalam
12	TMV-4	RRS, Vridhachalam
13.	TMV-5	RRS, Vridhachalam
14.	TMV-6	RRS, Vridhachalam
15.	AVTS.06.1	ORARS, Kayamkulam
16.	AVTS.06.3	ORARS, Kayamkulam
17.	AVTS.06.4	ORARS, Kayamkulam
18.	AVTS.06.5	ORARS, Kayamkulam
19.	AVTS.06.6	ORARS, Kayamkulam
20.	AVTS.06.7	ORARS, Kayamkulam
21.	AVTS.06.9	ORARS, Kayamkulam
22.	AVTS.06.10	ORARS, Kayamkulam
23.	IVTS-06.2	ORARS, Kayamkulam
24.	IVTS-06.3	ORARS, Kayamkulam
25	IVTS.06.6	ORARS, Kayamkulam
26.	IVTS.06.8	ORARS, Kayamkulam
27.	IVTS.06.12	ORARS, Kayamkulam
28	IVTS.06.13	ORARS, Kayamkulam
29.	IVTS.06.15	ORARS, Kayamkulam
30.	IVTS.06.16	ORARS, Kayamkulam
31.	IVTS.06.22	ORARS, Kayamkulam
32.	IVTS.06.26	ORARS, Kayamkulam
33.	IVTS.06.27	ORARS, Kayamkulam
34.	IVTS.06.28	ORARS, Kayamkulam
35.	TCR-2511	NBPGR Regional Station, Vellanikkara
36.	TCR-2527-C	NBPGR Regional Station, Vellanikkara
37.	TCR-3279-A	NBPGR Regional Station, Vellanikkara
38.	TCR-3105	NBPGR Regional Station, Vellanikkara
39.	TCR-4865	NBPGR Regional Station, Vellanikkara
40.	YLM-17	Krishi Bhavan, Alathur

different seed treatment methods as described below were undertaken to facilitate germination.

a) Mechanical scarification- Rubbing the seeds with sand to break the seed coat.

b) Hot water treatment - soaking seeds in water at 60° C for 10 minutes before sowing.

c) GA_3 treatment - soaking seeds in GA 100ppm for 6-8 hours before germination.

d) Acid treatment - soaking seeds in 1 per cent H_2SO_4 and 1 per cent HCl for 10 minutes each and then rinsing and sowing.

e) Alternate wetting and drying - Soaking of seeds and drying the soaked seeds for 48 hours at an interval of hours each before sowing.

Even after all these treatments, seeds of accession 2 failed to germinate. Hence local collection of *S. malabaricum* (accession 3) was undertaken during August 2010 from Alleppey-Ernakulam tracts of Kerala. Seeds were collected and raised in pots as above. Seedlings of accession 3 were assessed for morphological characteristics and used for crossing with the fourteen released varieties of *S indicum*.

3.2. Experiment II Intervarietal hybridization

3.2.1. Crossing programme

Eight lines were selected from the cultures and six testers from among the released hybrids based on their performance under local conditions. The details of the lines and testers selected for crossing are given in Table 2 and Plates 1,2,3 and 4.

The selected parents were sown in pots filled with potting mixture containing sand, vermicompost and soil in the ratio 1:1:1 during January 2009. The genotypes were crossed manually as per the technique suggested by Thangavelu and

Nallathambi(1982) to get all the 48 F_1 combinations. For crossing, the desired flower buds in the lines were identified by their pale greenish cream colour and hand emasculation was done by pulling out the entire corolla tube along with the four epipetalous stamens between 3 pm and 4 pm. The emasculated flower buds were bagged with butter paper cover and tagged. Next day morning, between 7 am and 8 am, healthy, robust and freshly opened flowers of the tester parents were collected and the pollen was brushed on the stigma of the emasculated flower. After pollination the butter paper cover was replaced and tagged once again with the details of the cross made which included the name of parents and the date of crossing. Visible pod set was noticed within four days. After that, the butter paper cover was removed but the tag with the details was retained. All other recommended agronomic and plant protection measures were followed to raise a successful crop. Matured capsules were harvested after they started yellowing but before they dehisced. A few flowers in all parents were covered with butter paper cover and tagged to collect selfed seeds. Selfed and crossed seeds were collected from the tagged capsules separately , cleaned and kept /stored for sowing in the next season.

3.2.2. Raising F_1 generation and parents

The experimental material consisting of 62 entries involving 14 parents and their 48 F_1 hybrids were sown in randomized block design with two replications during February 2010. Details of the crosses raised are given in Table 3. Each genotype was grown in a single row with a plant to plant spacing of 15 cm and row to row spacing of 45 cm. Observations were recorded for each genotype from five randomly selected and tagged plants of each replication for nine quantitative characters namely number of days to flowering, plant height, number of branches per plant, number of capsules per plant, capsule length, locules per capsule, 1000 seed weight, seed yield per plant and oil content.

Table 2 List of lines and testers used in the study (Experiment II)

Lines	Genotype	
L1	**AVTS-06-3**	
L2	**AVTS-06-5**	
L3	**AVTS-06-7**	
L4	**AVTS-06-10**	
L5	**IVTS-06-2**	
L6	**IVTS-06-6**	
L7	**IVTS-06-12**	
L8	**TCR -3279-A**	
Testers		
T1	**KYM-1**	
T2	**Soma**	
T3	**Tilak**	
T4	**VRI-2**	
T5	**TMV-3**	
T6	**TMV-6**	

Plate 1. Lines used in Experiment II

AVTS-06-3

AVTS-06-5

AVTS -06-7

AVTS -06-10

Plate 2. Lines used in Experiment II

IVTS -06-2

IVTS -06-6

IVTS -06-12

TCR-3279-A

Plate 3. Testers used in Experiment II

KYM-1

Soma

Tilak

Plate 4. Testers used in Experiment II

VRI-2

TMV-3

TMV-6

3.3. Observations recorded

The following observations were recorded in ten randomly tagged plants in each genotype for quantitative characters.

3.3.1.Number of days to flowering

Number of days from sowing to flowering in the first plant of the genotype was counted and expressed in days.

3.3.2.Plant height

The distance from ground level to the tip of the plant at maturity was recorded in centimeters.

3.3.3.Number of branches per plant

Number of branches was counted at harvest and recorded.

3.3.4. Number of capsules per plant

Total number of capsules on each plant was counted.

3.3.5. Capsule length

Length of five randomly selected mature capsules per plant were measured and expressed in centimetres.

3.3.6. Number of locules per capsule

The total number of locules in five randomly selected mature capsules of the sample plants was counted.

Table 3. Hybrids obtained in line x tester mating design (Experiment II)

Sl.No.	Cross	Code No.
1	AVTS-06-3 X KYM 1	C1
2	AVTS-06-3 X Soma	C2
3	AVTS-06-3 X Tilak	C3
4	AVTS-06-3 X VRI 2	C4
5	AVTS-06-3 X TMV 3	C5
6	AVTS-06-3 X TMV 6	C6
7	AVTS-06-5 X KYM 1	C7
8	AVTS-06-5 X Soma	C8
9	AVTS-06-5 X Tilak	C9
10	AVTS-06-5 X VRI 2	C10
11	AVTS-06-5 X TMV 3	C11
12	AVTS-06-5 X TMV 6	C12
13	AVTS-06-7 X KYM 1	C13
14	AVTS-06-7 X Soma	C14
15	AVTS-06-7 X Tilak	C15
16	AVTS-06-7 X VRI 2	C16
17	AVTS-06-7 X TMV 3	C17
18	AVTS-06-7 X TMV 6	C18
19	AVTS-06-10 X KYM 1	C19
20	AVTS-06-10 X Soma	C20
21	AVTS-06-10 X Tilak	C21
22	AVTS-06-10 X VRI 2	C22
23	AVTS-06-10 X TMV 3	C23
24	AVTS-06-10 X TMV 6	C24
25	IVTS-06-2 X KYM 1	C25
26	IVTS-06-2 X Soma	C26
27	IVTS-06-2 X Tilak	C27
28	IVTS-06-2 X VRI 2	C28
29	IVTS-06-2 X TMV 3	C29
30	IVTS-06-2 X TMV 6	C30
31	IVTS-06-6 X KYM 1	C31
32	IVTS-06-6 X Soma	C32
33	IVTS-06-6 X Tilak	C33
34	IVTS-06-6 X VRI 2	C34
35	IVTS-06-6 X TMV 3	C35
36	IVTS-06-6 X TMV 6	C36
37	IVTS-06-12 X KYM 1	C37
38	IVTS-06-12 X Soma	C38
39	IVTS-06-12 X Tilak	C39
40	IVTS-06-12 X VRI 2	C40
41	IVTS-06-12 X TMV 3	C41
42	IVTS-06-12 X TMV 6	C42
43	TCR-3279-A X KYM 1	C43
44	TCR -3279-A X Soma	C44
45	TCR-3279-A X Tilak	C45
46	TCR-3279-A X VRI 2	C46
47	TCR-3279-A X TMV 3	C47
48	TCR-3279-A X TMV 6	C48

3.3.7. 1000 seed weight

The weight of one thousand seeds of individual plant was taken and expressed in grams.

3.3.8. Seed yield per plant

All the matured capsules obtained from each single plant were dried uniformly, seed extracted and seed weight per plant recorded in grams.

3.3.9. Oil content

Clean seeds with 10-12 per cent moisture were used for oil estimation by cold percolation method where oil is extracted by repeated washing with petroleum spirit and estimated after removing the solvent (Nagaraj, 2009). For this one gram seeds were weighed, crushed and powdered with one spoonful of anhydrous sodium sulphate and oil was extracted with petroleum spirit with three repeated washings at one hour interval and was expressed in percentage.

3.4.Statistical Analysis

3.4.1. Components of heritable variation

The data recorded was analysed with statistical parameters namely range, mean, SE and coefficient of variation.

The mean sum of squares was used to estimate genetic parameters like genotypic and phenotypic variances (Singh and Chaudhary, 1995).

3.4.1.1. Analysis of variance

Source	Df	Mean sum of squares	Expected mean sum of squares	F value calculated
Replication	(r-1)	Mr	$\sigma^2 e + g \sigma^2 r$	Mr / E
Genotype	(g-1)	Mg	$\sigma^2 e + r \sigma^2 g$	Mg / E
Error	(g-1)(r-1)	E	$\sigma^2 e$	

Where r = Number of replications

g = Number of genotypes

$\sigma^2 e$ = error variance

$\sigma^2 r$ = replication variance

3.4.1.2. Estimation of mean and range

The mean value for each character was worked out using the following formula

Mean $X = 1/n \left(\sum^{n}_{1=1} x\ i\right)$

$\sum x_i$ = sum total of characters

n = number of observations

Range: The lowest and highest values from mean of each character were recorded as range.

3.4.1.3.Estimation of standard deviation and standard error

Standard deviation (SD) is derived from the following formula

$$\sqrt{\frac{\sum(x-X)^2}{n-1}}$$

Where

X = mean of all observations

x= individual observation

n = number of observations

Standard error (SE) = $\frac{SD}{\sqrt{n}}$

3.4.1.4. Estimation of variances, coefficients of variation

The phenotypic and genotypic variances were calculated by using the respective mean square values (Johnson *et al* , 1955)

1) Genotypic variance $\sigma^2 g = \frac{MSg - Mse}{r}$

2) Environmental variance $\sigma^2 e = MSe$

3) Phenotypic variance $\sigma^2 p = \sigma^2 g + \sigma^2 e$

Where MSg = genotypic mean sum of squares

MSe = Error mean sum of squares

r = Number of replications.

The genotypic and phenotypic coefficients of variation were calculated as suggested by Burton (1952).

1) PCV = $\frac{\sqrt{\sigma^2 P}}{X} \times 100$ where $\sigma^2 P$ = Phenotypic variance
X = General mean of characters

2) GCV= $\frac{\sqrt{\sigma^2 G}}{X} \times 100$ where $\sigma^2 G$ = Genotypic variance
X = General mean of characters

Categorization of the range of variation was effected as proposed by Subramanian and Menon (1973).

< 10% - Low

10-20% - Moderate

> 20% - High

3.4.1.5. Estimation of heritability percent

Heritability percentage in broad sense was estimated for various characters as per formula suggested by Lush (1940).

$$H^2 \text{(Broad sense)} = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

where H^2 =.Heritability

$\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

As suggested by Johnson *et al* (1955) heritability estimates were categorized as

0-30% - Low

30-60% - Medium

≥ 61% - High

3.4.1.6. Estimation of genetic advance

The genetic advance was calculated as per the formula suggested by Johnson *et al* (1955) and expressed as percent for each trait.

$$G.A = \frac{\sigma^2 g}{\sqrt{\sigma^2 p}} \times K$$

Where $\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

K = 2.06 (selection differential at 5 % selection intensity) (Falconer, 1967)

Genetic advance was expressed as percent of mean using the formula suggested by Govindasamy *et al* (1973).

$$\text{G.A as percent of mean} = \frac{\text{G.A.}}{\text{X}} \times 100$$

Where G.A. = genetic advance

X = grand mean

The range of genetic advance as percent of mean was classified as suggested by Johnson *et al* (1955)

0-10 percent – Low

11-20 percent – Moderate

> 20 percent – High.

3.4.1.7. Correlation studies

The correlation coefficients among all possible character combinations at phenotypic (rp) and genotypic (rg) level was estimated employing the formula suggested by Al-Jibouri *et al*; (1958). For each of the traits, analysis of variance was computed and the mean square expectations from which the estimates of variances components were obtained are given below.

Source	Df	MS	Expected mean squares
Replication	(r-1)		
Genotype	(g-1)	MS_1	$\sigma^2e + g.\ \sigma^2r$
Error	(r-1)(g-1)	MS_2	$\sigma^2e + r.\ \sigma^2g$
Total	(rg-1)		

Where r = Number of replications

g = Number of genotypes

σ^2g (genotypic variance) = $\frac{MS_1 - MS_2}{r}$

σ^2e (error variance) = MS_2

σ^2p (phenotypic variance) = $\sigma^2g + \sigma^2e$

3.4.1.7.1. Correlation coefficient (r)

Genotypic correlation coefficient $rg = \frac{\sigma^2g_{(1,2)}}{(\sigma^2g_1)(\sigma^2g_2)}$

Where $\sigma^2 g_1$ = Genotypic variance of first character

$\sigma^2 g_2$ = Genotypic variance of second character

$\sigma^2 g_{(1,2)}$ = Genotypic covariance between the two characters.

Phenotypic correlation coefficient $rp = \frac{\sigma^2 p_{(1,2)}}{(\sigma^2 p_1)(\sigma^2 p_2)}$

Where $\sigma^2 p_1$ = Phenotypic variance of first character

$\sigma^2 p_2$ = Phenotypic variance of second character

$\sigma^2 p_{(1,2)}$ = Phenotypic covariance between the two characters

The test of significance for association between characters was done by comparing table values of 'r' at (n-2) degrees of freedom for phenotypic and genotypic correlations with estimated values.

$$t = \frac{r\sqrt{(n-2)}}{\sqrt{1-r^2}}$$

3.4.1.8.Path coefficient analysis

Path coefficient analysis as applied by Dewey and Lu (1959) was used to partition the genotypic correlation into components of direct and indirect effects. The following set of simultaneous equations were formed and solved for estimating various direct and indirect effects.

$$r_{1y} = a + r_{12}b + r_{13}c + \ldots\ldots\ldots\ldots\ldots\ldots r_{1i}$$

$$r_{2y} = r_{21}a + b + r_{23}c + \ldots\ldots\ldots\ldots\ldots\ldots r_{2i}$$

$$r_{3y} = r_{31}a + r_{32}b + c + \ldots\ldots\ldots\ldots\ldots\ldots r_{3i}$$

$$r_{iy} = r_{11}a + r_{12}b + r_{13}c + \ldots\ldots\ldots\ldots\ldots\ldots 1$$

where $r_{1y \text{ to } iy}$ = coefficient of correlation among casual factors

a,b,c,.....i = direct effect of characters 'a' to 'i' on the dependant character 'y'.

Residual effect (R) was computed as follows

$$\text{Residual effect (R)} = 1 - \sqrt{a^2 + b^2 + c^2 + \ldots\ldots\ldots i^2 + 2abr_{12} + 2acr_{13} + \ldots\ldots\ldots}$$

The direct and indirect effects were classified based on the scale given by Lenka and Mishra (1973)

More than 1.0 - Very High

0.30 – 0.99 - High

0.20 – 0.29 - Moderate

0.10 – 0.19 - Low

0.00 – 0.09 - Negligible

3.4.1.9. Genetic Diversity

3.4.1.9.1. Mahalanobis D^2 statistics

Mahalanobis (1928) D^2 statistic analysis was used for assessing the genetic divergence among the test entries. The generalized distance between any two populations is given by the formula

$D^2 = \sum \lambda ij S^{ai} S^{aj}$

Where D^2 = Square of generalized distance

λij = reciprocal of the common dispersal matrix

$S^{ai} = (\mu_{i1} - \mu_{i2})$

$S^{aj} = (\mu_{ji} - \mu_{j2})$

μ = General mean

Since the formula for computation requires inversion of higher order determinant, transformation of the original correlated unstandardised character mean (X_s) to standardized uncorrelated variable (Y_s) was done to simplify the computational procedure.

Replication wise values for each character of each genotype was used for analysis of variance. After testing the difference a simultaneous test of significance to difference with regard to the pooled effects of the 10 characters under study was carried out using Wilk's criterion (Rao, 1948).

In order to determine the population constellation, the genotypes were grouped into a number of clusters on the basis of D^2 values as suggested by Suresh and Unnithan (1996).

3.4.1.9.2. Clustering of D^2 values

All the [n (n-1)/2} D^2 values were clustered using Tocher's method as directed by Rao (1952)

3.4.1.9.3. Intracluster distance

The intracluster distance was calculated by the formula given by Singh and Chaudhary (1995)

$$\text{Square of intracluster distance} = \frac{\sum Di^2}{n}$$

where $\sum Di^2$ is the sum of distance between all possible combinations

n is the number of all possible combinations

3.4.1.9.4. Intercluster distance

The inter cluster distance was calculated by the formula described by Singh and Chaudhary (1995)

$$\text{Square of inter cluster distance} = \frac{\sum Di^2}{n_i\, n_j}$$

$\sum Di^2$ = sum of distances between all possible combinations $n_i\, n_j$ of the entries included in the cluster study.

n_i = number of entries in cluster i.

n_j = number of entries in cluster j.

3.4.2. Line x Tester Analysis

3.4.2.1. Analysis of variance

Data collected on nine traits for the 62 genotypes were subjected to analysis of variance as suggested by Panse and Sukhatme (1964).

Source	df	MS	Expected mean of squares
Replication	(r-1)		
Treatments	(lt + 1 + t – 1)		
Parents	(l + t – 1)		
Hybrids	(lt -1)		
Lines	(l -1)	M_1	EMS + R(cov.FS – 2cov.HS) + RT(cov.hs)
Testers	(t-1)	M_2	EMS + r(cov.FS – 2cov.HS) + rl (cov.HS)
L x T interaction	(l - 1) (t – 1)	M_3	EMS + r(cov. FS – 2 cov. HS)
Parents vs hybrids	1		
Error	(r-1) (lt+1+t-1)	M_4	EMS
Total	r(lt+l+t)-1		

3.4.2.2. Combining ability analysis

The data for the biometrical traits were subjected to analysis of variance appropriate for line x tester analysis as suggested by Kempthorne (1957). The mean of squares due to different sources of variation as well as their genetic expectations were estimated as follows.

Source	df	Expected mean squares
Block	(b-1)	$\sigma^2e + g.\sigma^2b$
Genotype	(g-1)	$\sigma^2e + b.\sigma^2g$
Error	(b-1) (g-1)	

Where r = number of replications

l = number of lines

t = number of testers

EMS = Error Mean Square

From the genetic expectation of the mean squares, the covariance of full sibs (Cov FS) and half sibs (Cov HS) was estimated as given below.

$$\text{Cov H.S.} = \frac{1}{r(2lt - l - t)} \left[\frac{(l-1)(M_1) + (t-1)(M_2)}{l+t-2} - M_3 \right]$$

$$\text{Cov F.S.} = \frac{(M_1 - M_4) + (M_2 - M_3) + (M_3 - M_4)}{3r} + \frac{6r \text{ cov H.S} - r(l+t) \text{ cov H.S.}}{3r}$$

From this covariance values general and specific combining ability variances were computed as given below.

G.C.A. variance (σ^2 GCA) = Cov H.S.

SCA variance (σ^2 SCA) = Cov F.S. – 2Cov H.S.

G.C.A. variance for lines and testers and SCA variance for the hybrids were calculated as follows.

$$\sigma^2 \text{ GCA (lines)} = \frac{M_1 - M_3}{rt}$$

$$\sigma^2 \text{ GCA (testers)} = \frac{M2 - M3}{rl}$$

$$\sigma^2 \text{ SCA (hybrids)} = \frac{M_3 - M_4}{r}$$

3.4.3.3. Propotional contribution of lines, testers and their interaction to total variances

$$\text{Contribution of lines} = \frac{SS(\text{lines})}{SS(\text{crosses})} \times 100$$

$$\text{Contribution of testers} = \frac{SS(\text{testers})}{SS(\text{crosses})} \times 100$$

$$\text{Contribution of interaction} = \frac{SS(l \times t)}{SS(\text{crosses})} \times 100$$

3.4.3.4.Estimation of combining ability effects

Both the *gca* and *sca* of an ijk th observation was arrived at using the mathematical model given below.

$X_{ijk} = \mu + gi + gj + gij + eijk$

Where μ = population mean

gi = gca of the i^{th} line

gj = gca of the j^{th} tester

Sij = sca of ij^{th} hybrid

eijk = error associated with ijk th observation

i = number of lines

j = number of testers

k = number of replications

General combining ability effects of parents and specific combining ability effects of hybrids were estimated as given below

$$\text{Mean} = \frac{x.....}{rlt}$$

i. gca effects of lines

$$gi = \frac{xi....}{tr} - \frac{x.....}{rlt}$$

ii. gca effects of tester

$$gj = \frac{x.j.}{rl} - \frac{x.....}{rlt}$$

iii. sca effect of hybrid

$$sij = \frac{xij.}{r} - \frac{xi..}{rt} - \frac{x.j.}{rl} - \frac{x...}{rlt}$$

where x... = total of all hybrids over 'r' number of replications

x.i. = total of the i^{th} line over 't' testers and 'r' replication

x.j. = total of the j^{th} tester over 'l' lines and 'r' replication

xij = total of the hybrid between i^{th} line and j^{th} tester over 'r' replications.

Test of significance of combining ability effects.

i. SE of gca of lines $= \frac{EMS}{rt}$

ii. SE of gca of testers $= \frac{EMS}{rl}$

iii. SE of sca of hybrids $= \frac{EMS}{r}$

where SE = standard error

EMS = Error mean square

't' $= \frac{\text{parameter}}{SE}$

The calculated 't' value was compared with table 't' value at error degrees of freedom to test the significance.

3.4.3.5. Estimation of heterosis

Magnitude of heterosis for all hybrids was estimated over midparent, better parent and standard check as given below.

i. Relative heterosis (di)

The superiority / inferiority of F_1 over the mid parent value was estimated as follows.

$$di = \frac{\bar{F}_1 - \bar{MP}}{\bar{MP}} \times 100$$

Where F1 = mean value of hybrids

$\bar{MP}$ = mid parental value.

ii. Heterobeltiosis (dii)

Heterosis of F_1 over better parent was obtained as follows.

$$dii = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where $\overline{BP}$ = mean value of better parent

iii. Standard heterosis (diii)

Superiority or inferiority of F_1 over the standard check was calculated as given below

$$diii = \frac{\overline{F_1} - \overline{SV}}{\overline{SV}} \times 100$$

Where SV – mean value of standard variety

Tilak was adopted as standard check for yield and other components.

Test of significance of heterosis.

Significance of estimates of heterosis was tested at error degrees of freedom as suggested by Turner (1953)

't' for relative heterosis $= \frac{\overline{F_1} - \overline{MP}}{\frac{Me}{r} \times \frac{3}{2}} \times 100$

't' for heterobeltiosis $= \frac{\overline{F_1} - \overline{SV}}{\frac{Me}{r} \times 2} \times 100$

't' for standard heterosis $= \frac{F_1 - SV}{\frac{Me}{r} \times 2} \times 100$

where Me = error variance

r = number of replications

3.5. Experiment III Interspecific hybridization

3.5.2. Raising crossing block

Seedlings of *S. malabaricum* as female parent and those of *S. indicum* as pollen parent were raised in pots in sheds erected using UV stabilized polythene sheet to avoid heavy rainfall intervening hybridization. Crossing was done as per the technique suggested by Thangavelu and Nallathambi (1982) as explained in Experiment II. Hybrid capsules were collected at maturity and seeds were used to raise F_1 generation.

3.5.3. Raising F_1 generation of interspecific hybrids.

Hybrid seeds of the interspecific cross were sown in earthern pots filled with potting mixture and irrigated regularly. As the seeds failed to germinate even after 4 weeks, seed treatment practices like GA_3 treatment, hot water treatment and mechanical scarification were carried out.

To further understand the reasons behind germination failure, the mature seeds were dissected and observed under stereomicroscope.

Studies on the longitudinal section of mature seed revealed the presence of a rudimentary structure which could not be retrieved. Hence seeds at different maturity stages (15^{th}, 30^{th} and 45^{th} day after crossing) were also observed under stereomicroscope to observe the embryo development. It was observed that normal embryo and cotyledon was retained upto 45^{th} day. Hence seeds were retrieved from capsules 45 days after pollination and taken up for culturing under *in vitro* conditions.

3.5.3.1. Micro propagation

All the laboratory experiments were conducted under defined conditions of culture room maintained at $30 \pm 2^{\circ}$ C, uniform light (Ca 1000lux) provided by fluorescent tubes.

3.5.3.1.1.Nutrient medium

Murashige and Skoog (1962) medium was used for culturing hybrid embryos. Macro nutrients, micro nutrients, Fe EDTA and growth regulators were maintained as separate stock solutions and stored in refrigerator until further use.(Table 4). Sucrose and agar were weighed and added in required quantities during media preparation. Growth regulators were added in required quantities from stock solutions of suitable strength. After mixing the required quantities of the stock solution and sucrose, the volume made little short of final volume, the pH was verified with pH paper and adjusted to 5.8 using 0.1 N NaOH or 0.1N HCl. The volume was finally made up and required amount of agar added and media heated to dissolve it. 15ml of medium was poured into test tubes (150 x 15cm) plugged with non-absorbent cotton and autoclaved at 121°C for 20 minutes.

3.5.3.1.2. Standardization of protocol for rescue of young embryos.

Embryos from fully matured seeds were degenerated and hence did not respond to *in vitro* culture. The seeds were collected at 15DAP, 30DAP, 45DAP and 60DAP and embryos examined. It was found that upto 45DAP, cotyledons and embryos were retained in the seeds. Hence the partially mature capsules were harvested and seeds used for *in vitro* culture. The capsules were collected and seed retrieved from them. The seeds were washed thoroughly in running tap water and soaked for 24 hours in distilled water for the ease of removal of testa.

The soaked seeds were surface sterilized with 0.1% $HgCl_2$ for 5 minutes in the laminar flow chamber under aseptic conditions. The seeds were then rinsed thoroughly in sterile distilled water 4-5 times. The seed coat was removed carefully and the cotyledon along with embryo was transferred to the sterile test tubes containing MS medium with forceps. The inoculated tubes were kept in culture room and monitored further.

Table 4. Composition of MS medium for *in vitro* culture of sesame

Sl.No.	Compound	Concentration (mg/l)
1	NH_4NO_3	1650
2	KNO_3	1900
3	$MgSO_4.7H_2O$	370
4	KH_2PO_4	170
5	$CaCl_2.2H_2O$	440
6	KI	0.83
7	H_3BO_3	6.2
8	$MnSO_4.4H_2O$	22.3
9	$ZnSO_4.7H_2O$	8.6
10	$Na_2MoO_4.2H_2O$	0.25
11	$CuSO_4.5H_2O$	0.025
12	$CoCl_2.6H_2O$	0.025
13	$FeSO_4.7H_2O$	27.8
14	$Na_2EDTA.2H_20$	37.3
15	Inositol	100
16	Nicotinic Acid	0.5
17	Pyridoxine HCl	0.5
18	Thiamine HCl	0.1
19	Glycine	2
20	Sucrose (g/l)	30
21	Agar (g/l)	7.5
pH - 5.8		

Results

4. EXPERIMENTAL RESULTS

Oilseed crops are being cultivated since antiquity and they are a vital part of agricultural sector. Sesame, also called gingelly is considered to be the oldest oil yielding crop known to man. Success in crop improvement depends on genetic variability and the magnitude and extent to which the desirable traits are heritable. Estimates of variability with respect to yield and yield contributing characters and their heritable nature in the material with which a breeder is working are hence, prerequisites for any crop breeding program. In the present study, the extent of variability for nine quantitative characters in a set of forty sesame accessions is estimated.

The first and foremost important step in the development of hybrids is the selection of parents having good general combining ability and knowing the occurrence of commercially viable extent of heterosis. Knowledge on nature of gene action involved in the inheritance of yield and yield components will give an idea about the future course of action to be undertaken while raising the subsequent generations of the cross. In this study, 14 parents were used for intervarietal hybridization in line x tester mating design and the F_1 progeny studied.

The practical utility of hybrid sesame is mainly dependent on the utilization of male sterility which eliminates hand emasculation and makes production of hybrid seed cost effective. The use of male sterility however depends on the availability of stable cytoplasmic genic male sterile (CGMS) lines and identification of suitable restorers. Hence, interspecific hybridization of sesame was attempted with a wild species *Sesamum malabaricum* in order to develop male sterile lines in sesame as *S.malabaricum* is a known source for CGMS in sesame.

The results of the three experiments conducted are discussed below.

4.1. Experiment 1 Genetic variability and diversity studies

The results of variability studies of 40 sesame genotypes conducted during October 2007- February 2008 in the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara are presented under the following headings.

4.1.1 Range and mean for different characters

4.1.2 Variability studies

4.1.3 Correlation studies

4.1.4 Path coefficient analysis

4.1.5 Genetic divergence

Analysis of variance of diversity studies of 40 genotypes of sesame revealed highly significant differences among genotypes with respect to number of days to flowering, plant height and number of capsules per plant as represented in Table 5.

4.1.1. Range and mean for different characters

The mean values for different characters for the genotypes under study are given in Appendix 1. The range and overall mean for different characters studied is given in Table 6.

4.1.1.1.Number of days to flowering

Among the genotypes KYM-1 took less number of days to flower (18.73) while Tilarani was the last to flower (34.8 days). The overall mean for days to flowering was 27.35 among the genotypes.

4.1.1.2.Plant height

Significant variation was noticed for plant height which ranged between 31.40 cm (IVTS-06-12) and 107.97 cm (Soma) with an average of 53.44 cm.

Table 5. Analysis of variance for yield and yield contributing characters in base collection

Source of variation	Degrees of freedom	Mean sum of squares								
		Number of days to flowering	Plant height	Number of branches per plant	Number of capsules per plant	Capsule length	Locules per capsule	1000 seed weight	Seed yield per plant	Oil content
Replication	2	1.6591	0.086961	0.1892	20.9630*	0.0014	0.0000	0.0014	0.2922	0.2031
Treatment	39	32.3377**	1153.4615**	12.4678	255.0877**	0.0340	0.3000	0.0026	4.3093	3.2988
Error	78	0.4456	0.9560	0.1150	1.4284	0.0018	0.0000	0.0001	0.0190	0.1715
SE		0.5451	0.7984	0.2769	0.9758	0.0348	0.0000	0.0085	0.1126	0.3382
CV (%)		21.84	16.365	51.83	43.56	18.97	-	2.95	35.56	7.615

* significant at 5% level
** significant at 1% level

4.1.1.3.Number of branches per plant

Number of branches per plant recorded a mean of 5.85 with a range from 4.27 (Soma) to 12.13 (Tilak).

4.1.1.4.Number of capsules per plant

The genotypes differed significantly with respect to number of capsules per plant which ranged from 9.96 (IVTS-06-22) to 50.93 (Tilatara) with an average of 24.54.

4.1.1.5.Capsule length

Average capsule length recorded was 2.01 cm with a range from 1.82cm (TMV-6) to 2.26cm (IVTS-06-27).

4.1.1.6. Locules per pod

All the genotypes studied were tetralocular (4 locules) except Soma which had eight locules per pod.

4.1.1.7. 1000 seed weight

The weight of 1000 seeds ranged between 3.11g (IVTS-06-8 and TCR-4865) and 3.21g (AVTS-06-7) with an overall mean of 3.15g.

4.1.1.8. Seed yield per plant

The genotypes exhibited maximum variation for seed yield per plant which ranged from 1.35g (IVTS-06-22) to 7.02g (SVPR – 1) with an average of 3.47g.

4.1.1.9. Oil content

Oil content exhibited a mean of 48.65 per cent with a range between 45.53 percent (AVTS-06-7) and 50.17 per cent (KYM – 1).

4.1.2. Variability studies

The results of genetic parameters observed for 40 genotypes of *Sesamum indicum* are presented in the Table 6.

4.1.2.1.Genotypic coefficient of variation and Phenotypic coefficient of variation

As the genotypic and phenotypic variances are associated with units, the coefficients of variations were worked out for valid comparisons among the characters. The highest genotypic coefficient of variation (GCV) was observed for number of capsules per plant (37.47) followed by plant height (36.68) and number of branches per plant (34.67). 1000 seed weight recorded the lowest GCV of 0.91 per cent.

Phenotypic coefficient of variation (PCV) exhibited similar trend. Number of capsules per plant (37.78) recorded the maximum PCV followed by plant height (36.72) and number of branches per plant (35.15) while the lowest PCV of 0.97 per cent was recorded for 1000 seed weight.

The maximum difference between PCV and GCV estimated was noticed for the trait, number of branches per plant (0.4804), followed by capsule length (0.4199). Plant height showed minimum difference (0.0456).

4.1.2.2.Heritability and Genetic advance

All the characters studied showed high degree of broad sense heritability (>85 percent). Maximum heritability was observed for locules per pod (1.000) followed by plant height (0.9975), seed yield per plant (0.9869) and number of capsules per plant

Table 6. Genetic parameters for yield and yield contributing characters in base collection

Character	Mean	Range		Genotypic variance	Environmental variance	Phenotypic variance	Genotypic coefficient of variation (%)	Environmental coefficient of variation (%)	Phenotypic coefficient of variation (%)	Heritability (Braod sense)	Genetic Advance as % mean at 5% Selection intensity
		Minimum	Maximum								
Number of days to flowering	27.35	18.73	34.8	10.6307	0.4456	11.0763	11.9234	2.4412	12.1707	0.9598	24.0630
Plant height (cm)	53.44	31.40	107.97	384.1685	0.9561	385.1245	36.6755	1.8296	36.7211	0.9975	75.4576
Number of branches per plant	5.85	4.27	12.13	4.1176	0.1150	4.2326	34.6707	5.7930	35.1515	0.9728	70.4450
Number of capsules per plant	24.54	4.27	50.93	84.5531	1.4284	85.9815	37.4695	4.8701	37.7847	0.9834	76.5434
Capsule length (cm)	2.01	1.82	2.26	0.0107	0.0018	0.0125	5.1537	2.1223	5.5736	0.8550	9.8169
Locules per capsule	4.05	4.00	8.00	0.1000	0.0000	0.1000	7.8081	0.000	7.8081	1.0000	16.0847
1000 seed weight (g)	3.15	3.11	3.21	0.0008	0.0001	0.0009	0.9113	0.3318	0.9698	0.8830	1.7641
Seed yield per plant (g)	3.47	1.36	7.02	1.4301	0.0190	1.4491	34.4780	3.9742	34.7063	0.9869	70.5574
Oil content (%)	48.65	45.53	50.17	1.0424	0.1715	1.2140	2.0986	0.8513	2.2647	0.8587	4.0060

(0.9834). Minimum heritability of 0.855 was observed for the character capsule length.

Genetic advance as a percentage of mean ranged from 1.764 (1000 seed weight) to 76.54 (number of capsules per plant). Low values of genetic advance over mean were recorded for the characters 1000 seed weight, oil content and capsule length, while the rest of characters observed high GA over mean.

4.1.3. Correlation studies

Genotypic and phenotypic correlation coefficients were calculated from variance and covariance analysis for all possible combinations for eight characters (Table 7). In general, genotypic correlation coefficients were higher than phenotypic correlation coefficients for all characters.

Number of days to flowering had significant positive correlation with number of branches per plant, number of capsules per plant, capsule length and seed yield per plant at both genotypic and phenotypic levels.

Plant height recorded significant positive correlation with number of branches per plant, number of capsules per plant, locules per capsule, seed yield per plant and oil content at both levels.

Number of branches per plant had significant positive genotypic and phenotypic correlation with number of days to flowering, plant height, number of capsules per plant, locules per capsule, seed yield per plant and oil content.

Number of capsules per plant had high significant positive correlation with number of days to flowering, plant height, number of branches per plant, locules per capsule, seed yield per plant and oil content at both levels.

Capsule length recorded significant positive correlation at both genotypic and phenotypic levels with days to flowering.

Table 7. Genotypic and phenotypic correlation coefficients between yield and yield contributing characters in base collection

Character	Number of days to flowering	Plant height	Number of branches per plant	Number of capsules per plant	Capsule length	Locules per capsule	1000 seed weight	Seed yield per plant	Oil content
Number of days to flowering	1	0.2155	0.3014*	0.4094**	0.2991*	-.0802	0.2947*	0.3211*	-0.0381
Plant height	0.2083	1	0.5915**	0.6309**	0.2497	0.4511**	-0.1221	0.6325**	0.5307**
Number of branches per plant	0.2897*	0.5817**	1	0.6954**	0.0709	0.3954**	-0.0963	0.5516**	0.4032**
Number of capsules per plant	0.4012**	0.6250**	0.6829**	1	0.1531	0.2938*	0.1013	0.9558**	0.4631**
Capsule length	0.2697*	0.2316	0.0714	0.1467	1	0.1203	-0.1008	0.2399	0.2005
Locules per capsule	-0.0785	0.4506**	0.3900**	0.2914*	0.1112	1	-0.0005	0.3121*	0.0925
1000 seed weight	0.2659	-0.1153	-0.0856	0.0996	-0.0802	-0.0505	1	0.1092	-0.2895
Seed yield per plant	0.3156*	0.6272*	0.5432**	0.9510**	0.2216	0.3100*	0.1067	1	0.4693**
Oil content	-0.0383	0.4910**	0.3666*	0.4226**	0.1667	0.0857	-0.2140	0.4384**	1

* p = 0.05 ** p = 0.01

Above the diagonal – genotypic correlation coefficient

Below the diagonal - phenotypic correlation coefficient

Significant positive correlation of locules per capsule was recorded with plant height, number of branches per plant, number of capsules per plant and seed yield per plant.

1000 seed weight recorded positive correlation with number of days to flowering at genotypic level.

Seed yield per plant was significantly correlated with days to flowering, plant height, number of branches per plant, number of capsules per plant, locules per capsule and oil content at both phenotypic and genotypic levels.

Oil content recorded significant positive correlation with plant height, number of branches per plant, number of capsules per plant and seed yield per plant.

4.1.3. PATH COEFFICIENT ANALYSIS

The genotypic correlation coefficients of seed yield per plant with its components were further positioned into direct and indirect effects (Table 8)

4.1.4.1.Direct effects

Number of capsules per plant had the highest positive direct effect (1.1063) on seed yield per plant followed by capsule length, plant height and 1000 seed weight.

Number of branches per plant recorded maximum negative direct effect (-0.2305) followed by number of days to flowering (-0.1075) and oil content (-0.0201) on seed yield per plant.

4.1.4.2. Indirect effects

Days to first flowering exerted positive indirect effects on number of capsules per plant, capsule length and oil content and negative indirect effects on number of days to flowering, plant height, number of branches per plant and 1000 seed weight.

Table 8. Direct and indirect effects of yield and yield contributing characters on seed yield per plant in base collection

Character	Number of days to flowering	Plant Height	Number of branches per plant	Number of capsules per plant	Capsule Length	1000 seed weight	Oil Content
Number of days to flowering	**-0.1075**	-0.0227	-0.0324	-0.0440	-0.0322	-0.0687	-0.0041
Plant Height	-0.0163	**0.0771**	0.0456	0.0486	0.0192	-0.0044	0.0409
Number of branches per plant	-0.0695	-0.1363	**-0.2305**	-0.1603	-0.0163	0.0190	-0.0929
Number of capsules per plant	0.4529	0.6980	0.7693	**1.1063**	0.1694	0.1093	0.5124
Capsule length	-0.0317	0.0265	0.0075	0.0162	**0.1060**	-0.0113	0.0213
1000 seed weight	-0.0036	0.0007	0.0001	-0.0018	-0.0022	**0.0222**	0.0037
Oil Content	0.0008	-0.0107	-0.0081	-0.0093	-0.0040	0.0013	**-0.0201**
Seed Yield	**0.3211**	**0.6325**	**0.5516**	**0.9558**	**0.2399**	**0.1092**	**0.4693**

RESIDUAL EFFECT = 0.2034

Plant height had positive indirect effects on number of capsules per plant (0.6980), capsule length and 1000 seed weight. Negative indirect effect was exerted through number of branches per plant, number of days to flowering and oil content.

Number of branches per plant registered positive indirect effects through number of capsules per plant, plant height, capsule length and 1000 seed weight while negative indirect effects were recorded through number of days to flowering and oil content.

Capsule number per plant exerted positive indirect effects through plant height and capsule length. Negative indirect effects were exerted through number of days to flowering, number of branches per plant, 1000 seed weight and oil content.

Capsule length exhibited positive indirect effects through number of capsules per plant and plant height while negative indirect effects were obtained through number of days to flowering, number of branches per plant, 1000 seed weight and oil content.

1000 seed weight recorded positive indirect effects through number of capsules per plant, number of branches per plant and oil content and negative direct effects through number of days to flowering, capsule length and plant height.

Oil content registered positive direct effect through number of capsules per plant, capsule length, plant height and 1000 seed weight. Negative direct effects were exerted through number of branches per plant and number of days to flowering.

4.1.4. GENETIC DIVERGENCE

Mahalanobis D^2 technique is a unique tool for identifying degree of divergence in biological population at genetic level. The present investigation was carried out to assess the genetic diversity of 40 sesame genotypes and the results are discussed below.

4.1.5.1. Contribution of each character towards total divergence

The relative ranking of different character components of D^2 analysis showed that maximum contribution towards total divergence (Table 9 and Figure 1) was attributed to plant height (69.74 per cent). This was followed by days to flowering (7.56 per cent) and seed yield per plant (6.67 per cent).

4.1.5.2. Group constellation : Intra and inter cluster D^2

Using the estimated D^2 values as the squares of generalized distance, all the 40 genotypes were grouped into six clusters (Fig.1) following the method suggested by Tocher (Rao, 1952). The average D^2 value within (intra) and between (inter) clusters are shown in Table 10.

The inter cluster D^2 values of six clusters revealed that maximum divergence occurred between Cluster III and Cluster IV (75.04) while closer proximity existed between Cluster V and Cluster VI (26.19). Among the intra clusters, maximum divergence was reported for cluster II (22.69) and minimum for solitary clusters III, IV, V and VI (0.00) (Table 10).

Different cluster composition of genotypes is presented in Table 11. Among the six clusters, cluster I was the largest with thirty genotypes. For cluster I, the maximum divergence distance was with cluster IV (75.04) and minimum with cluster III ($D^2 = 28.70$). Intra cluster D^2 value of cluster I was 17.82.

Cluster II had six genotypes with intra cluster distance of 22.69. Maximum inter cluster distance was recorded with cluster III (37.51) and minimum with cluster VI (33.09). Cluster III with a single genotype recorded highest divergence with cluster V (60.94) and lowest with cluster II(37.51) while the other solitary clusters, Cluster IV, Cluster V and Cluster VI recorded maximum and minimum values of 57.05 (with cluster V), 26.19 (with cluster VI); 57.05(with cluster IV), 36.40 (with cluster II) and 61.29 (with cluster I), 26.19 (with cluster IV) respectively.

Table 9. Proportion of yield and yield contributing characters towards total divergence in base collection

Sl No:	Character	Contribution percentage
1.	Number of days to flowering	7.56
2.	Plant height	69.74
3.	Number of branches per plant	5.13
4.	Number of capsules per plant	5.26
5.	Capsule length	2.05
6.	1000 seed weight	0.13
7.	Seed yield per plant	6.67
8.	Oil content	3.46

Table 10. Intra (bold) and inter cluster distances among different genotypes in base collection

Clusters	I	II	III	IV	V	VI
I	**17.82**	46.87	28.70	75.04	36.70	61.29
II		**22.69**	37.51	36.13	36.40	33.09
III			**0.00**	60.94	45.24	47.42
IV				**0.00**	57.05	26.19
V					**0.00**	45.26
VI						**0.00**

Figure 1. Proportion of yield and yield contributing characters towards total divergence in base collection

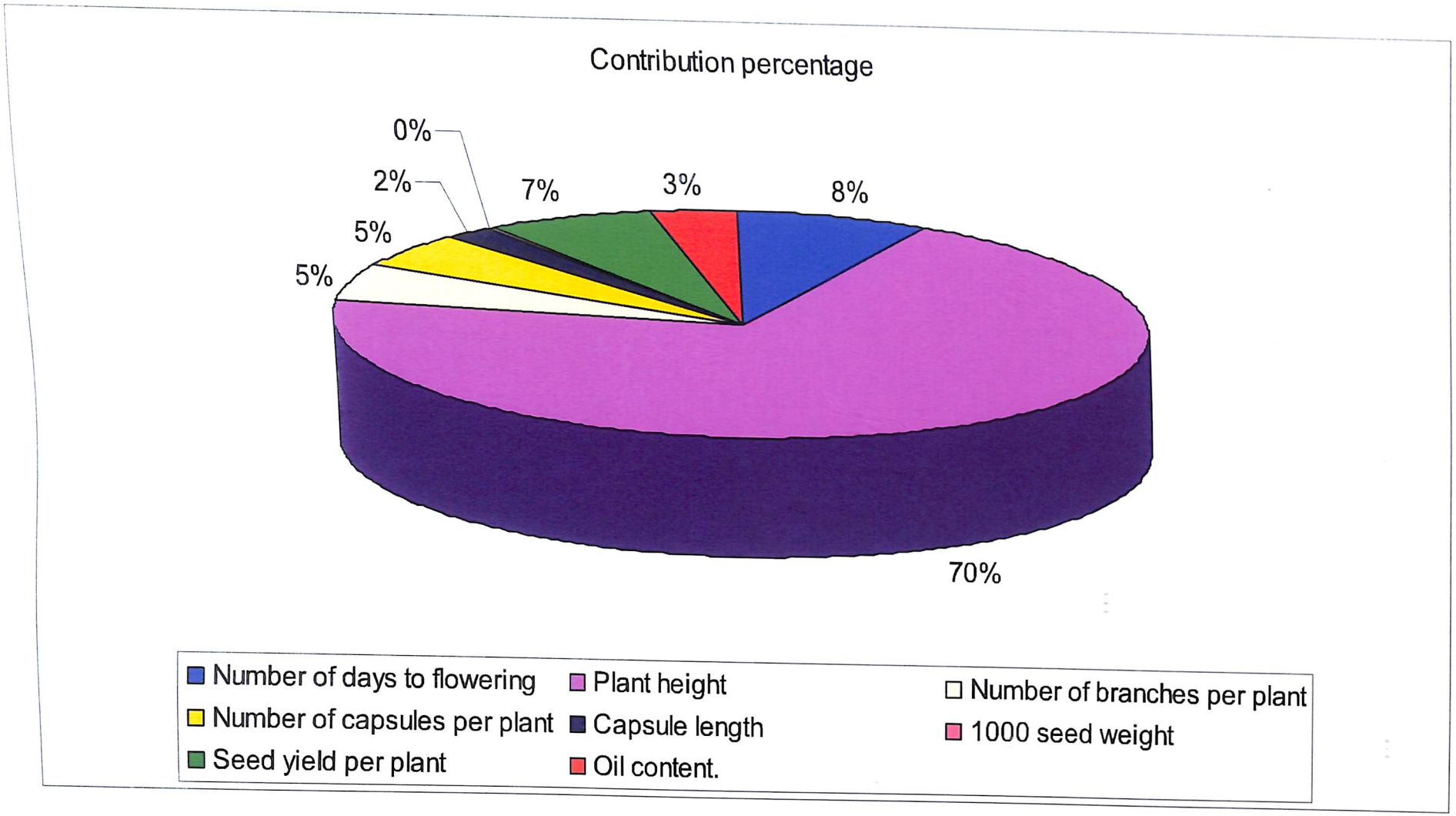


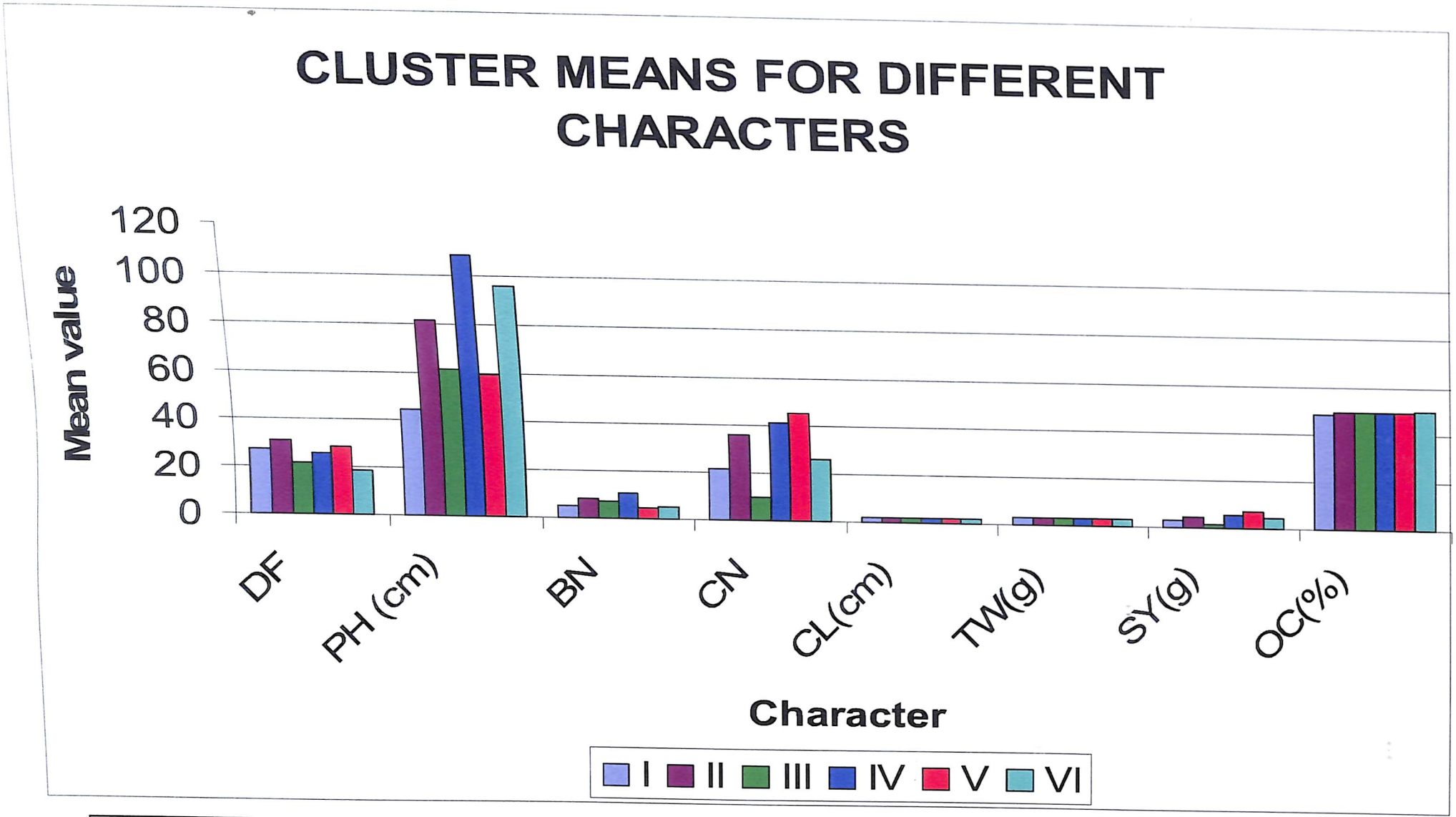
Table 11. Cluster composition in base collection

Cluster	Genotypes	Total number of genotypes
I.	IVTS-06-2, IVTS-06-3, YLM-17, AVTS-06-6, TCR-4865, TCR-3105, VRI-2, IVTS-06-16, IVTS-06-8, AVTS-06-10, TCR-2527-C, IVTS-06-15, AVTS-06-5, AVTS-06-4, IVTS-06-6, AVTS-06-3, AVTS-06-7, AVTS-06-1, AVTS-06-1, IVTS-06-28, IVTS-06-27, IVTS-06-13, TCR-2511, IVTS-06-12, TCR-3279-A, TMV-4, TMV-5, IVTS-06-26, TMV-6, VRI-1	30
II	Tilatara, CO-1, Tilak, Tilarani, TMV-3, Surya.	6
III	IVTS-06-22	1
IV	Soma	1
V	SVPR-1	1
VI	KYM-1	1

Table 12. Cluster means of yield and yield contributing characters in base collection

Character	I	II	III	IV	V	VI
Number of days to flowering	27.17	30.77	21.41	25.73	28.13	18.73
Plant Height (cm)	44.13	81.58	61.33	107.97	59.30	95.60
Number of branches per plant	5.20	8.39	7.34	10.80	4.73	5.00
Number of capsules per plant	21.42	36.07	9.96	41.20	45.43	26.07
Capsule length (cm)	2.0	2.03	2.01	2.09	2.07	1.99
1000 seed weight (g)	3.15	3.16	3.12	3.14	3.17	3.15
Seed yield per plant (g)	3.07	4.59	1.36	5.77	7.02	4.79
Oil content (%)	48.35	49.54	49.33	49.23	49.53	50.17

Figure 2. Cluster means of yield and yield contributing characters in base collection



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

4.1.5.3. Cluster means

The cluster means obtained for varying number of genotypes in each cluster are presented in Table 12 and Figure 2.

Number of days to flowering had the lowest mean in cluster VI (18.73) and highest in cluster II(30.77). On an average, cluster IV had tall plants (107.97cm) while cluster I reported short plants (44.13cm). Number of branches per plant ranged from 4.73 (cluster V) to 10.80(cluster IV). Cluster IV recorded highest number of capsules per plant (41.20) and the lowest was recorded by cluster III (9.96). Among the clusters, capsule length varied from 1.99(cluster VI) to 2.09 (cluster IV). Test weight was recorded between 3.12(cluster III) and 3.17 (cluster V). Seed yield per plant was lowest in cluster III (1.36) and highest in cluster V (7.02). Cluster means for oil content ranged from 50.17 (cluster VI) to 48.35 (cluster I).

4.1.6. Morphology of *S.malabaricum*

Morphological characterization of *Sesamum malabaricum* accessions obtained from two locations raised in the field are presented in the Table 13 and Plate 5. The plants are pubescent compared to *Sesamum indicum.* The flowering is indeterminate and the purple flowers have a dark lip. Capsules of *S.malabaricum* are densely hairy and have a clefted beak while those of *S.indicum* are sparsely hairy with a pointed beak. Seeds of *S.malabaricum* have a rough and reticulate testa whereas the seed coat of *S.indicum* seeds is smooth. A morphological comparison of *S.indicum* and *S.malabaricum* is given in Table 14 and Plates 6 and 7.

4.2. Experiment II Intervarietal hybridization

The experiment was conducted with the objective of estimating the heterosis in 48 crosses in line x tester mating design for eight quantitative characters and also to study the combining ability of eight lines and six testers of sesame. The results obtained from the study are presented under the following headings.

4.2.1 Analysis of variance

4.2 2. Evaluation of parents and hybrids

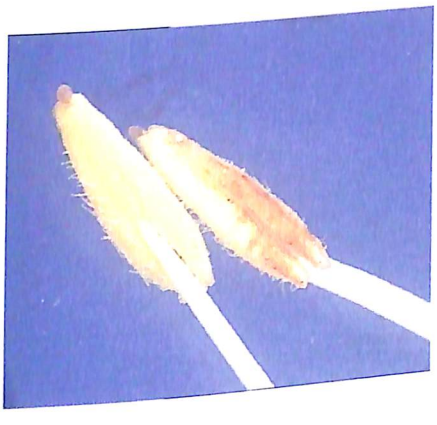
Table 13. Morphological characterization of *Sesamum malabaricum*

Character	Accession 2	Accession 3
Root system	Extensive thick tap root	Extensive thick tap root
Stem	Greenish purple, erect, pubescent, branching	Greenish purple, erect, pubescent, profuse branching
Plant height (cm)	78	90 -130
Number of branches	3	8-10
Leaves	Trilobed basal leaves, Upper leaves longitudinal, Pubescent	Trilobed basal leaves, Upper leaves longitudinal, Pubescent
Days to flowering	38	40
Corolla	Purple with dark tinged tip	Purple with dark tinged tip
Anthesis	5 to7 am	5 to7 am
Anthers	Yellowish white	Yellowish white
Stigma	Bifid and hairy	Bifid and hairy
Capsule	Clefted beak and densely hairy	Clefted beak and densely hairy
Capsule length (cm)	3	3.2
No.of capsules per plant	31	34
Locules per pod	4	4
Seeds	Dark with rough testa	Dark with rough testa
Test weight (g)	2.16	2.20
Seed yield per plant (g)	2.40	2.92
Oil content (%)	23.2	23.0

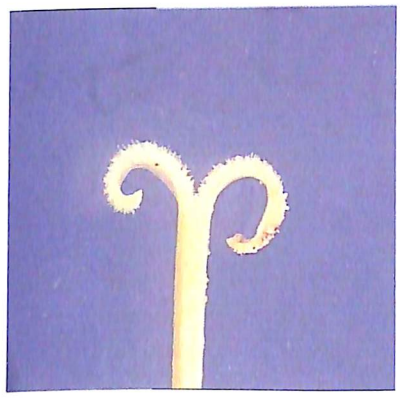
Plate 5. Morphology of *S.malabaricum*

Plant

Flower



Anthers



Stigma

Table 14. Morphological characteristics of *Sesamum indicum* and *Sesamum malabaricum*

Character	*S.indicum*	*S.malabaricum*
Habit	Annual, erect	Annual, erect
Root system	Extensive thick tap root	Extensive thick tap root
Stem	Pale green, quadrangular at the base, rounded above, sparsely pubescent, moderately branching	Green with purplish tinge, quadrangular, densely pubescent, profuse branching
Leaves	Simple leaves, medium sized, basal leaves ovate and wavy, upper leaves linear and entire, pale green colour	Larger basal leaves trilobed with dentate margin, upper leaves linear and entire, pubescent, dark green colour
Flowers	Solitary, medium sized	Solitary, large sized
Corolla	Pale white to light pink with purplish to yellow tinged lip	Purple with dark purple tinged tip
Anthesis	5 to7 am	5 to7 am
Anthers	Yellowish white without dark pink markings	Yellowish white with dark pink markings
Stigma	Bifid and hairy	Bifid and hairy
Capsule	Acute beak, moderately hairy	Clefted beak, densely hairy
Seeds	Medium, brownish black to cream with smooth, thin testa	Medium, black with rough, thick testa

Plate 6. Comparison of morphology of *S.indicum* and *S.malabaricum*

S.malabaricum

S.indicum

Plant morphology

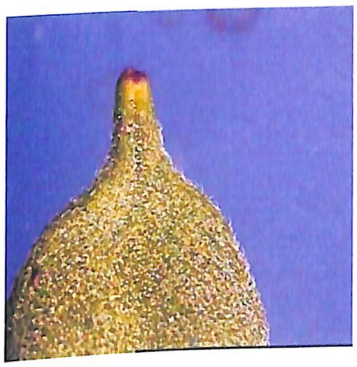
Corolla

Plate 7. Comparison of capsule and seed of *S.indicum* and *S.malabaricum*

S.malabaricum

S.indicum

Capsule



Capsule beak

Seeds

4.2.3. Heterosis – Relative heterosis(di), Heterobeltiosis(dii), Standard Heterosis(diii)

4.2.4. Combining ability Analysis

4.2.1.Analysis of variance

The analysis of variance revealed the presence of significant differences among the genotypes for all the nine characters studied (Table 15)

4.2.2. Evaluation of parents and hybrids

The mean values of parents and hybrids are given in Tables 16 and 17.

4.2.2.1.Number of days to flowering

The number of days to flowering ranged between 21.3 (AVTS-06-3) to 27.3 (AVTS-06-7) among lines and from 19.1 (KYM-1) to 31.7 (TMV-6) among testers. Among the hybrids, the range was between 29.6 (C39) and 37.3 (C17 and C21). Twenty one hybrids took significantly lesser days to flower than general mean.

4.2.2.2.Plant height

IVTS-06-6 was found to be tallest (49.35cm) while IVTS-06-12 was the shortest (31.43cm) among lines. Two lines and one tester registered significant values for plant height. Among testers the range was between 61.6cm (TMV-6) and 108.8cm (Soma). Twenty one among forty eight hybrids were significant for plant height and the range was from 179cm (C36) to 83.9cm (C1).

4.2.2.3.Number of branches per plant

Number of branches per plant ranged from 4.3 (TCR-3279-A) to 5.8 (AVTS-06-3), 4.9 (KYM-1) to 12.2 (Tilak), 3.3 (C14) and (C4) to 8.6 (C29) among lines,

Table 15. Analysis of variance for line x tester mating design

Source of variation	Degrees of freedom	Number of days to flowering	Plant height	Number of branches per plant	Number of capsules per plant	Capsule length	Locules per capsule	1000 seed weight	Seed yield per plant	Oil content
Replication	1	1.9575	0.0765	0.00163	29.391**	0.00039	0.00000	0.00317	0.6737	0.4658
Treatment	61	28.920**	2494.5**	4.2864**	306.43**	0.05674**	0.12903	0.00158**	11.862**	1.7802**
Lines	7	8.4436**	65.367*	0.40502**	23.516**	0.01438*	0.00000	0.00190	0.5726**	4.8829
Testers	5	48.781**	603.29	15.579	156.31	0.04614	1.3333	0.00058**	1.5635	0.8093
Lines X Testers	35	8.1662**	774.88**	0.49075**	60.127**	0.0555**	0.0000	0.00191**	2.01**	0.82911**
Error	61	0.43119	1.2503	0.4312	2.3214	0.001769	0.0000	0.00025	0.07975	0.10056
SE		0.342805	3.159391	0.12999	1.081568	0.0148	-	0.0158	0.211342	0.086902
CV %		12.00	32.33	28.90	27.51	7.98	-	5.60	31.81	1.97

* significant at 5% level

** significant at 1% level

testers and hybrids respectively. One line, one tester and eight hybrids showed significantly positive values for branch number.

4.2.2.4.Number of capsules per plant

Maximum number of capsules per plant was recorded by IVTS-06-2 (23.9) and minimum by IVTS-06-12 (13.18) among lines. Among testers, it ranged from 25.4 (TMV-6) to 46 (Tilak). Two lines and one tester recorded significant values. Eighteen hybrids showed significant values for this trait, highest and lowest being 67.4 (C7) and 36.4 (C4) respectively.

4.2.2.5. Capsule length

Length of capsule varied between 1.83cm (IVTS-06-12) and 2.09cm (AVTS-06-5), 1.79cm (TMV-6) and 2.25cm (VRI-2), 1.88cm (C44) and 2.52cm (C22) among lines, testers and hybrids respectively. One line, one tester and fifteen hybrids recorded significant positive values for capsule length.

4.2.2.6. Locules per capsule

All lines, testers and hybrids recorded four locules per pod except one tester (Soma) which expressed eight locules per pod.

4.2.2.7. 1000 seed weight

Test weight ranged from 3.09g (IVTS-06-6) to 3.21g (AVTS-06-7) and from 3.14g (Tilak and Soma) to 3.19g (TMV-3) among lines and testers respectively. One line and two testers differed significantly from the mean for test weight. The range among hybrids was between 3.07g (C23) and 3.21g (C3). Of the forty eight hybrids, eighteen recorded significant values.

Table 16. Yield and yield contributing characters of parents used in line x tester mating design

Genotype	Number of days to flowering	Plant height	Number of branches per plant	Number of capsules per plant	Capsule length	Locules per capsule	1000 seed weight	Seed yield per plant	Oil content
AVTS-06-3	21.30**	34.00	5.80**	23.10**	1.85	4.00	3.15	3.37**	49.25**
AVTS-06-5	25.10	35.50	4.60	19.90	2.09**	4.00	3.13	3.08**	49.35*
AVTS-06-7	27.30	39.30	5.10	17.60	1.97	4.00	3.21**	2.70	45.70
AVTS-06-10	26.47	36.29	4.93	21.39	1.99	4.00	3.17	3.18**	47.40
IVTS-06-2	25.69	43.51**	5.02	23.90**	1.90	4.00	3.18*	3.17**	48.75
IVTS-06-6	23.14*	49.35**	4.74	20.55	1.90	4.00	3.09	2.77	48.65
IVTS-06-12	27.09	31.43	4.63	13.18	1.83	4.00	3.17	1.67	45.80
TCR -3279-A	25.70	37.40	4.30	18.10	1.99	4.00	3.13	2.58	49.50**
SE	0.73	2.02	0.16	1.21	0.03	0.00	0.01	0.19	0.55
Mean of lines	25.22	38.35	4.89	19.72	1.94	4.00	3.15	2.81	48.05
CV (%)	8.15	14.91	9.20	17.39	4.39	0.00	1.14	19.03	3.25
KYM-1	19.10**	95.10	4.90	26.20	1.98	4.00	3.15	4.78	50.05*
Soma	26.00	108.80**	10.50	40.40	2.09	8.00**	3.14	5.65**	49.30
Tilak	31.50	89.80	12.20**	46.00**	1.98	4.00	3.14	5.33	49.05
VRI-2	30.80	82.70	8.10	40.60	2.25**	4.00	3.16	5.11	50.15*
TMV-3	30.30	68.70	8.40	28.60	2.06	4.00	3.19**	3.79	49.75
TMV-6	31.70	61.60	5.60	25.40	1.79	4.00	3.15	3.44	48.50
SE	2.02	7.09	1.14	3.61	0.06	0.67	0.01	0.36	0.26
Mean of lines	28.23	84.45	8.28	34.53	2.03	4.67	3.15	4.68	49.47
CV (%)	17.49	20.57	33.69	25.60	7.50	18.84	0.58	18.88	1.29

Table 17. Yield and yield contributing characters of hybrids obtained in line x tester mating design

Genotype	DF	PH	BN	CN	CL	CL	TW	SY	OC
C1	34.90	83.90	4.50	48.00	2.01	4.00	3.16**	8.38	49.60*
C2	31.50**	90.80	5.10	39.20	1.95	4.00	3.19**	6.53	48.90
C3	33.50	137.90**	4.50	43.90	2.41**	4.00	3.21**	7.73	50.20**
C4	34.60	103.00	3.30	36.40	1.84	4.00	3.12	5.99	50.60**
C5	34.50	122.80	4.40	52.40**	1.88	4.00	3.15*	8.70	49.80**
C6	35.50	98.40	4.60	44.70	2.12	4.00	3.10	8.16	48.20
C7	30.30**	143.50**	7.00**	67.40**	1.91	4.00	3.13	11.72**	47.90
C8	31.50**	111.00	6.50**	49.50	2.31**	4.00	3.09	9.56**	49.50
C9	30.80**	97.90	5.90**	39.90	2.34**	4.00	3.13	6.93	50.60**
C10	30.80**	146.60**	5.70**	40.70	2.06	4.00	3.13	7.07	50.10**
C11	32.40**	126.00	6.00**	49.20	2.34**	4.00	3.16**	9.15**	50.20**
C12	34.20	100.50	6.00**	50.00	2.42**	4.00	3.20**	9.41**	49.50
C13	33.00	122.50	4.70	52.40**	2.10	4.00	3.20**	9.31**	49.80**
C14	35.10	104.10	3.30	45.10	2.06	4.00	3.12	7.83	48.20
C15	34.60	98.60	4.00	46.30	1.98	4.00	3.16*	8.59	49.50
C16	35.50	113.10	4.00	46.00	2.13	4.00	3.13	7.99	49.70**
C17	37.30	124.90	4.60	49.70	2.41**	4.00	3.17**	9.26**	48.70**
C18	31.60**	140.30**	4.60	52.40**	1.98	4.00	3.14	8.65	48.90
C19	35.70	147.60**	4.80	39.40	2.09	4.00	3.10	6.79	49.90**
C20	33.30	105.50	4.60	42.30	2.39**	4.00	3.19**	7.94	50.90**
C21	37.30	102.90	4.90	52.10	2.38**	4.00	3.16**	9.68**	50.20**
C22	33.80	135.10**	5.00	43.00	2.52**	4.00	3.13	7.92	49.40
C23	32.00**	109.90	4.60	47.60	2.00	4.00	3.07	7.65	49.70**
C24	36.40	134.50**	4.60	52.60**	2.08	4.00	3.13	9.16**	49.60**
C25	32.30**	112.20	4.50	51.90*	1.99	4.00	3.16**	9.12**	48.90
C26	30.50**	131.00*	4.90	50.80	2.10	4.00	3.13	8.83	48.60
C27	35.60	105.20	4.70	50.40	1.97	4.00	3.16	8.85	49.80**
C28	32.20**	147.80**	4.60	46.30	2.26**	4.00	3.10	7.98	48.60
C29	34.70	111.60	8.60**	46.20	1.94	4.00	3.13	7.61	47.90
C30	32.70*	139.90**	4.80	45.60	2.18**	4.00	3.16**	8.00	49.20
C31	34.70	146.70**	4.70	52.90**	2.16*	4.00	3.14	9.24**	50.20**
C32	36.60	106.00	4.70	40.10	2.01	4.00	3.15*	7.02	49.80**
C33	32.00**	100.90	4.90	52.10	2.11	4.00	3.16**	9.14**	48.90
C34	32.60	134.50**	5.00	48.50	1.89	4.00	3.11	7.93	49.20
C35	29.70**	112.70	5.00	58.60**	1.96	4.00	3.14	9.69**	48.70
C36	30.60	179.00**	7.30**	43.30	2.39**	4.00	3.12	7.96	48.40
C37	33.60	140.70**	4.60	54.10**	2.09	4.00	3.12	9.39**	49.20
C38	32.30**	161.10**	4.50	46.30	2.09	4.00	3.11	8.01	49.60**
C39	29.60**	108.90	4.50	49.90	2.08	4.00	3.11	8.63	50.30**
C40	33.10	144.20**	4.80	51.70*	2.07	4.00	3.15*	9.04*	48.90
C41	34.00	151.40**	4.60	60.00**	2.16**	4.00	3.13	10.43**	49.50
C42	34.50	133.90**	4.50	61.60**	2.18**	4.00	3.13	10.72**	49.10
C43	35.50	139.10**	4.70	60.40**	2.10	4.00	3.13	10.49**	48.70
C44	31.90**	151.30**	4.70	51.20	1.88	4.00	3.14	8.45	49.30
C45	35.00	112.00	4.60	61.80**	2.06	4.00	3.10	10.65**	47.70
C46	32.00**	110.80	4.60	60.70**	1.99	4.00	3.15*	10.60**	49.20
C47	30.20**	140.80**	4.60	52.00	2.08	4.00	3.13	9.04*	48.70
C48	34.40	110.80	4.60	55.00**	2.01	4.00	3.13	9.57**	49.80**
SE	0.29	3.02	0.13	0.97	0.02	0.00	0.01	0.17	0.11
Mean	33.34	123.62	4.92	49.62	2.11	4.00	3.14	8.68	49.33

4.2.2.8. Seed yield per plant

Among the lines, maximum seed yield was recorded by IVTS-06-3 (3.37g) and minimum by IVTS-06-12 (1.67g). The range for testers was from 5.65g (Soma) to 3.44g (TMV-6). Four lines and one tester recorded significant values. Twenty one hybrids reported values significantly higher than the mean for this trait. Hybrids ranged from 11.72g (C7) to 5.99g (C4).

4.2.2.9. Oil yield per plant

Oil yield per plant ranged between 45.8 per cent (IVTS-06-12) and 49.5 per cent (TCR-3279-A); 48.5 per cent (TMV-6) and 50.15 per cent (VRI-2) and 47.7 per cent (C45) and 50.9 per cent (C20) among the lines, testers and hybrids respectively. Three lines, two testers and twenty one hybrids recorded significant values.

4.2.3. Heterosis

The percentage of heterosis estimated for all characters compared to mid, better and standard parent is presented below (Figure 3 and Tables 18, 19 and 20and).

4.2.3.1.Number of days to flowering

The relative heterosis for this trait ranged from 1.04 (C39) to 72.77 (C1). None of the hybrids showed significant negative relative heterosis. The heterobeltiosis varied from -6.03 (C39) to 63.85 (C1). Significant negative heterobeltiosis was recorded in one hybrid only (C39). The standard heterosis for days to flowering was between -6.03 (C39) and 18.41 (C17 and C21). Three crosses exhibited significant negative standard heterosis.

4.2.3.2.Plant height

Almost all hybrids expressed significant positive values for all three estimates of heterosis. The ranges varied from 27.17 (C2) to 222.65 (C36) and -16.54 (C2) to

Table 18. Expression of heterosis in hybrids for days to flowering, plant height and number of branches per plant

Genotype	Number of days to flowering			Plant height			Number of branches per plant		
	di	dii	diii	di	dii	diii	di	dii	diii
C1	72.77**	63.85**	10.79**	29.98**	-11.78**	-6.57**	-15.89**	-22.41**	-63.11**
C2	33.19**	21.15**	0.00	27.17**	-16.54**	1.11	-37.42**	-51.43**	-58.20**
C3	26.89**	6.35**	6.35**	122.78**	53.56**	53.56**	-50**	-63.11**	-63.11**
C4	32.82**	12.34**	9.84**	76.52**	24.55**	14.70**	-52.52**	-59.26**	-72.95**
C5	33.72**	13.86**	9.52**	139.14**	78.75**	36.75**	-38.03**	-47.62**	-63.93**
C6	33.96**	11.99**	12.70**	105.86**	59.74**	9.58**	-19.3**	-20.69**	-62.30**
C7	37.1**	20.72**	-3.81	119.75**	50.89**	59.80**	47.37**	42.86**	-42.62**
C8	23.29**	21.15**	0.00	53.85**	2.02	23.61**	-13.91**	-38.1**	-46.72**
C9	8.83**	-2.22	-2.22	56.26**	9.02**	9.02**	-29.76**	-51.64**	-51.64**
C10	10.2**	0	-2.22	148.05**	77.27**	63.25**	-10.24*	-29.63**	-53.28**
C11	16.97**	6.93**	2.86	141.84**	83.41**	40.31**	-7.69	-28.57**	-50.82**
C12	20.42**	7.89**	8.57**	107**	63.15**	11.92**	17.65**	7.14	-50.82**
C13	42.24**	20.88**	4.76*	82.29**	28.81**	36.41**	-6	-7.84	-61.48**
C14	31.71**	28.57**	11.43**	40.58**	-4.32**	15.92**	-57.69**	-68.57**	-72.95**
C15	17.69**	9.84**	9.84**	52.75**	9.8**	9.80**	-53.76**	-67.21**	-67.21**
C16	22.2**	15.26**	12.70**	85.41**	36.76**	25.95**	-39.39**	-50.62**	-67.21**
C17	29.51**	23.1**	18.41**	131.3**	81.8**	39.09**	-31.85**	-45.24**	-62.30**
C18	7.12**	-0.32	0.32	178.1**	127.76**	56.24**	-14.02**	-17.86**	-62.30**
C19	56.7**	34.9**	13.33**	124.67**	55.21**	64.37**	-2.39	-2.74	-60.66**
C20	26.94**	25.83**	5.71*	45.43**	-3.03**	17.48**	-40.4**	-56.19**	-62.30**
C21	28.7**	18.41**	18.41**	63.22**	14.59**	14.59**	-42.81**	-59.84**	-59.84**
C22	18.05**	9.74**	7.30**	127.08**	63.36**	50.45**	-23.28**	-38.27**	-59.02**
C23	12.75**	5.61*	1.59	109.35**	59.97**	22.38**	-31.01**	-45.24**	-62.30**
C24	25.16**	14.83**	15.56**	174.8**	118.34**	49.78**	-12.67*	-17.86**	-62.30**
C25	44.23**	25.73**	2.54	61.89**	17.98**	24.94**	- 9.27	-10.36	-63.11**
C26	18.01**	17.31**	-3.17	72.02**	20.4**	45.88**	-36.86**	-53.33**	-59.84**
C27	24.5**	13.02**	13.02**	57.83**	17.15**	17.15**	-45.41**	-61.48**	-61.48**
C28	14**	4.55*	2.22	134.21**	78.72**	64.59**	-29.88**	-43.21**	-62.30**
C29	23.95**	14.52**	10.16**	98.91**	62.45**	24.28**	-32.94**	-46.43**	-63.11**
C30	13.96**	3.15	3.81	166.2**	127.11**	55.79**	-9.6	-14.29**	-60.66**
C31	64.32**	49.99**	10.16**	103.11**	54.26**	63.36**	-2.44	-4.08	-61.48**
C32	48.98**	40.77**	16.19**	34.05**	-2.57*	18.04**	-38.3**	-55.24**	-61.48**
C33	17.14**	1.59	1.59	45.02**	12.36**	12.36**	-42.13**	-59.84**	-59.84**
C34	20.89**	5.84**	3.49	103.7**	62.64**	49.78**	-22.09**	-38.27**	-59.02**
C35	11.16**	-1.98	-5.71**	90.93**	64.05**	25.50**	-23.87**	-40.48**	-59.02**
C36	11.61**	-3.47	-2.86	222.65**	190.58**	99.33**	41.27**	30.36**	-40.16**
C37	45.49**	24.03**	6.67**	122.41**	47.95**	56.68**	-3.41	-6.12	-62.30**
C38	21.68**	19.23**	2.54	129.77**	48.07**	79.40**	-40.5**	-57.14**	-63.11**
C39	1.04	-6.03**	-6.03**	79.67**	21.27**	21.27**	-46.51**	-63.11**	-63.11**
C40	14.35**	7.47**	5.08*	152.71**	74.37**	60.58**	-24.56**	-40.74**	-60.66**
C41	18.49**	12.21**	7.94**	202.42**	120.38**	68.60**	-29.37**	-45.24**	-62.30**
C42	17.37**	8.83**	9.52**	187.88**	117.37**	49.11**	-11.98*	-19.64**	-63.11**
C43	58.48**	38.13**	12.70**	109.96**	46.27**	54.90**	2.17	-4.08	-61.48**
C44	23.4**	22.69**	1.27	106.98**	39.06**	68.49**	-36.49**	-55.24**	-61.48**
C45	22.38**	11.11**	11.11**	76.1**	24.72**	24.72**	-44.24**	-62.3**	-62.30**
C46	13.27**	3.9	1.59	84.51**	33.98**	23.39**	-25.81**	-43.21**	-62.30**
C47	7.86**	-0.33	-4.13	165.41**	104.95**	56.79**	-27.56**	-45.24**	-62.30**
C48	19.86**	8.52**	9.21**	123.84**	79.87**	23.39**	-7.07	-17.86**	-62.30**

** significant at 1%
* significant at 5%

di- Relative Heterosis
dii- Heterobeltiosis
diii- Standard heterosis

190.58 (C36) and from -6.57 (C1) to 99.33 (C36) for relative heterosis, heterobeltiosis and standard heterosis respectively.

4.2.3.3 Number of branches per plant

Hybrids C7 and C36 registered significant positive values for relative heterosis and heterobeltiosis while hybrid C12 registered significant positive value for relative heterosis. The range of heterosis expressed for number of branches per plant was between -57.69(C14) and 47.37(C7) and -68.57 (C14) and 42.86 (C7) and between -72.95 (C4 and C14) and -40.16 (C36) for relative heterosis, heterobeltiosis and standard heterosis respectively. None of the hybrids showed positive values for standard heterosis.

4.2.3.4.Number of capsules per plant

Maximum relative heterosis for this trait was recorded in the hybrid C42 (219.34) while the minimum was recorded in the hybrid C4 (14.29). The percentage of heterosis over better parent varied between -13.26 (C9) and 157.25 (C7) while the standard heterosis recorded a range from -20.87(C4) to 46.52 (C7). Most of the hybrids showed significant positive values for relative heterosis, heterobeltiosis and standard heterosis.

4.2.3.5.Capsule length

The percentage of relative heterosis was low (-10.24) in C4 while it was higher (29.54) in C36. Twenty nine hybrids showed positive significant relative heterosis. Twenty two hybrids showed positive significant heterobeltiosis ranging from -18.22 (C4) to 25.79 (C36). The standard heterosis varied from -7.07 (C4) to 27.27 (C22) and thirty one hybrids registered significant positive values.

4.2.3.6.1000 seed weight

Relative heterosis ranged from -2.00 (C8) to 2.5 (C12). Five hybrids registered positive significant values for 1000 seed weight. Heterobeltiosis was the highest in

Table 19. Expression of heterosis in hybrids for number of capsules per plant, capsule length and 1000 seed weight

Genotype	Number of capsules per plant			Capsule length			1000 seed weight		
	di	dii	diii	dii	diii	diii	di	dii	diii
C1	94.73**	83.21**	4.35	4.96*	1.52	1.52	0.41	0.25	0.68
C2	23.46**	-2.97	-14.78**	-1.02	-6.70**	-1.52	1.64**	1.36**	1.48**
C3	27.06**	-4.57	-4.57	25.85**	21.72**	21.72**	1.74**	1.68**	1.79**
C4	14.29**	-10.34**	-20.87**	-10.24**	-18.22**	-7.07**	-0.92*	-0.98	-0.75
C5	102.71**	83.22**	13.91**	-3.84*	-8.74**	-5.05*	-0.44	-0.97	0.21
C6	84.33**	75.98**	-2.83	16.48**	14.59**	7.07**	-1.35**	-1.36**	-1.22*
C7	192.41**	157.25**	46.52**	-6.14**	-8.61**	-3.54	-0.03	-0.54	-0.11
C8	64.18**	22.52**	7.61*	10.53**	10.53**	16.67**	-2.00**	-2.07**	-2.49**
C9	21.09**	-13.26**	-13.26**	14.99**	11.96**	18.18**	-0.45	-0.75	-0.75
C10	34.55**	0.25	-11.52**	-5.07**	-8.44**	4.04	-0.73	-1.14*	-0.91
C11	102.89**	72.03**	6.96*	12.77**	11.96**	18.18**	0.54	-0.35	0.84
C12	120.75**	96.85**	8.70*	24.74**	15.79**	22.22**	2.50**	2.12**	2.27**
C13	139.27**	100**	13.91**	6.33**	6.06**	6.06**	0.44	-0.16	1.48**
C14	55.52**	11.63**	-1.96	1.48	-1.44	4.04	-1.5**	-2.50**	-0.91
C15	45.6**	0.65	0.65	0.25	0	0.00	-0.61	-1.41**	0.21
C16	58.08**	13.3**	0.00	0.95	-5.33**	7.58**	-1.67**	-2.34**	-0.75
C17	115.15**	73.78**	8.04*	19.6**	16.99**	21.72**	-0.25	-0.47	1.16*
C18	143.72**	106.3**	13.91**	5.32**	0.51	0.00	-1.31**	-2.03**	-0.43
C19	65.58**	50.38**	-14.35**	5.29**	5.03*	5.56*	-1.77**	-1.80**	-1.38**
C20	36.92**	4.7	-8.04*	17.16**	14.35**	20.71**	1.51**	1.11*	1.48**
C21	54.62**	13.26**	13.26**	19.9**	19.6**	20.20**	0.66	0.47	0.84
C22	38.73**	5.91	-6.52	18.87**	12**	27.27**	-0.41	-0.47	-0.11
C23	90.44**	66.43**	3.48	-1.23	-2.91	1.01	-1.83**	-2.23**	-1.06*
C24	124.83**	107.09**	14.35**	10.05**	4.52*	5.05**	-0.21	-0.32	0.05
C25	107.19**	98.09**	12.83**	2.45	0.51	0.51	-0.11	-0.31	0.52
C26	58.01**	25.74**	10.43**	5.13**	0.48	6.06**	-0.79	-1.42**	-0.59
C27	44.21**	9.57**	9.57**	1.42	-0.51	-0.51	-0.69	-1.10*	-0.27
C28	43.57**	14.04**	0.65	8.78**	0.44	14.14**	-1.44**	-1.73**	-0.91
C29	76**	61.54**	0.43	-2.14	-5.83**	-2.02	-1.75**	-1.91**	-0.75
C30	84.99**	79.53**	-0.87	18**	14.44**	10.10**	0.19	-0.16	0.68
C31	126.29**	101.91**	15.00**	11.34**	9.09**	9.09**	0.45	-0.54	-0.11
C32	31.57**	-0.74	-12.83**	0.75	-3.83	1.52	1.20**	0.64	0.21
C33	56.56**	13.26**	13.26**	8.76**	6.57**	6.57**	0.66	-0.11	-0.11
C34	58.61**	19.46**	5.43	-8.92**	-16**	-4.55*	-0.74	-1.62**	-1.38**
C35	138.43**	104.9**	27.39**	-1.01	-4.85*	-1.01	-0.10	-1.44**	-0.27
C36	88.45**	70.47**	-5.87	29.54**	25.79**	20.71**	0.59	-0.25	-0.11
C37	174.76**	106.49**	17.61**	9.57**	5.56*	5.56*	-0.74	-0.79	-0.27
C38	72.83**	14.6**	0.65	6.5**	0	5.56*	-1.11*	-1.58**	-1.06*
C39	68.64**	8.48*	8.48*	9.04**	5.05*	5.05*	-0.69	-0.95	-0.43
C40	92.26**	27.34**	12.39**	1.35	-8**	4.55*	-0.49	-0.63	-0.11
C41	187.22**	109.79**	30.43**	10.91**	4.85*	9.09**	-1.12*	-1.44**	-0.27
C42	219.34**	142.52**	33.91**	20.28**	18.8**	10.10**	-0.76	-0.95	-0.43
C43	172.69**	130.53**	31.30**	5.79**	5.53*	6.06**	-0.22	-0.70	-0.27
C44	75.04**	26.73**	11.30**	-7.84**	-10.05**	-5.05*	0.05	0	-0.43
C45	92.82**	34.35**	34.35**	3.78*	3.52	4.04	-0.33	-0.59	-0.59
C46	106.81**	49.51**	31.96**	-6.13**	-11.56**	0.51	0.51	0.13	0.37
C47	122.7**	81.82**	13.04**	2.72	0.97	5.05*	-1.08*	-1.91**	-0.75
C48	152.87**	116.54**	19.57**	6.35**	1.01	1.52	-0.24	-0.57	-0.43

** significant at 1%
* significant at 5%

di- Relative Heterosis
dii- Heterobeltiosis
diii- Standard heterosis

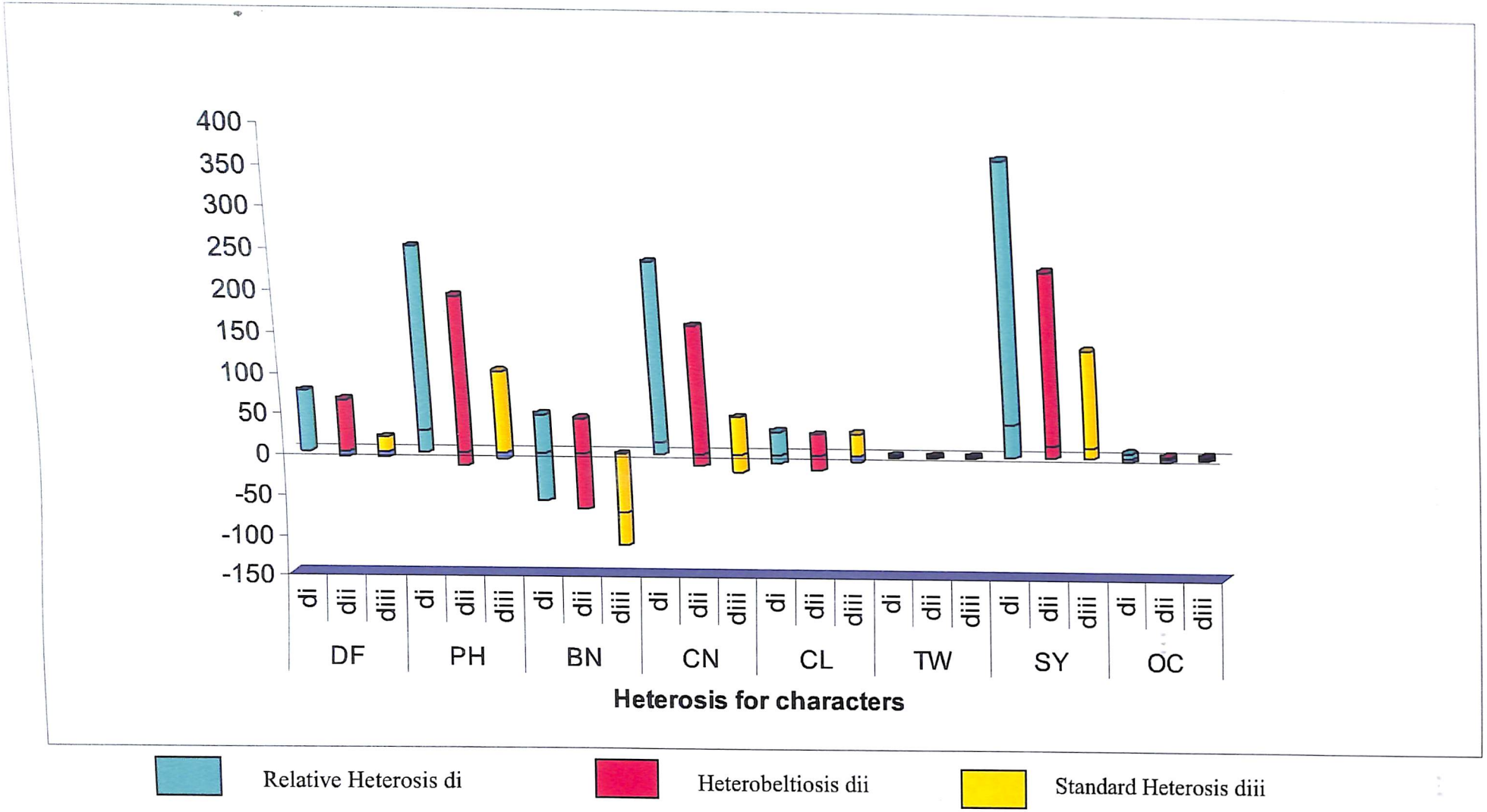
Table 20. Expression of heterosis in hybrids for seed yield per plant and oil content

Genotype	Seed Yield per plant			Oil Content		
	di	dii	diii	di	dii	diii
C1	105.72**	75.31**	57.20**	-0.1	-0.9	1.12
C2	44.71**	15.51**	22.33**	-1.07	-1.12	-0.61
C3	77.64**	44.92**	44.92**	2.03**	1.83**	2.24**
C4	41.27**	17.19**	12.30*	1.51**	0.6	2.85**
C5	143.19**	129.79**	63.10**	0.4	-0.1	1.33*
C6	139.81**	137.45**	52.98**	-0.97	-1.73*	-1.33*
C7	198.17**	144.93**	119.63**	-3.22**	-3.9**	-1.94**
C8	119.17**	69.23**	79.23**	0.76	0.71	1.33*
C9	64.82**	29.92**	29.92**	2.74**	2.43**	3.06**
C10	72.72**	38.32**	32.55**	0.8	0	2.24**
C11	166.72**	141.68**	71.54**	1.51**	1.11	2.55**
C12	189.03**	173.83**	76.42**	0.77	0.1	0.51
C13	148.83**	94.54**	74.45**	3.6**	-0.9	1.12
C14	87.66**	38.61**	46.79**	2**	-1.72*	-1.22
C15	114.07**	61.14**	61.14**	4.38**	0.82	0.82
C16	104.80**	56.41**	49.89**	3.39**	-1.2	1.02
C17	185.87**	144.72**	73.70**	2.15**	-2.01**	-0.61
C18	182.10**	151.71**	62.17**	3.18**	0.21	-0.92
C19	70.66**	42.07**	27.39**	2.21**	-0.5	1.53*
C20	79.98**	40.64**	48.95**	4.76**	2.74**	3.26**
C21	127.51**	81.57**	81.57**	4.72**	2.96**	2.96**
C22	91.04**	54.94**	48.48**	1.69**	-1.1	1.12
C23	119.64**	102.06**	43.42**	2.21**	-0.2	1.22
C24	176.88**	166.55**	71.73**	3.23**	2.06**	0.92
C25	129.29**	90.68**	70.98**	-0.81	-2.1**	-0.10
C26	100.32**	56.40**	65.64**	-0.56	-1.12	-0.61
C27	108.21**	66.01**	66.01**	1.74**	1.43*	1.43*
C28	92.67**	56.12**	49.61**	-1.42*	-2.79**	-0.61
C29	118.88**	101.14**	42.76**	-2.34**	-3.32**	-1.94**
C30	142.26**	132.94**	50.07**	1.39*	1.13	0.51
C31	144.83**	93.18**	73.23**	2.23**	0.8	2.85**
C32	66.98**	24.36**	31.70**	1.07	0.41	0.92
C33	125.58**	71.26**	71.26**	0.72	0.31	0.31
C34	101.36**	55.14**	48.67**	0.3	-1.2	1.02
C35	195.83**	155.94**	81.66**	-0.81	-1.91**	-0.51
C36	156.55**	131.49**	49.14**	0.36	0.21	-0.61
C37	190.80**	96.32**	76.04**	3.18**	-1.2	0.82
C38	118.73**	41.80**	50.17**	4.21**	0.51	1.02
C39	146.25**	61.79**	61.79**	6.59**	3.06**	3.06**
C40	166.41**	76.86**	69.48**	2.34**	-2.09**	0.10
C41	281.98**	175.49**	95.54**	3.72**	-0.4	1.02
C42	319.25**	211.80**	100.88**	4.45**	1.55*	0.41
C43	184.78**	119.32**	96.66**	-2.76**	-3.3**	-1.33*
C44	105.27**	49.58**	58.42**	0.3	0.1	1.02
C45	168.88**	99.57**	99.57**	-2.79**	-3.23**	-2.34**
C46	175.62**	107.47**	98.82**	-0.55	-1.2	1.02
C47	183.83**	138.77**	69.48**	-1.46*	-1.71*	-0.31
C48	217.75**	178.34**	79.32**	1.02	0	0.92

** significant at 1%
* significant at 5%

di- Relative Heterosis
dii- Heterobeltiosis
diii- Standard heterosis

Figure 3. Range of heterosis in sesame hybrids



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

C12 (2.12) and the lowest in C14(-2.5). Four hybrids had positive significant heterobeltiosis and five hybrids had positive significant standard heterosis. Standard heterosis varied between -2.49 (C8) and 2.27 (C12). Four hybrids registered significant positive values for all three types of heterosis.

4.2.3.7.Seed yield per plant

All the hybrids showed positive significant relative heterosis, heterobeltosis and standard heterosis for this trait. The relative heterosis ranged between 41.27 (C4) and 319.25 (C42) while heterosis over better parent varied from 15.51 (C2) to 211.80 (C42). Standard heterosis for this trait was maximum in C7 (119.63) and minimum for C4 (12.30).

4.2.3.8.Oil content

Relative heterosis for oil content ranged between C7 (-3.22) and C39 (6.59) with 26 hybrids recording positive values. Seven hybrids expressed significant positive heterobeltiosis, the range being -3.90 (C7) to 3.06 (C39). The standard heterosis varied from -2.34 (C45) to 3.26 (C20).

4.2.4. Combining ability analysis

The analysis of variance for combining ability (Table 15) was significant for number of days to flowering, plant height, number of branches per plant , number of capsules per plant, capsule length and seed yield per plant in lines. Among testers, it was significant for number of days to flowering and 1000 seed weight. The line x tester interaction was significant for all characters.

4.2.4.4.Combining ability variance

The variances due to general as well as specific combining ability for different characters are presented in Table 21. Number of days to flowering, plant height, number of capsules per plant, capsule length, 1000 seed weight, seed yield per plant and oil content showed higher SCA variance than GCA variance (Figure 4). The ratio

Table 21. Magnitude of combining ability variances and proportional contribution of lines, testers and hybrids to total variance

Character	Variance (σ^2) of GCA	Variance(σ^2) of SCA	σ^2GCA / σ^2SCA	Proportional contribution %		
				Lines (l)	Testers (t)	Hybrids (l x t)
Number of days to flowering	1.464	3.8675	0.3776	23.2551	3.0943	73.6506
Plant Height	31.4682	386.81	0.0814	19.8738	14.0939	66.0323
Number of branches per plant	0.5358	0.02978	17.9919	62.6412	4.5920	32.7669
Number of capsules per plant	2.128	28.9028	0.0736	32.8802	17.2225	49.8973
Capsule length	0.0018	0.0269	0.0669	21.3726	6.0421	72.5843
1000 seed weight	0.00000675	0.0008425	0.0080	7.5624	6.7981	85.6395
Seed yield per plant	0.0673	0.9651	0.0697	30.5626	16.3289	53.1084
Oil Content	0.1441	0.3643	0.3956	24.7712	10.9901	64.2387

of GCA to SCA variance was lesser than unity for all characters studied except number of branches per plant.

4.2.4.5.Proportional contribution of parents and hybrids to total variance

The proportional contribution of lines, testers and line x tester interaction to the total variance is presented in Table 21 and Figure 5. The proportional contribution of lines was high for number of branches per plant. All other characters, namely, number of days to flowering, plant height, number of capsules per plant, capsule length, 1000 seed weight, seed yield per plant and oil content showed higher contribution due to line x tester interaction.

4.2.5 Combining ability effects

The general combining ability effects (*gca*) of lines and testers and specific combining ability effects (*sca*) of hybrids for all characters studied are given in Table 22, 23 and 24 respectively.

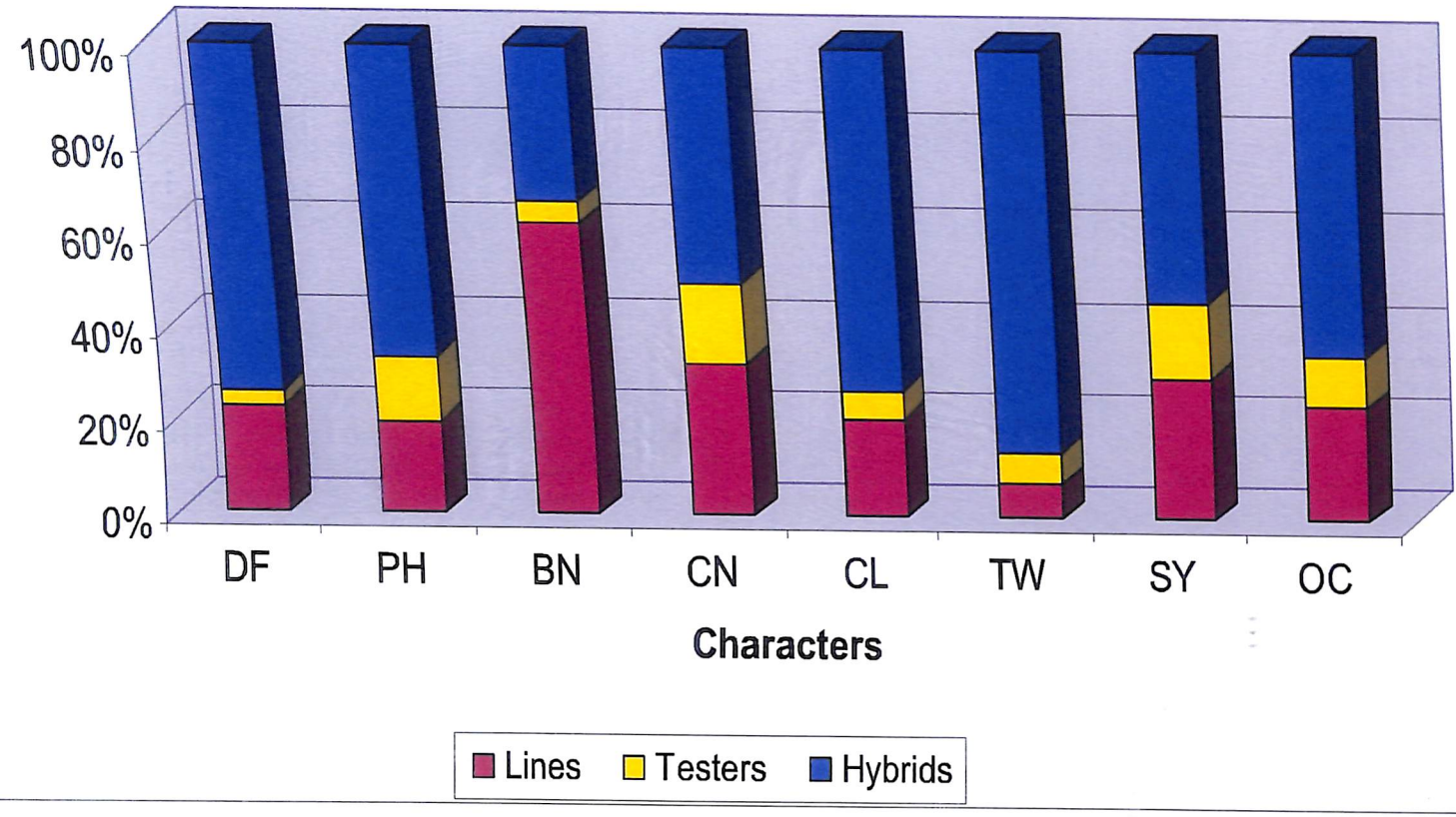
4.2.5.1. Number of days to flowering

The *gca* effects of lines for days to flowering ranged from -1.675 (AVTS-06-5) to 1.408 (AVTS -06-10) while for testers it varied between -0.504 (Soma) and 0.408(KYM-1). Among parents, three lines (AVTS-06-5, IVTS-06-6, IVTS-06-2) and three testers (Soma, VRI-2 and TMV-3) showed significant negative *gca* effects. The range of *sca* effects among hybrids was from -3.458 (C39) to 4.404 (C32).

4.2.5.2.Plant height

The *gca* effects for plant height ranged from -17.487 (AVTS-06-3) to 16.413 (IVTS-06-12) among lines and between -15.583 (Tilak) and 6.042 (TMV-6) among testers. Five lines and three testers showed significant positive *gca* for this trait. Among the hybrids, twenty one had significant positive *sca* for plant height. The range of *sca* effects varied from 47.35 (C3) to -28.138 (C1).

Figure 5. Proportional contribution of lines, testers and hybrids in sesame



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

Table 22. General combining ability effects of lines for yield and yield contributing characters

Character / Parents	Number of days to Flowering	Plant Height	Number of branches per plant	Number of capsules per plant	Capsule Length	1000 seed weight	Seed yield per plant	Oil content
AVTS -06-3	0.742**	-17.487**	-0.435**	-5.517**	-0.079**	0.016**	-1.096**	0.125
AVTS-06-5	-1.675**	-2.704**	1.348**	-0.167	0.116**	-0.002	0.295**	0.300**
AVTS- 06-7	1.175**	-6.371**	-0.635**	-0.967*	-0.004	0.008	-0.071	-0.317**
AVTS- 06.10	1.408**	1.038**	-0.085	-3.450**	0.130**	0.003	-0.485**	0.567**
IVTS -06-2	-0.342	0.996**	-0.169	-1.083*	-0.040**	-0.003	-0.276**	-0.442**
IVTS-06-6	-0.642**	6.346**	0.431**	-0.367	-0.027*	-0.005	-0.182*	-0.008
IVTS-06-12	-0.492*	16.413**	-0.252**	4.317**	-0.002	-0.009	0.692**	0.192*
TCR -3279-A	-0.175	3.846**	-0.202*	7.233**	-0.094**	-0.007	1.122**	-0.417**
SE (LINE)	0.1896	0.3288	0.0859	0.4398	0.0121	0.0046	0.0815	0.0915

4.2.5.3.Number of branches per plant

The *gca* of lines varied between 1.348 (AVTS-06-5) and -0.635 (AVTS-07-7) while for testers it ranged from 0.29 (TMV-6) to -0.21 (VRI-2). Two lines and two testers showed significant positive *gca* for this trait. The *sca* effects of the hybrids exhibited a variation ranging from1.744 (C36) to -0.890 (C4). Five hybrids showed significant positive *sca* effects for this trait.

4.2.5.4. Number of capsules per plant

Two lines and three testers showed positive significant *gca* effects for number of capsules per plant. The range varied from -5.517 (AVTS-06-3) to 7.233 (TCR-3279-A) among lines and from -4.054 (Soma) to 3.696 (KYM-1) among testers. The *sca* effects among hybrids ranged between -10.463 (C19) and 14.254 (C7). Thirteen hybrids exhibited positive significant *sca* effects.

4.2.5.6. Capsule length

The *gca* effects for capsule length ranged from -0.094 (TCR-3279-A) to 0.130 (AVTS-06-10) among lines and from -0.058 (KYM-1) to 0.056 (TMV-6) among testers. Two lines (AVTS-06-7 and AVTS-06-10) and two testers registered significant positive *gca* effects. Thirteen hybrids exhibited significant positive *sca* effects for capsule length ranging between -0.226 (C23) and 0.323 (C3).

4.2.5.7. 1000 seed weight

The *gca* effects for lines ranged from -0.007 (TCR-3279-A) to 0.016 (AVTS-06-3) and for testers from -0.014 (VRI-2) to 0.007 (Tilak). Line AVTS-06-3 and testers KYM-1, Tilak and TMV-6 recorded positive significant values for *gca* effects for test weight. The *sca* effects ranged from -0.056 (C6) to 0.053 (C20) for 1000 seed weight with ten hybrids registering positive significant *sca* effects.

Table 23. General combining ability effects of testers for yield and yield contributing characters

Character / Parents	Number of days to Flowering	Plant Height	Number of branches per plant	Number of capsules per plant	Capsule Length	1000 seed weight	Seed yield per plant	Oil content
KYM -1	0.408**	5.904**	0.102*	3.696**	-0.058**	0.006*	0.628**	-0.083
Soma	-0.504**	-3.521**	-0.048	-4.054**	-0.015*	-0.005*	0.655**	-0.021
Tilak	0.208*	-15.583**	-0.085	-0.067	0.053**	0.007*	0.098*	0.373**
VRI- 2	-0.267**	5.767**	-0.210**	-2.954**	-0.019**	-0.014**	-0.611**	0.204**
TMV-3	-0.242*	1.392**	-0.048	2.346**	-0.017**	0.001	0.265**	-0.165**
TMV- 6	0.396**	6.042**	.290**	1.033**	0.056**	0.006*	0.275**	-0.308**
SE (TESTER)	0.1642	0.2795	0.0744	0.3809	0.0105	0.0040	0.0706	0.0793

4.2.5.8. Seed yield per plant

Among lines the *gca* effects ranged from 1.122 (TCR-3279-A) to -1.096 (AVTS-06-3) with three lines showing positive significant *gca* effects. Five testers registered positive significant *gca* effects ranging from 0.655 (Soma) to -0.611 (VRI-2). The *sca* effects of hybrids ranged from 2.115 (C7) to -2.025 (C19) with twelve hybrids recording positive significant *sca* effects.

4.2.5.9. Oil content

The *gca* effects of parents ranged between -0.442 (IVTS-06-2) and 0.567 (AVTS-06-10) among lines and from -0.308 (TMV-6) to 0.373 (Tilak) among testers. Three lines and two testers recorded significant positive *gca* effects for oil content. Eleven hybrids registered positive significant *sca* effects ranging between -1.5 (C7) and 1.158 (C31).

4.3. Interspecific hybridisation

S.malabaricum is a wild variety under *Sesamum* species and its morphological characteristics were studied in comparison with the cultivated *S.indicum*. Crossing of *S.malabaricum* with *S.indicum* to obtain male sterility in the latter was tried and the results are presented below.

4.3.1.Crossing of *S.malabaricum* with *S.indicum*

Crossing was attempted with 14 released varieties from Kerala Agricultural University and Tamil Nadu Agricultural University. Seed set was noticed in the crosses (Table 25) with CO-1 and KYM-1 with accession 2 as female parent and with KYM-1, Soma and Surya with accession 3 as female parent. In the rest of the cases, though visible capsule set was noticed four days after pollination, the immature capsules shed from the plant within two days. The fallen capsules were examined but no visible seed set was noticed and hence were discarded.

Table 24. Specific combining ability effects for yield and yield contributing characters

Trait / Hybrid	Number of days to flowering	Plant height	Number of branches per plant	Number of capsules per plant	Capsule length	1000 seed weight	Seed yield per plant	Oil content
C1	0.408	-28.138**	-0.002	0.204	0.033	0.004	0.176	0.175
C2	-2.079**	-11.813**	0.748**	-0.846	-0.070*	0.040**	-0.402*	-0.737**
C3	-0.792	47.35**	0.185	-0.133	0.323**	0.038**	0.050	0.269
C4	0.783	-8.9**	-0.890**	-4.748**	-0.176**	-0.021	-0.981**	0.737**
C5	0.658	15.275**	0.048	5.954**	-0.138**	-0.006	0.853**	0.356
C6	1.021*	-13.775**	-0.090	-0.433	0.029	-0.056**	0.303	-0.800**
C7	-1.775**	16.679**	0.715**	14.254**	-0.262**	-0.004	2.115**	-1.500**
C8	0.337	-6.396**	0.365	4.104**	0.095**	-0.067**	1.242**	0.038
C9	-1.075*	-7.433**	-0.198	-9.483**	0.057	-0.024*	-2.141	0.494*
C10	-0.600	19.917**	-0.273	-5.796**	-0.151**	-0.009	-1.291**	0.262
C11	0.975*	3.692**	-0.135	-2.596*	0.127**	0.032**	-0.088	0.781**
C12	2.138**	-26.458**	-0.473*	-0.483	0.134**	0.072**	0.162	-0.075
C13	-1.925**	-0.654	0.398	0.054	0.047	0.036**	0.071	0.617**
C14	1.087*	-9.629**	-0.852**	0.504	-0.035	-0.027*	-0.122	-0.596*
C15	-0.125	-3.067**	-0.115	-2.283*	-0.182**	-0.004	-0.110	-0.010
C16	1.250**	-9.917**	0.010	0.304	0.039	-0.014	-0.001	0.279
C17	3.025**	6.258**	0.448*	-1.296	0.318**	0.032**	0.393	-0.152
C18	-3.312**	17.008**	0.110	2.717*	-0.186**	-0.023*	-0.232	-0.158
C19	0.542	19.112**	-0.052	-10.463**	-0.096**	-0.049**	-2.025**	-0.067
C20	-0.946*	-13.562**	-0.102	0.187	0.162**	0.053**	0.407*	0.721**
C21	2.342**	-4.100**	0.235	6.000**	0.084**	0.021	1.394**	0.177
C22	-0.683	6.75**	0.460*	-0.212	0.295**	0.011	0.339	-0.554*
C23	-2.508**	-14.075**	-0.102	-0.912	-0.226**	-0.033**	-0.808**	-0.135
C24	1.254**	5.875**	-0.440*	5.400**	-0.22**	-0.003	0.692	-0.142
C25	-1.108*	-18.321**	-0.269	-0.329	-0.026	0.017	0.091	0.142
C26	-1.996**	9.904**	0.281	6.321**	0.042	-0.007	1.088**	-0.171
C27	2.392**	-3.833**	0.119	1.933	-0.156**	-0.008	0.355	0.435
C28	-0.533	17.417**	0.144	0.721	0.205**	-0.008	0.189	-0.396
C29	1.942**	-14.408**	-0.119	-4.679**	-0.116**	-0.017	-1.052**	-0.677**
C30	-0.696	9.242**	-0.156	-3.967**	0.050	0.023*	-0.672**	0.667**
C31	1.592**	10.829**	-0.669**	-0.046	0.131**	0.00	0.117	1.158**
C32	4.404**	-20.446**	-0.519*	-5.096**	-0.062*	0.021	-0.816**	0.146
C33	-0.908	-13.483**	-0.281	2.917**	-0.029	-0.001	0.541**	-0.548*
C34	0.167	-1.233	-0.056	2.204*	-0.178**	-0.020	0.045	-0.029
C35	-2.758**	-18.658**	-0.219	7.004**	-0.109**	0.00	0.929**	-0.410
C36	-2.496**	42.992**	1.744**	-6.983**	0.247**	0.00	-0.816**	-.317
C37	0.342	-5.237**	-0.085	-3.529**	0.036	-0.001	-0.607**	-0.042
C38	-0.046	24.588**	-0.035	-3.579**	-0.007	-0.015	-0.704**	-0.004
C39	-3.458**	-15.550**	0.002	-3.967**	-0.084**	-0.007	-0.837**	0.602**
C40	0.517	-1.600*	0.427*	0.721	-0.023	0.024*	0.282	-0.679**
C41	1.392**	9.975**	0.065	3.721**	0.066*	0.004	0.796**	0.140
C42	1.254**	-12.175**	-0.373	6.633**	0.012	-0.006	1.071**	-0.017
C43	1.925**	5.729**	-0.035	-0.146	0.137**	-0.004	0.063	0.483*
C44	-0.762	27.354**	0.115	-1.596	-0.125**	0.003	-0.694**	0.604**
C45	1.625**	0.117	0.052	5.017**	-0.013	-0.014	0.748**	-1.440**
C46	-0.900	-22.433**	0.177	6.804**	-0.011	0.036**	1.417**	0.379
C47	-2.725**	11.942**	0.015	-7.196**	0.077*	-0.013	-1.024**	0.098
C48	0.837	-22.708**	-0.323	-2.883*	-0.066*	-0.008	-0.509*	0.842**
SE	0.4643	0.7907	0.2104	1.0773	0.0297	0.0112	0.1997	0.2242

4.3.2.Raising of F_1 seeds

Crossed seeds of the interspecific hybrids were sown in earthern pots filled with potting mixture and irrigated regularly. As the seeds failed to germinate even after 4 weeks, seed treatment practices like GA_3 treatment, hot water treatment and mechanical scarification were carried out.

To further understand the reasons behind germination failure, the mature seeds were dissected and observed under stereomicroscope. Studies on the longitudinal section of mature seed revealed the presence of a rudimentary structure which could not be retrieved. Seeds were retrieved from capsules 45 days after pollination and taken up for culturing under *in vitro* conditions in MS medium with 0.1 per cent benzyl amino purine (BAP).

F_1 seeds of *S. malabaricum* x Surya and *S.malabaricum* x KYM-1 responded to tissue culture techniques (Table 26 and Plate 8). Seeds germinated with shoot position emerging within two weeks of culturing. In some cultures callusing was noticed. When the shoot was 1-1.5cm long, root was noticed in the same tube. The two month old cultured plants are now kept for hardening.

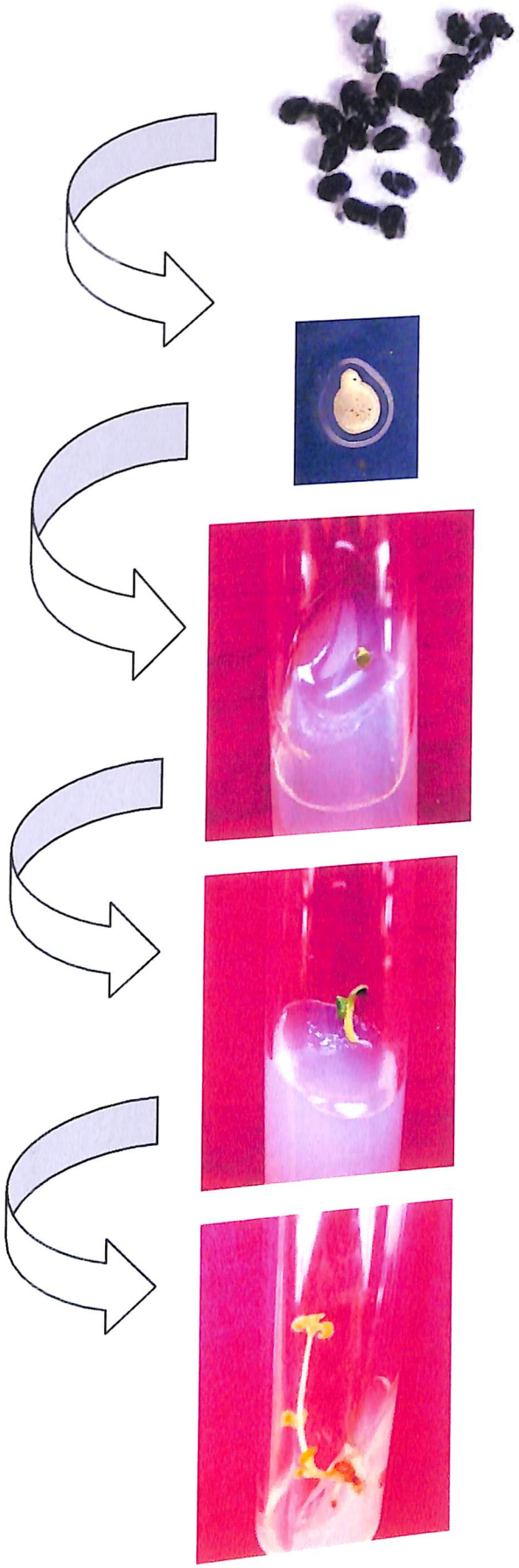
Table 25. Interspecific hybrid combinations studied (Experiment III)

Pollen parent	Seed set	
	Accession 2	Accession 3
KYM-1	Present	Present
Surya	Absent	Present
Soma	Absent	Present
Tilak	Absent	Absent
Tilarani	Absent	Absent
Tilatara	Absent	Absent
CO-1	Present	Absent
SVPR-1	Absent	Absent
VRI-1	Absent	Absent
VRI-2	Absent	Absent
TMV-3	Absent	Absent
TMV-4	Absent	Absent
TMV-5	Absent	Absent
TMV-6	Absent	Absent

Table 26. *In vitro* culture of interspecific hybrids

	No. of inoculates	No. contaminated	No. of callus initiation	No. of shoot initiations
S. malabaricum x KYM-1	3	-	1	1
S. malabaricum x Surya	7	1	4	1
S. malabaricum x Soma	5	-	-	-

Plate 8. *In vitro* culture of interspecific hybrid



Seeds

Explant- Embryo

Two weeks after inoculation

One month after inoculation

Two months after inoculation

Discussion

5. DISCUSSION

Yield components play an important role in crop breeding programme. Plant breeders always aim to improve productivity by seeking selection for appropriate yield components. Selection plays a vital role in plant breeding and has played an important role in the history of mankind. Evolution and domestication created improved plant species that are important for human survival. Ever since the beginning of agriculture consciously or unconsciously man has created genotypes which are more efficient in providing food, fibre and fuel. This is a continuous never ending process.

In the context of agricultural production, varietal breeding programmes are important factors of technological progress. Providing a better variety than the existing one has always been the aim of plant breeders. The basic theme of plant breeding is the management of genetic variability to develop superior variety, combining productivity with quality, resistance to biotic and abiotic stresses both under favourable and unfavourable situation. However, superiority of improved type is caused by certain specific gene combinations and how rapidly these specific gene combinations can be marshalled in a single plant or variety depends upon the system through which the genes in the material available are mobilized. The plants of the world have a lot of wonderful genes. The plant breeder's job is just to find out and combine them.

Sesame is an important self pollinated annual oilseed crop of the warm tropics. Sesame seed yields are often low. Higher seed yield is a major breeding goal and several workers have stressed the importance and genetic control of different yield components namely: number of branches per plant, number of capsules per plant, capsule length, seed weight and harvest index (Ashri, 1998). Although India ranks first in area and production of sesame globally, productivity of the crop is very low here. One of the methods to break the yield ceiling is heterosis breeding. More than fifty per cent standard heterosis has been reported by several workers for seed yield in sesame. Hand emasculation and pollination which requires skilled labour is practised to develop hybrids which increases the cost of hybrid seed production. Presence of a genetic tool of emasculation like male sterility will reduce the hybrid seed cost. The

evidence for cytoplasmic male sterility was first reported by Prabakaran *et al.* (1995) when the wild species *S.malabaricum* was crossed with cultivated *S.indicum*. Thus wide hybridization will result in development of cytoplasmic genic male sterile lines which are useful for exploitation of hybrid vigour for quantum jump in yield.

Any successful hybridization programme for varietal improvement depends mainly on the selection of parents having genetic variability so that the desirable character combinations may be selected for higher grain yield. Thus genetic diversity in breeding for higher productivity has obvious importance. For improvement of any plant character through hybridization it is necessary to understand the nature of gene action and genetic architecture of the donor parents for that character. The present investigations were carried out with a view to assess the variability, to estimate the combining ability of selected lines and aimed at exploitation of male sterility in sesame.

5.1. VARIABILITY STUDIES

Range is the difference between high and low values of observation in a population. It is the simplest but a crude measure of variability. It is commonly used as a measure of variability in plant breeding populations and its computation is very easy. In the present study, plant height, number of branches per plant, number of capsules per plant and seed yield per plant showed a high range of variability which are in accordance with the results of Banerjee and Kole (2006), Parameshwarappa *et al.* (2009) and Mandal et al. (2010 b).

Enhancing variability is one of the initial steps in a breeding programme. This becomes essential in self pollinated crops like sesame where the variability is low. Variability estimates like PCV, GCV, heritability and genetic advance helps in selecting and assessing the existing variability. Genetic coefficient of variation would be useful for assessing the variability, since it depends upon the heritable portions of variability (Allard, 1960).

The estimates of phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV). High GCV and PCV were observed for

plant height, number of branches per plant, number of capsules per plant and seed yield per plant. These results are in confirmation with that of Banerjee and Kole (2006); Parameshwarappa *et al.* (2009) and Mandal *et al.*, (2010b) for the traits plant height, number of branches per plant and number of capsules per plant. Begum and Dasgupta (2003) and Solanki and Gupta (2004) also reported high GCV and PCV for seed yield per plant. When coefficient of variation is higher, the population has greater variation and selection can be practiced.

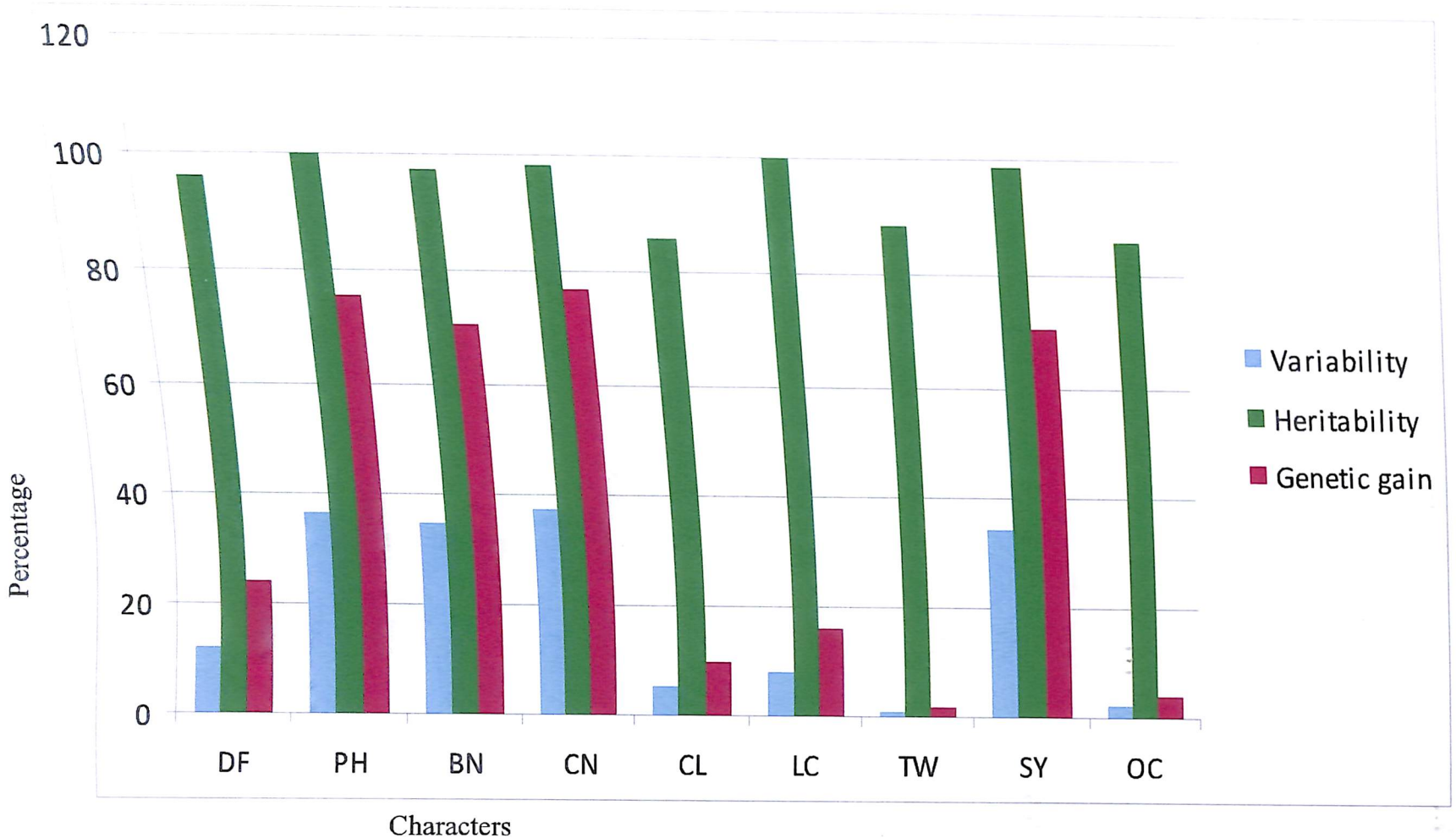
Genetic coefficient of variability along with heritability gives an idea of expected genetic gain from selection (Burton, 1952). In the present study high heritability was observed for all the nine characters studied (Figure 6). High heritability in broad sense does not always mean better response to selection since it is inclusive of non-additive genetic variance. The estimation of genetic advance furnishes the nature of gene effects from which response to selection can be predicted (Panse, 1942).

High heritability with high genetic advance as per cent of mean was recorded for number of days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant. These results are in confirmation with the findings of Pathak and Dixit (1992) and Biswas and Akbar (1995) for number of days to flowering; Mothilal (2006), Prasad *et al* (2007) and Parameshwarappa *et al* (2009) for plant height, number of branches per plant and number of capsules per plant and Babu *et al* (2005) and Parameshwarappa *et al*, (2009) for seed yield per plant.

High heritability along with moderate genetic advance as per cent of mean was found for locules per capsule which was consistent with the findings of Shadakshari *et al* (1995). Chopra (1984) opined that resorting to straight selection for characters which have high heritability along with high to moderate genetic advance will be rewarding.

High heritability coupled with low genetic advance as per cent of mean was registered for capsule length, 1000 seed weight and oil content. Similar findings were reported by Solanki and Paliwal (1981) for capsule length and Shadakshari *et al*

Figure 6. Genetic parameters for yield and yield contributing characters in base collection



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule
LC- Number of locules per capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

(1995) for capsule length and oil content suggesting the preponderance of non additive gene action in the inheritance of those traits. High heritability with moderate genetic advance as per cent of mean was reported for 1000 seed weight by Ganesan (2005).

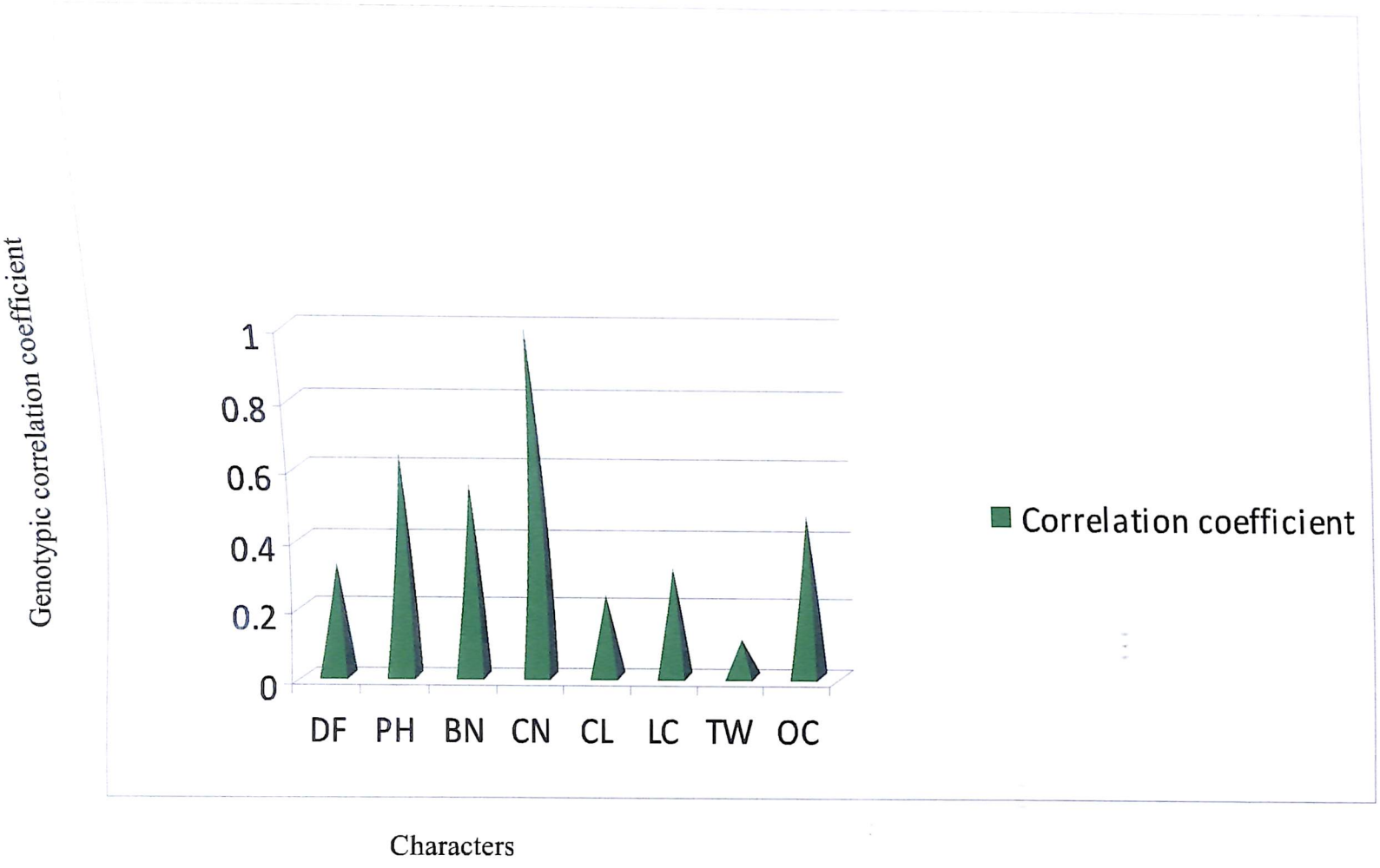
5.1. 1. Comparison of *S.indicum* and *S.malabaricum*

S.indicum plants are less pubescent compared to *S.malabaricum* plants and the characteristic feature of *S.malabaricum* flowers is the purple lipped corolla. Capsules of *S.malabaricum* are densely hairy and have a clefted beak while those of *S.indicum* are sparsely hairy with a pointed beak. Seeds of *S.malabaricum* have a rough and reticulate testa whereas the seed coat of *S.indicum* seeds is smooth. These characteristics are in accordance with the observations of Kulkarni (2006).

5.2. Correlation and path analysis

Correlation provides information on the nature and extent of relationship between characters. When the breeder applies selection pressure for a trait, the population being improved for that trait is also improved in respect of all other characters associated with it. Thus correlation facilitates simultaneous improvement of two or more characters. Knowledge of the relationship among yield components is essential for the formulation of breeding programmes aimed at achieving the desired combination of various components of yield. The estimates of the genotypic and phenotypic correlation coefficients between different characters indicate the extent and direction of association. The phenotypic correlation provides a reliable measure of genetic association between the characters and helps to differentiate the vital associations useful in breeding from the non-vital ones (Falconer, 1967). In general, genotypic correlation coefficients were higher than phenotypic correlation coefficients for all characters studied. Low phenotypic correlations might be due to the masking or modifying effect of the environment in genetic association between characters (Johnson *et al.*, 1955).

Figure 7. Genotypic correlation of yield contributing characters with seed yield per plant in sesame



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule
LC- Number of locules per capsule

TW – 1000 seed weight
OC- Oil content

Number of days to flowering, plant height, number of branches per plant, number of capsules per plant, locules per capsule and oil content showed positive and significant association with seed yield per plant (Figure 7). Similar results were recorded by Manjunatha *et al*, (2008) and Alake *et al* (2010) for number of days to flowering; Sumathi *et al* (2009), Das *et al* (2010) and Sarwar and Hussain (2010) for plant height; Sumathi *et al* (2009), Alake *et al* (2010), Das *et al* (2010) and Sarwar and Hussain (2010) for number of capsules per plant and Vanishri *et al* (1994) and Thiyagarajan and Ramanathan (1995) for oil content. It is thus evident that the above characters would serve as useful indices for selection for improvement in grain yield.

It is clear that selection for any one of the above characters would automatically lead to selection for the associated trait also. The genotypic and phenotypic correlation coefficients do not vary much indicating less environmental influence. Hence selection at phenotypic level will lead to genotypic selection as well.

As yield is influenced by many factors, selection based on simple correlation without taking into consideration the interaction between the different component characters can be misleading. Therefore, the genotypic correlations were partitioned into direct and indirect effects as genotypic correlations will give the true position. Path analysis revealed that number of capsules per plant registered maximum positive direct effect on seed yield per plant followed by capsule length, plant height and 1000 seed weight (Figure 8). On the contrary, the direct effects of number of branches per plant, number of days to flowering and oil content were negative. Similar results have been reported by several workers on sesame including Manjunatha *et al.* (2008), Suvarna *et al.* (2008), Parameshwarappa *et al.* (2009), Das *et al.* (2010) and Sarwar and Hussain (2010) for the trait number of capsules per plant, Manjunatha *et al.* (2008), Suvarna *et al* (2008), Gangarde *et al.* (2009) and Parameshwarappa *et al.* (2009) for capsule length, Manjunatha *et al.* (2008), Suvarna *et al.* (2008), Parameshwarappa *et al.* (2009) for plant height; Mothilal (2005) and Rao (2007) for 1000 seed weight; Reddy *et al.* (1984) and Patil and Sheriff (1996) for number of branches per plant and Raghuvanshi (2007), Rao (2007) and Manjunatha *et al.* (2008) for number of days to flowering.

The indirect effects of plant height through number of capsules per plant and number of branches per plant through number of capsules per plant on seed yield per plant were high. Similar reports have been given by Sengupta and Datta (2004) and Parimala and Mathur (2006). The combined results of correlation and path analysis indicated that maximum weightage may be given for plant height and number of capsules per plant for improvement of seed yield in plant (Figure 7).

5.3.GENETIC DIVERGENCE

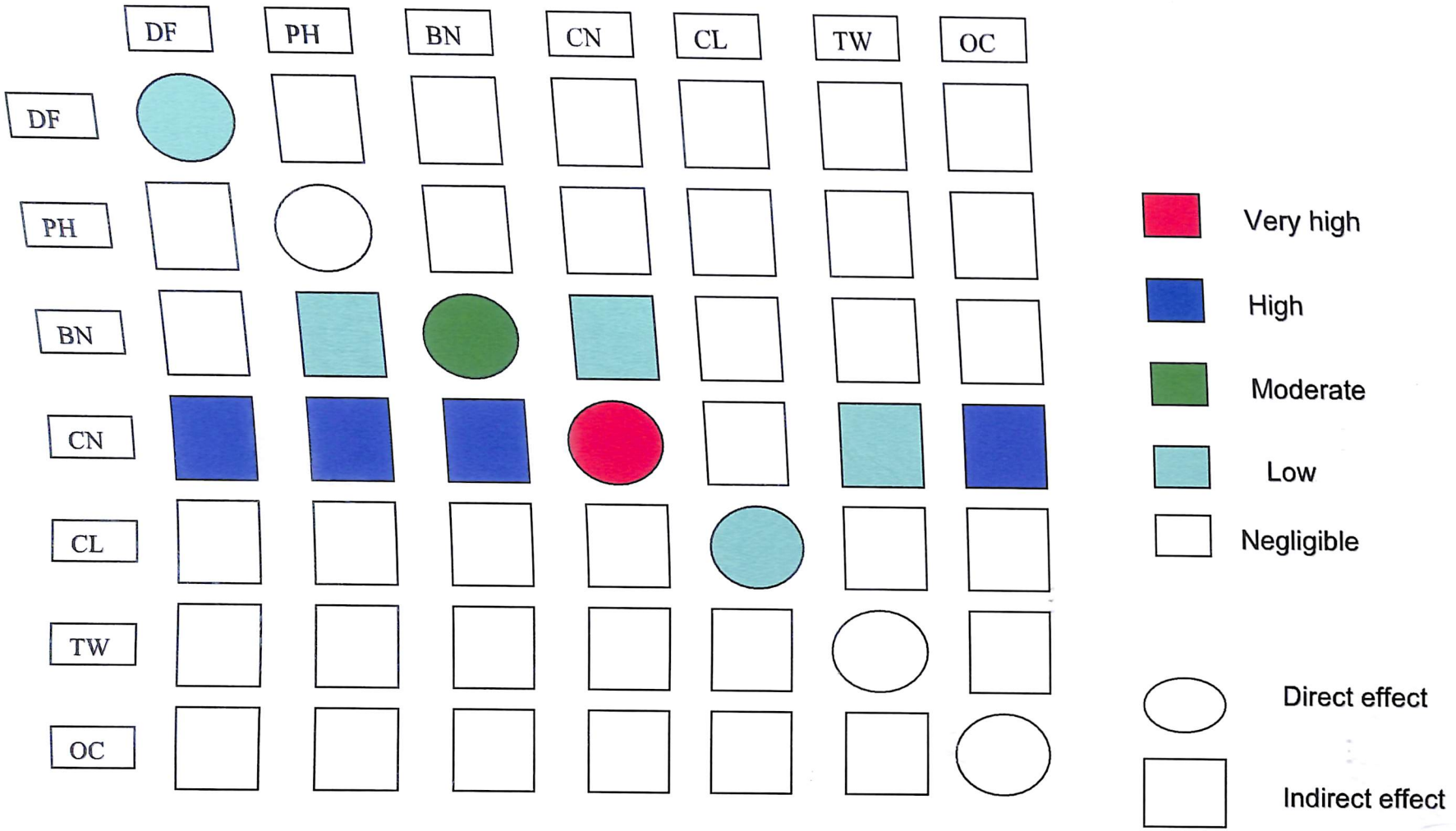
Genetic improvement mainly depends upon the amount of genetic variability present in the population. The more diverse the parents, the greater are the chances of obtaining higher amount of heterotic expression in F_1 and broad spectrum of variability in segregating populations.

5.3.1. Clustering

D^2 statistics employing a combined classificatory approach with respect to nine important yield characters revealed that the 40 genotypes studied could be grouped into clusters (Figure 9).

Murthy and Kulkarni (1996) explained that wide adaptability of divergent types could be possible due to reasons such as heterogeneity, genetic architecture of the populations, past history of selection, developmental factors and degree of general combining ability. Hence for pedigree breeding, intercrossing these groups of parents from the same geographical region which were divergent among themselves are more desirable than choosing the parents from other regions (Kumar and Subramanian, 1992). In the present study, varieties developed at the same location were found to be grouped in different clusters indicating more divergence. For example, sesame varieties from Kerala Agricultural University were found to be grouped in Clusters II, IV and VI. This confirms to the earlier findings of Raut *et al* (1991) that genetic drift and human selection could cause greater diversity than geographical spacing. Genetic diversity must form the sound base for the selection of parents for hybridization. Similar results were also reported by Thangavelu and Rajasekharan (1983), Anitha and Dorairaj (1990) and Ganesh and Thangavelu(1995).

Figure 8. Path diagram of sesame



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

Intra and inter cluster distances represent the index of genetic diversity among clusters. The magnitude of heterosis was largely dependent on the degree of genetic diversity of parental lines. Greater distance between clusters will result in wider genetic diversity among genotypes. Clusters separated by largest statistical distance (D^2) show maximum divergence such as Clusters III and IV in the present investigation.

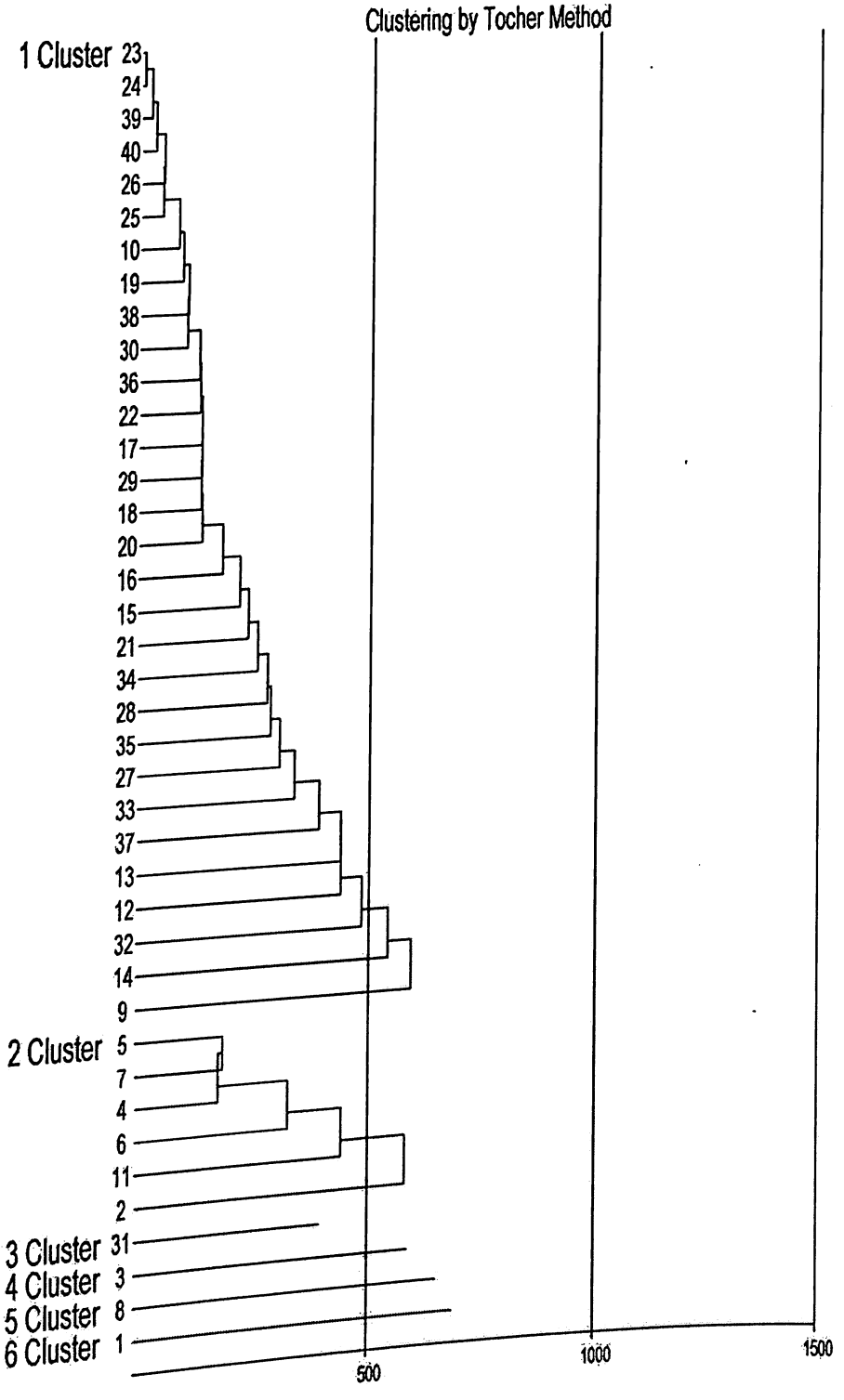
Angadi (1976) reported that varieties in a cluster with high order of divergence among themselves would be the best breeding materials for achieving maximum genetic advance with regard to yield. Selection within a cluster might also be exercised based on the highest mean performance of the varieties for desirable traits such as seed yield. Hence all the lines were selected from Cluster I in the present study.

It has been well established by several workers like Ramanujam *et al.* (1974), Reddy (1986), Singh *et al.* (1987), De *et al.* (1988) and Roy and Panwar (1993) that the intercluster distance in D^2 analysis plays a key role in the selection of varieties, as parents for hybridization. Varieties belonging to the clusters with maximum intercluster distances were obviously more divergent genetically.

5.4. Intervarietal hybridisation

Hybridization is the most potent technique for breaking the yield ceiling and evolving varieties having high yield potential. Success in any breeding programme involving hybridization depends on the choice of parents. Selection of parents based on their performance *per se* alone, may not always be a sound procedure, since phenotypically superior genotypes may yield inferior hybrids and/or poor recombinants in the segregating generations. It is, therefore, essential that parents should be selected on the basis of their genetic worth. High *gca* effects of the parents are mainly due to additive and additive x additive type of gene action (Griffing, 1956), which is fixable in the segregating generations. Thus to enable isolation of superior segregates in the F_2 and subsequent generations, selection of parents for hybridization should be made on the basis of their *gca* effects.

Figure 9 Cluster diagram of sesame



For initiating hybridization programme in sesame, parents could be selected based on their desirable performance *per se*. However, it would be desirable to select parents based on performance *per se* as well as *gca* effects to initiate any breeding programme.

Diversity in parental *gca* effects played an important role for the production of hybrids with significant positive *sca* effects in sesame (Banerjee and Kole, 2009). Reddy and Arunachalam (1981) reported that diversity in parental *gca* effects was necessary for the development of specific combinations with high value. This kind of superiority of high x low crosses might involve dominant x recessive type of gene interaction and therefore might tend to be non fixable (Singh and Gupta, 1969). Crosses involving at least one parent with high *gca* effect could produce good segregates, only if, the additive genetic system present in the good general combiner and the complementary epistatic effects in the other, act in the same direction to maximize the desirable plant attribute (Singh and Choudhary, 1995).

Superiority of a hybrid involving parents with high *gca* effects for a trait might be due to additive and additive x additive type of interaction which is fixable (Singh *et al.*,1971). Arunachalam (1977) reported that pure additive action at individual loci coupled with favourable additive x additive interaction could produce heterotic combinations. The realized heterosis was related to *gca* of parents and *sca* of crosses (Reddy and Arunachalam, 1981). If so, then it would be possible to recover homozygous lines as good as or close to the heterotic hybrids from a cross involving parents with good *gca* and F_1 hybrids with satisfactory *sca* (Banerjee and Kole, 2009).

A knowledge of the nature of combining ability effects and their resulting variances has a paramount significance in deciding the selection procedure for exploiting either heterosis or obtaining new recombinants of desirable types in sesame. It has been commonly experienced that lines with adequate *gca* effects coupled with reasonably high means tend to result in superior hybrids (Solanki and Gupta, 2003).

The association between *gca* effects and mean performance of the parents suggested that the performance *per se* could be a good indicator of its ability to transmit the desirable attributes to its progenies.

5. 4.1. Evaluation of parents

Line x tester mating design with eight lines and six testers proposed by Kempthorne (1957) was used in the present study to evaluate parents and hybrids.

Best hybrids and good segregants can be obtained from parents with superior *per se* performance. The potential of the variety or commercial hybrid could be adjudged by comparing mean performance and combining ability effects of parents. Gilbert (1958) suggested that parents with good *per se* performance would result in good hybrids. The parents with high mean performance would be useful in producing better offspring in any breeding programme (Singh *et al*, 1993).

5.4.2.*Per se* performance of parents

In the present study, a score chart was prepared (Table 27) based on *per se* performance of parents. Assuming 'm' as the *per se* of parents for a character and 's' standard differences of *per se* based on the analysis of variance, three classes viz, i) varietal *per se* falling above m & s, ii) varietal *per se* falling between m+s and m-s and iii) varietal *per se* falling below m-s were formed with respective scores equal to +1, 0 and -1. The status of a parent was high if the score for a particular character was +1, moderate and low for the scores 0 & -1 respectively (Thirumeni, 1998 and Bastian, 1999)

Among lines IVTS-06-2 was identified as best parent for plant height, number of branches per plant, number of capsules per plant, capsule length, 1000 seed weight, seed yield per plant and oil content and AVTS-06-03 for number of days to flowering, number of branches per plant, number of capsules per plant, capsule length, seed yield per plant and oil content. Among testers, Soma and Tilak, were identified as best for plant height, number of branches per plant, number of capsules per plant, seed yield per plant and oil content. Hence the above parents were adjudged as the best and

could be utilized in further breeding programmes for the improvement of the respective trait.

5.4.3. GCA : SCA variance

Success in breeding for quantitative traits depends upon the gene action involved for the trait concerned and the nature of gene effects controlling the characters. If additive variance is greater, then the chance of fixing superior genotypes in the early segregating generations will be greater. If non-additive variance is predominant, the selection have to be postponed to later generations and appropriate breeding techniques adopted to sieve the material for obtaining useful genotypes (Panse, 1942). Baker (1978) suggested that the relative importance of general and specific combining ability should be assessed by estimating the components of genetic variance and expressed as a ratio between GCA and SCA. In the present study the SCA variance was found to be higher than GCA variance for all characters which was in accordance with the findings of Yamanura and Nadaf (2009). Further GCA/SCA ratio was observed to be more than one for number of branches per plant indicating the influence of additive gene action. Similar results where GCA variance was high for number of branches per plant was reported by Gaikwad *et al.* (2009) and Parameshwarappa and Salimath (2010).

When additive genes are more important, the choice of parents based on *per se* performance may be effective (Sharma and Chauhan, 1985). However Thirumeni (1998) and Bastian (1999) opined that the nature of gene action varies with the material, the analytical procedure used and the environment under which the test is carried out.

5.4.4.*gca* effects of parents

The *gca* effects of parents were estimated by several breeders for different crops to evaluate the ability of parents to transmit desirable characters to their offspring. Dhillon (1975) was of the opinion that combining ability provides useful information on the choice of parents in terms of expected performance of the hybrids

Traits / Parents	Number of days to flowering		Plant height		N umber of branches per plant		Number of capsules per plant		Capsule length		1000 seed yield		Seed yield per plant		Oil content		Overall		Status	
	X	gca	X	gca	X	gca	X	gca	X	gca	X	gca	X	gca	X	gca	X	gca	X	gca
Lines AVTS-06-3	+1	+1	-1	-1	+1	-1	+1	-1	+1	-1	0	+1	+1	-1	+1	0	+4	-3	H	L
AVTS-06-5	0	-1	-1	-1	-1	-1	0	0	+1	+1	-1	0	+1	+1	+1	+1	0	+1	M	H
AVTS -06-7	-1	+1	+1	-1	+1	-1	-1	-1	+1	0	+1	+1	-1	0	-1	-1	+1	-1	H	L
AVTS -06-10	-1	+1	-1	-1	0	0	+1	-1	+1	+1	+1	0	+1	-1	-1	+1	+2	+1	H	H
IVTS-06-2	-1	0	+1	+1	+1	0	+1	-1	+1	-1	+1	0	+1	-1	+1	-1	+7	-3	H	L
IVTS-O6-6	+1	-1	+1	+1	-1	+1	+1	0	+1	-1	-1	0	0	-1	-1	0	0	-2	M	L
IVTS -06-12	-1	-1	-1	+1	-1	-1	-1	+1	+1	0	+1	-1	-1	+1	+1	+1	-1	+1	L	H
TCR 3279A	-1	-1	-1	+1	-1	-1	-1	+1	+1	-1	-1	-1	-1	+1	+1	-1	-3	-2	L	L
Testers KYM-1	+1	+1	+1	+1	-1	+1	-1	+1	+1	-1	-1	+1	+1	+1	+1	0	0	+6	M	H
Soma	0	-1	+1	-1	+1	0	+1	-1	0	-1	-1	+1	+1	-1	+1	0	+4	-5	H	L
Tilak	-1	+1	+1	-1	+1	0	+1	0	-1	+1	-1	+1	+1	+1	+1	+1	+3	+4	H	H
VRI – 2	-1	-1	-1	+1	-1	-1	+1	-1	+1	-1	0	-1	+1	-1	+1	+1	+2	-5	H	L
TMV – 3	-1	-1	-1	+1	+1	0	-1	+1	+1	-1	+1	0	-1	+1	+1	-1	+1	-1	H	L
TMV .6	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	0	0	-1	+1	+1	-1	-4	+6	L	H

and their progenies. Singh and Harisingh (1985) had also suggested that parents having high *gca* effects could produce transgressive segregation.

The *gca* effects of the parents were also scored and the score chart is presented in Table 27. Scoring was done for the significant parents as the non significant parents are statistically not different from zero. The positively significant parents were given a score of +1 and negatively significant parents a score of -1. The score obtained for each character was summed up to judge the combining ability status of parents. Parents were considered as good combiners if the total score was more than +1, bad combiners if the sum of scores was -1 or lesser and medium combiners if the total score equaled zero (Murthy and Kulkarni, 1996). Based on the score, lines AVTS-06-5, AVTS-06-10 and IVTS-06-12 were high combiners and AVTS-06-3, AVTS-06-7, IVTS-06-2, IVTS-06-6 and TCR 3279 A were low combiners. Among testers, KYM-1, Tilak and TMV-6 were high combiners while Soma, VRI 2 and TMV-3 were low combiners. The present investigation identified the tester TMV-6 as the best combiner since it had favourable genes for majority of the traits as revealed by superior *gca* effects.

5.4.5.*Per se* performance and *gca* effects

Evaluation of parents based on mean and *gca* separately might result in identification of different sets of parents as promising ones. However, assessing the parents using both the parameters would be more relevant. Superior parents based on *per se* performance and *gca* effects are given in Table 28 and Figures 10 and 11.

This led to the identification of KYM-1 for number of days to flowering, plant height and seed yield per plant; Tilak for seed yield per plant and oil content; AVTS-06-5 for capsule length, seed yield per plant and oil content; AVTS-06-7 for 1000 seed weight; AVTS-06-10 for capsule length; IVTS-06-2 and IVTS-06-6 for plant height; Tilak for seed yield per plant and IVTS-06-12 for oil content as best for both *per se* performance and *gca* effects together. However, the ranking of parents based on *per se* performance and *gca* effects does not exist always as observed by Singh and Harisingh (1985), Thirumeni (1998) and Bastian (1999). Hybridization involving

Table 28 Lines and testers with desirable *per se* performance and *gca* effects for yield and yield contributing characters

Characters	*Per se* performance	*gca* effects
Number of days to flowering	AVTS -06 -3, IVTS -06-6, KYM-1	AVTS-06-7, AVTS-06-10, KYM-1, Tilak, TMV-6
Plant height	AVTS-06-7, IVTS-06-2, IVTS-06-6, KYM-1, Soma, Tilak.	IVTS-06-2, IVTS-06-6, IVTS-0-12, TCR-3279-A, KYM-1, VRI-2, TMV-2, TMV-6
Number of branches per plant	AVTS-06-3, AVTS-06-7, IVTS-06-2, Soma, Tilak, TMV-3	AVTS-06-5, IVTS-06-6, KYM-1, TMV-6
Number of capsules per plant	AVTS-06-3, AVTS-06-10, IVTS-06-2, IVTS-06-6, Soma, Tilak, VRI-2	IVTS-06-12, TCR-3279-A, KYM-1, TMV-3, TMV-6
Capsule length	AVTS-06-3, AVTS-06-5, AVTS-06-7, AVTS-06-10, IVTS-06-2, IVTS-06 -6, IVTS-06-12, TCR-3279-A, KYM-1, VRI-2, TMV.3	AVTS-06-5, AVTS-06-10, Tilak, TMV.6
1000 Seed weight	AVTS-06-7, AVTS-06-10, IVTS-06-2, IVTS-06-12, TMV-3	AVTS-06-3, AVTS-06-7, KYM-1, Soma, Tilak
Seed yield per plant	AVTS-06-3, AVTS-06-5, AVTS-06-10, IVTS-06-2, KYM-1, Soma, Tilak	AVTS-06-5, IVTS-06-12, TCR-3279-A, KYM-1, Tilak, TMV-3, TMV-6
Oil content	AVTS.06-3, AVTS-06-5, IVTS-06-2, IVTS-06-12, TCR-3279-A, KYM-1, Soma, Tilak, VRI-2, TMV-3, TMV-6	AVTS-06-5, AVTS-06-10, IVTS-06-12, Tilak, VRI-2

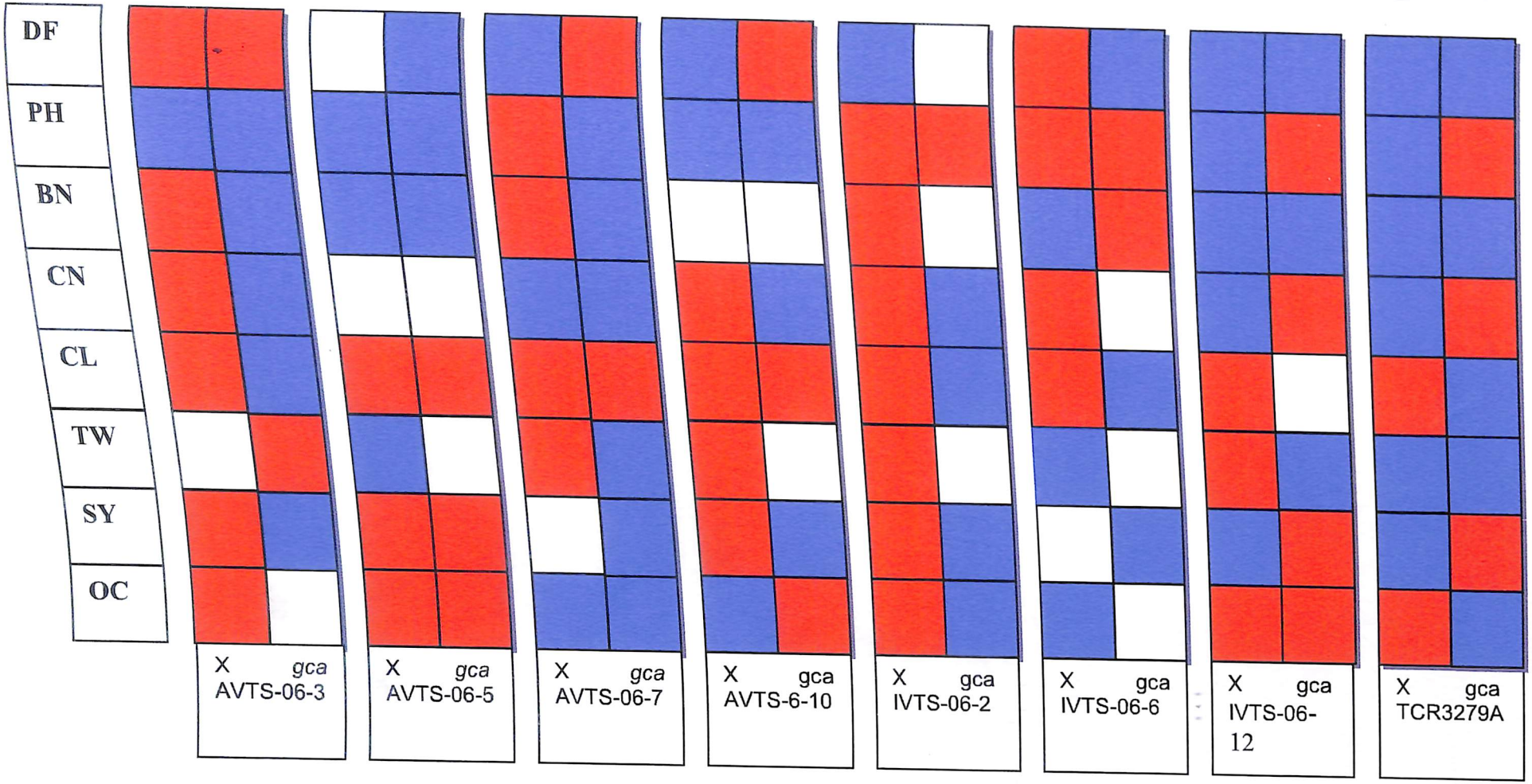
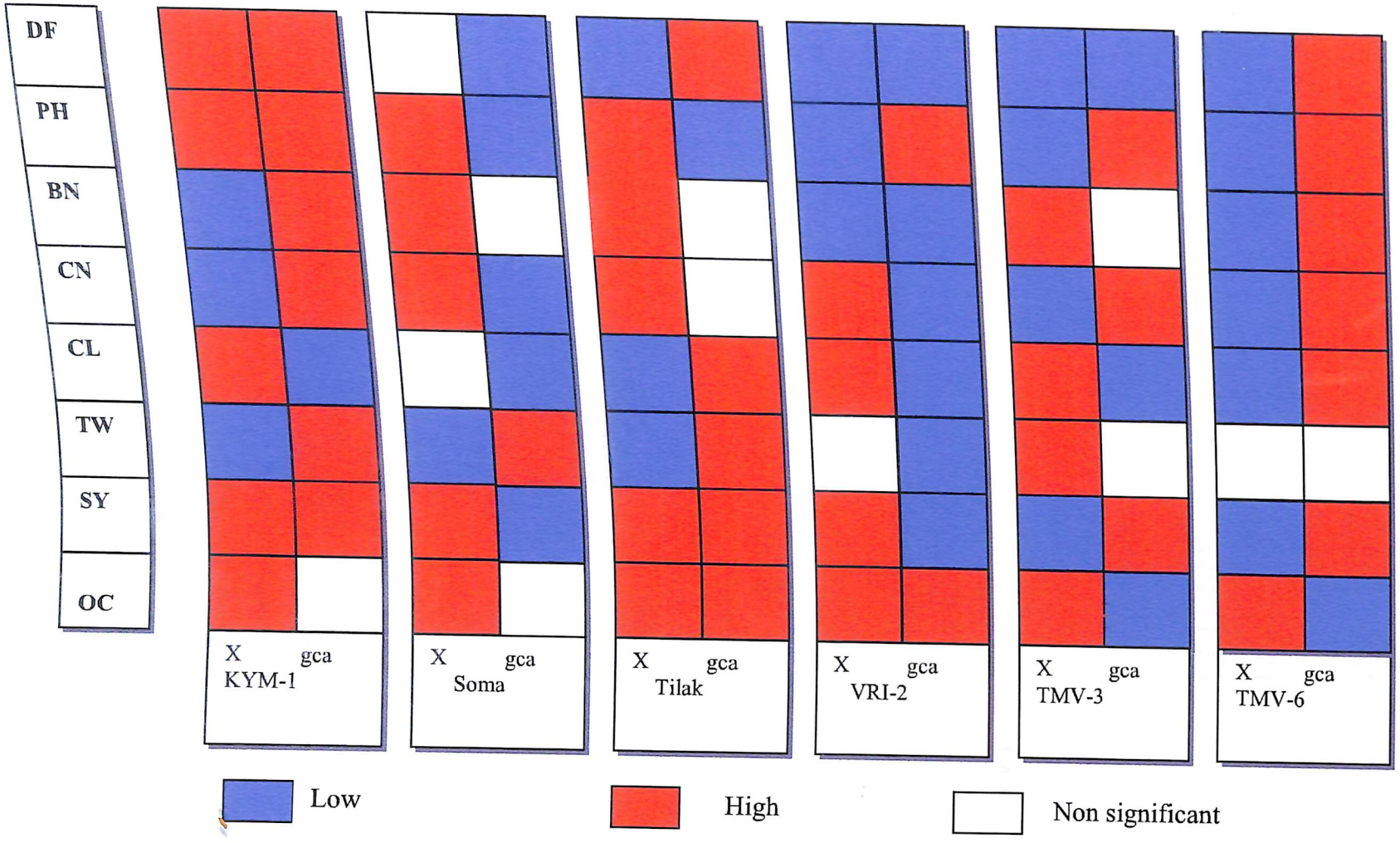

DF
PH
BN
CN
CL
TW
SY
OC
X gca AVTS-06-3
X gca AVTS-06-5
X gca AVTS-06-7
X gca AVTS-6-10
X gca IVTS-06-2
X gca IVTS-06-6
X gca IVTS-06-12
X gca TCR3279A
Low
High
Non significant
DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant
CN – Number of capsules per plant
CL- Length of capsule
TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

Figure 11. *Per se* performance and *gca* effects of testers for yield and yield contributing characters



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

these parents would result in more desirable and superior recombinants for economic characters.

The score chart also indicated that parents with high per se performance had low combining ability viz. AVTS-06-3, AVTS-06-7, IVTS-06-2, Soma, VRI-2 and TMV-3 Though they were not having both parameters, they cannot be eliminated since the *per se* performance of the parents is the actual value of the character concerned while *gca* effects are predictable. Therefore, even if the parents are not having desirable *gca* effects, the parents can be considered for further exploitation if they possess high order of *per se* performance.

5.4.6. Evaluation of hybrids

The basic idea of hybridization is to combine favourable genes present in different parents into a single genotype. The utilization of hybrids in any crop can be had in two different ways viz; 1) utilizing the F_1 hybrids commercially with a view to exploit heterosis and 2) selecting superior segregants from the hybrids in the subsequent generations and releasing best performing recombinants after attaining homozygosity. The hybrids obtained by line X tester mating design in the present investigation were evaluated for their performance based on the mean, heterosis and *sca* effects. To exploit hybrid vigour, the parameters like *per se* performance of hybrids, *sca* effects and standard heterosis of hybrids have to be taken into account (Shunmugavalli, 1996 and Thirumeni, 1998)

5.4.7. *Per se* performance of hybrids

The first criterion used for the evaluation of hybrids was the degree of *per se* expression of the hybrids for different characters. Scoring of hybrids (Table 29) based on *per se* performance was done as in the case of parents.

Gilbert (1958) suggested that parents with good *per se* performance would result in good hybrids. Among hybrids, AVTS-06-3 X Tilak had good *per se* performance for plant height, capsule length, 1000 seed weight and oil content; AVTS-06-5 X KYM-1 for number of days to flowering, plant height, number of branches per plant, number

Table 29 Ranking of hybrids for *per se* performance and *sca* effects

Hybrid	No. days to flowering		Plant height		No of branches per plant		No of capsules per plant		Capsule length		1000 seed weight		Seed yield per plant		Oil content		Overall		Status	
	X	*sca*	X	*sca*	X	*sca*	X	*sca*	X	*sca*	X	*sca*	X	*sca*	X	*sca*	X	*sca*	X	*sca*
C1	-1	0	-1	-1	-1	0	0	0	0	0	+1	0	-1	0	+1	0	-2	-1	L	L
C2	+1	+1	-1	-1	+1	+1	-1	0	-1	-1	+1	+1	-1	-1	-1	-1	-2	-1	L	L
C3	0	0	+1	+1	-1	0	-1	0	+1	+1	+1	+1	-1	0	+1	0	+1	+3	H	H
C4	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	+1	+1	-4	-4	L	L
C5	-1	0	0	+1	-1	0	+1	+1	-1	-1	0	0	0	+1	+1	0	-1	+2	L	H
C6	-1	-1	-1	-1	-1	0	-1	0	0	0	-1	-1	-1	0	-1	-1	-6	-3	L	L
C7	+1	+1	+1	+1	+1	+1	+1	+1	-1	-1	0	0	+1	+1	-1	-1	+3	+3	H	H
C8	+1	0	-1	-1	+1	0	0	+1	+1	+1	-1	-1	+1	+1	+1	0	+3	+1	H	H
C9	+1	+1	-1	-1	+1	0	-1	-1	+1	0	0	-1	-1	-1	+1	+1	+1	-2	H	L
C10	+1	0	+1	+1	+1	0	-1	-1	-1	-1	0	-1	-1	-1	+1	0	+1	-3	H	L
C11	+1	-1	0	+1	+1	0	0	-1	+1	+1	+1	+1	+1	0	+1	+1	+6	+2	H	H
C12	-1	-1	-1	-1	+1	-1	0	0	+1	+1	+1	+1	+1	0	+1	0	+3	-1	H	L
C13	+1	+1	0	0	-1	0	+1	0	0	0	+1	+1	+1	0	+1	+1	+4	+3	H	H
C14	-1	-1	-1	-1	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	-1	-8	-5	L	L
C15	-1	0	-1	-1	-1	0	-1	-1	-1	-1	+1	0	0	0	+1	0	-3	-3	L	L
C16	-1	-1	-1	-1	-1	0	-1	0	0	0	0	0	-1	0	+1	0	-4	-2	L	L
C17	-1	-1	0	+1	-1	+1	0	0	+1	+1	+1	+1	+1	0	-1	0	0	+3	M	H
C18	+1	+1	+1	+1	-1	0	+1	+1	-1	-1	0	-1	0	0	-1	0	0	0	M	M
C19	-1	0	+1	+1	0	0	-1	-1	0	-1	-1	-1	-1	-1	+1	0	-1	-4	L	L
C20	0	+1	-1	-1	-1	0	-1	0	+1	+1	+1	+1	-1	+1	+1	+1	-2	+4	L	H
C21	-1	-1	-1	-1	0	0	+1	+1	+1	+1	+1	0	+1	+1	+1	0	+3	+1	H	H
C22	-1	0	+1	+1	0	+1	-1	0	+1	+1	0	0	-1	0	0	-1	-1	+2	L	H
C23	+1	+1	-1	-1	-1	0	-1	0	-1	-1	-1	-1	-1	-1	+1	0	-4	-3	L	L
C24	-1	-1	+1	+1	-1	-1	+1	+1	-1	-1	0	0	+1	0	+1	0	+1	-1	H	L
C25	+1	+1	-1	-1	-1	0	+1	0	-1	0	+1	0	+1	0	-1	0	0	0	M	M
C26	+1	+1	+1	+1	0	0	+1	+1	0	0	0	0	0	+1	-1	0	+2	+4	H	H
C27	-1	-1	-1	-1	-1	0	0	0	-1	-1	+1	0	0	0	+1	0	-2	-3	L	L
C28	+1	-1	+1	+1	-1	0	-1	0	+1	+1	-1	0	-1	0	-1	0	-2	+1	L	H
C29	-1	-1	-1	-1	+1	0	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-5	-5	L	L
C30	+1	-1	+1	+1	0	0	-1	-1	+1	0	+1	+1	-1	-1	-1	+1	+1	0	H	M
C31	-1	-1	+1	+1	-1	-1	+1	0	-1	-1	0	0	+1	0	+1	+1	+3	+1	H	H
C32	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	0	+1	0	-5	-5	L	L
C33	+1	0	-1	-1	0	0	+1	+1	0	0	+1	0	+1	+1	-1	-1	+2	0	H	M
C34	+1	0	+1	0	0	0	-1	+1	-1	-1	-1	0	-1	0	-1	0	-3	0	L	M
C35	+1	+1	-1	-1	0	0	+1	+1	-1	-1	0	0	+1	+1	-1	0	0	+1	M	H
C36	+1	+1	+1	+1	+1	+1	-1	-1	+1	+1	-1	0	-1	-1	-1	0	0	+2	M	H
C37	0	0	+1	-1	-1	0	+1	-1	0	0	-1	0	+1	-1	-1	0	0	-3	M	L
C38	+1	0	+1	+1	-1	0	-1	-1	0	0	-1	0	-1	-1	+1	0	-1	-1	L	L
C39	+1	+1	-1	-1	-1	0	0	-1	-1	-1	-1	0	0	-1	+1	+1	-2	-2	L	L
C40	0	0	+1	-1	0	+1	+1	0	-1	0	0	+1	+1	0	-1	-1	+1	0	H	M
C41	-1	-1	+1	+1	-1	0	+1	+1	+1	+1	0	0	+1	+1	+1	0	+3	+3	H	H
C42	-1	-1	+1	-1	-1	0	+1	+1	+1	0	0	0	+1	+1	-1	0	+1	0	H	M
C43	-1	-1	+1	+1	-1	0	+1	0	0	+1	0	0	+1	0	-1	+1	0	+2	M	H
C44	+1	0	+1	+1	-1	0	+1	0	-1	-1	0	0	-1	-1	0	+1	0	0	M	M
C45	-1	-1	-1	0	-1	0	+1	+1	+1	0	-1	0	+1	+1	-1	-1	-2	0	L	M
C46	+1	0	-1	-1	-1	0	+1	-1	-1	+1	0	0	+1	-1	-1	0	+1	+1	H	H
C47	+1	+1	+1	+1	-1	0	+1	-1	-1	-1	0	0	+1	-1	+1	+1	-1	-3	L	L
C48	-1	0	-1	-1	-1	0														

of capsules per plant and seed yield per plant; AVTS-06-5 X Soma for days to flowering, number of branches per plant, capsule length, seed yield per plant and oil content; AVTS-06-5 X TMV-3 for number of days to flowering, number of branches per plant, capsule length, 1000 seed weight, seed yield per plant and oil content; AVTS-06-7 X KYM-1 for number of days to flowering, number of capsules per plant, 1000 seed weight, seed yield per plant and oil content; AVTS-06-10 X Tilak for number of capsules per plant, capsule length, 1000 seed weight, seed yield per plant and oil content; IVTS-06-2 X Soma for number of days to flowering, plant height and number of capsules per plant; IVTS-06-6 X KYM-1 for plant height, number of capsules per plant, capsule length, seed yield per plant and oil content; IVTS-06-12 X TMV-3 for plant height, number of capsules per plant, capsule length, seed yield per plant and oil content and TCR 3279A X TMV-3 for number of days to flowering, plant height, number of capsules per plant and seed yield per plant.

The present study revealed that although better performance of hybrids reflected from parents with high *per se* performance, there were many hybrids with high *per se* performance involving parents with poor performance. To quote examples, IVTS-06-12 X TMV-6 for seed yield per plant. There were cases that parents with high *per se* performance also resulted in hybrids with poor *per se* performance like AVTS-06-10 X KYM-1 and AVTS-06-10 X TMV-3 for seed yield per plant. This has clearly indicated that the *per se* performance of F_1 hybrid is decided by the genetic architecture of parents and the interaction of genes concerned for the character.

5.4.8. *sca* effects

The *sca* effects are due to non additive gene action (Sprague and Tatum, 1942). High *gca* values of the parents contribute much for the expression of heterotic vigour. The *sca* effects of the hybrids have also been attributed to the combination of positive favourable genes from different parents or might be due to the presence of linkage in repulsion phase. The *sca* of hybrids over different hybrids was also scored as was done with the *gca* of parents. The score charts are presented in Table 29. AVTS-06-3 X Tilak, AVTS-06-3 X TMV-5, AVTS-06-5 X KYM-1, AVTS-06-5 X Soma, AVTS-06-5 X TMV-3, AVTS-06-7 X KYM-1, AVTS-06-7 X TMV-3, AVTS-

06-10 X Soma, AVTS-06-10 X Tilak, AVTS-06-10 X VRI-2, IVTS-06-2 X Soma, IVTS-06-2 X VRI-2, IVTS-06-6 X KYM-1, IVTS-06-6 X TMV-3, IVTS-06-6 X TMV-6, IVTS-06-12 X TMV-3, TCR 3279A X KYM-1, TCR 3279A X VRI-2 and TCR 3279A X TMV-3 had high *sca* effects. AVTS-06-5 X KYM-1 had high *sca* effects for number of days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant; IVTS-06-2 X Soma for number of days to flowering, plant height, number of capsules per plant and seed yield per plant and IVTS-06-12 X TMV-3 for plant height, number of capsules per plant, capsule length and seed yield per plant.

5.4.9. Heterosis

The term heterosis was coined by Shull in 1914 and it refers to the superiority of F_1 hybrid over its parents. In the present study heterosis was estimated in three ways viz. relative heterosis (over midparental value), heterobeltiosis (over superior parent) and standard heterosis (over standard variety). For practical purposes, heterosis over superior parent and standard variety are considered. Hence discussion is confined to heterobeltiosis and standard heterosis.

Exploitation of hybrid vigour needs a sound knowledge on the extent of heterosis. Identification of heterotic crosses was done. For every character, a cross was assigned a status B if its mean exceeded that of superior parent, otherwise a status B is ¼ and that of W is ¾ . The mean of this distribution (8 x ¼ = 2.0) was scored as 2.0. Hybrids with 2.0 or more B's were taken to be overall heterotic (Arunachalam and Bandyopadhyay, 1979). The score of the crosses is presented in Table 30. All the hybrids found to be overall heterotic. IVTS-06-6 X TMV-6 had a score of seven while AVTS-06-5 X TMV-6, AVTS-06-7 X TMV-6, AVTS-06-10 X Soma, IVTS-06-6 X Tilak and IVTS-06-12 X Tilak had a score of six.

When a cross is checked for heterosis over eight characters, the number of B's it scored was determined by the binomial distribution $(3/4 + ¼)^8$ where probability of

cross.

Table 30. Heterotic hybrids based on heterobeltiosis for yield and yield contributing characters

Hybrid	DF	PH	BN	CN	CL	TW	SY	OC	Total B's
C1	W	W	W	B	B	B	B	W	4
C2	W	W	W	W	W	B	B	W	2
C3	W	B	W	W	B	B	B	B	5
C4	W	B	W	W	W	W	B	B	3
C5	W	B	W	B	W	W	B	W	3
C6	W	B	W	B	B	W	B	W	4
C7	W	B	B	B	W	W	B	W	4
C8	W	B	W	B	B	W	B	B	5
C9	B	B	W	W	B	W	B	B	5
C10	B	B	W	B	W	W	B	W	4
C11	W	B	W	B	B	W\	B	B	4
C12	W	B	B	B	B	B	B	W	6
C13	W	B	W	B	B	W	B	W	4
C14	W	B	W	B	W	W	B	W	3
C15	W	B	W	B	W	W	B	B '	4
C16	W	B	W	B	W	W	B	W	4
C17	W	B	W	B	B	W	B	W	4
C18	B	B	W	B	B	W	B	B	6
C19	W	B	W	B	B	W	B	W	4
C20	W	B	W	B	B	B	B	B	6
C21	W	B	W	B	B	W	B	B	5
C22	W	B	W	B	B	W	B	W	4
C23	W	B	W	B	W	W	B	W	3
C24	W	B	W	B	B	W	B	B	5
C25	W	B	W	B	B	W	B	W	4
C26	W	B	W	B	B	W	B	W	4
C27	W	B	W	B	W	W	B	B	4
C28	W	B	W	B	B	W	B	W	4
C29	W	B	W	B	W	W	B	W	3
C30	W	B	W	B	B	W	B	B	5
C31	W	B	W	B	B	W	B	B	5
C32	W	B	W	W	W	B	B	B	4
C33	W	B	W	B	B	B	B	B	6
C34	W	B	W	B	W	W	B	W	3
C35	B	B	W	B	W	W	B	W	5
C36	B	B	B	B	B	W	B	B	7
C37	W	B	W	B	B	W	B	W	4
C38	W	B	W	B	W	W	B	B	4
C39	B	B	W	B	B	W	B	B	6
C40	W	B	W	B	W	W	B	W	3
C41	W	B	W	B	B	W	B	W	4
C42	W	B	W	B	B	W	B	W	4
C43	W	B	W	B	B	W	B	W	4
C44	W	B	W	B	W	W	B	B	4
C45	W	B	W	B	B	W	B	W	4
C46	W	B	W	B	W	W	B	W	3
C47	B	B	W	B	B	W	B	W	5
C48	W	B							4

B- superior to better parent W- inferior to better parent

DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant
CN – Number of capsules per plant
CL- Length of capsule
TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

In practice, selection of productive hybrid is weighed not by the expression of heterosis over better parent alone but in relation to the standard variety (Bhandari, 1978). The same idea was also stressed by Kadambavanasundaram (1983) and Grakh and Chaudhary (1985) in the use of standard heterosis for commercial exploitation of hybrid vigour. Hence it is clear that standard heterosis could be taken as criterion for the evaluation of hybrids. Therefore, the hybrids were evaluated based on the standard heterosis and presented in Table 31.

The expression of standard heterosis is highly variable for all the characters in all the hybrids studied. Two hybrids found to possess desirable standard heterosis for earliness indicating the possibility of developing early hybrids. Seventeen hybrids possessed significant standard heterosis for plant height with IVTS-06-6 X TMV-6 registering highest value. Seven hybrids registered desirable standard heterosis for number of capsules per plant with the highest value for AVTS-06-5 X KYM-1. Standard heterosis for capsule length was observed in thirteen hybrids. Significant standard heterosis for 1000 seed weight, seed yield per plant and oil content were recorded for six, nineteen and nine hybrids respectively. However, none of the hybrids were found to be heterotic for all the eight characters studied. High standard heterosis indicates superiority of the hybrid over standard variety for that particular character.

5.4.10. *Per se* performance and *sca* effects

The sum effect of the hybrids is the result of the *sca* effect in combination with *per se* performance. In the present investigation, the hybrids with significant *per se* performance were analysed for their *sca* effects. Hybrids expressing both high *per se* performance and *sca* effects are presented in Table 32 and Figures 12,13 and 14. High *per se* performance and *sca* effects were expressed by AVTS-06-5 X KYM-1 for days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant; IVTS-06-12 X TMV-3 for plant height, number of capsules per plant, capsule length and seed yield per plant and IVTS-06-12 X TMV-6 for number of capsules per plant and seed yield per plant. However, some of the cross combinations had either low *per se* performance and high *sca* effects, high *per se* performance and low *sca* effects and low *per se* performance and low *sca* effects.

Table 31 Heterotic hybrids based on high standard heterosis for yield and yield contributing characters

Character	Hybrids with high standard heterosis
Number of days to flowering	IVTS-06-6 x TMV-3, IVTS-06-12 x Tilak
Plant height	AVTS-06-3 x Tilak, AVTS-06-5 x KYM-1, AVTS-06-6 x VRI-2, AVTS-06-7 x TMV-6, AVTS-06-10 x KYM-1, AVTS-06-10 x VRI-2, IVTS-06-2 x VRI-2, IVTS-06-2 x TMV-6, IVTS-06-6 x KYM-1, IVTS-06-6 x TMV-6, IVTS-06-12 x KYM-1, IVTS-06-12 x Soma, IVTS-06-12 x VRI-2, IVTS-06-12 x TMV-3, TCR- 3279-A x KYM-1, TCR-3279-A x Soma, TCR-3279-A x TMV-3
Number of capsules per plant	AVTS-06-5 x KYM-1, IVTS-06-6 x TMV-6, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x KYM-1, TCR- 3279-A x Tilak, TCR-3279-A x VRI-2
Capsule length	AVTS-06-3 x Tilak, AVTS-06-5 x Soma, AVTS-06-6 x Tilak, AVTS-06-5 x TMV-3, AVTS-06-5 x KYM-1, AVTS-06-7 x TMV-3, AVTS-06-10 x Soma, AVTS-06-10 x Tilak, AVTS-06-10 x VRI-2, IVTS-06-2 x VRI-2, IVTS-06-2 x TMV-6, IVTS-06-6 x TMV-6, IVTS-06-12 x TMV-6
1000 Seed weight	AVTS-06-3 x Soma, AVTS-06-3 x Tilak, AVTS-06-5 x TMV-6, AVTS-06-7 x KYM-1, AVTS-06-7 x TMV-3, AVTS-06-10 x Soma
Seed yield	AVTS-06-5 x KYM-1, AVTS-06-5 x Soma, AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, AVTS-06-7 x KYM-1, AVTS-06-7 x TMV-3, AVTS-06-10 x Tilak, AVTS-06-10 x TMV-6, IVTS-06-2 x KYM-1, IVTS-06-6 x KYM-1, IVTS-06-6 x Tilak, IVTS-06-6 x TMV-3, IVTS-06-12 x KYM-1, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x KYM-1, TCR-3279-A x Tilak, TCR-3279-A x VRI-2, TCR-3279-A x TMV-6
Oil content	AVTS-06-3 x Tilak, AVTS-06-3 x VRI-2, AVTS-06-5 x Tilak, AVTS-06-6 x VRI-2, AVTS-06-5 x TMV-3, AVTS-06-10 x Soma, AVTS-06-10 x Tilak, IVTS-06-6 x KYM-1, IVTS-06-12 x Tilak

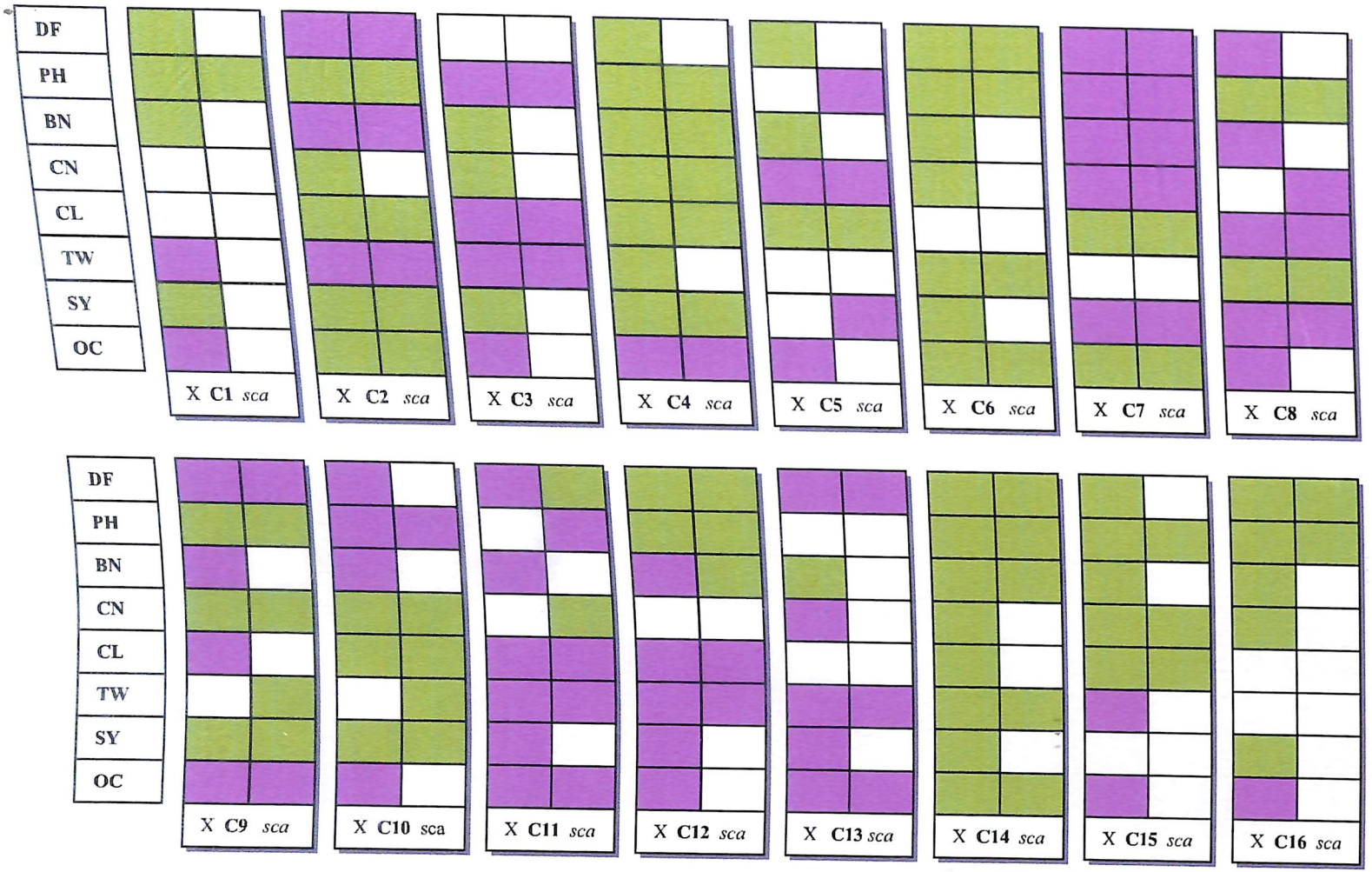
Table 32 Hybrids with desirable *per se* performance and *sca* effects

Character	*Per se* performance	*sca* effects
Days to flowering	AVTS-06-3 x Soma, AVTS-06-5 x KYM-1, AVTS-06-5 x Soma, AVTS-6-5 x Tilak, AVTS-06-5 x VRI-2, AVTS-06-5 x TMV-3, AVTS-06-7 x TMV-6, AVTS-06-10 x TMV-3, IVTS-06-2 x KYM-1, IVTS-06-2 x Soma, IVTS-06-2 x VRI-2, IVTS-06-2 x TMV-6, IVTS-06-6 x Tilak, IVTS-06-6 x TMV-3, IVTS-06-12 x Soma, IVTS-06-12 x Tilak, TCR-3279-A x Soma , TCR-3279-A x VRI-2, TCR-3279-A x TMV-3	AVTS-06-3 x Soma , AVTS-06-5 x KYM-1, AVTS-06-5 x Tilak, AVTS-06-7 x KYM-1, AVTS-06-7 x TMV-6, AVTS-06-10 x Soma , AVTS-06-10 x TMV-3, IVTS-02-2 x KYM-1, IVTS-06-2 x Soma , IVTS-06-6 x TMV-3, IVTS-06-6 x TMV-6, IVTS-06-12 x Tilak, TCR-3279-A x TMV-3
Plant Height	AVTS-06-3 x Tilak, AVTS-06-5 x KYM-1, AVTS-06-5 x VRI-2, AVTS-06-7 x TMV-6, AVTS-06-10 x KYM-1, AVTS-06-10 x VRI-2, AVTS-06-10 x TMV-6, IVTS-06-2 x Soma , IVTS-06-2 x VRI-2, IVTS-06-2 x TMV-6, IVTS-06-6 x KYM-1, IVTS-06-6 x VRI-2, IVTS-06-6 x TMV-6, IVTS-06-12 x KYM-1, IVTS-06-12 x Soma , IVTS-06-12 x VRI-2, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x KYM-1, TCR-3279-A x Soma , TCR-3279-A x TMV-3	AVTS-06-3 x TMV-3, AVTS-06-5 x KYM-1, AVTS-06-5 x VRI-2, AVTS-06-5 x TMV-3, AVTS-06-7 x TMV-3, AVTS-06-7 x TMV-6, AVTS-06-10 x KYM-1, AVTS-06-10 x VRI-2, AVTS-06-10 x TMV-6, IVTS-06-2 x Soma , IVTS-06-2 x VRI-2, IVTS-06-2 x TMV-6, IVTS-06-6 x KYM-1, IVTS-06-6 x TMV-6, IVTS-06-12 x Soma , IVTS-06-12 x TMV-3, TCR-3279-A x KYM-1, TCR-3279-A x Soma , TCR-3279-A x TMV-3
Number of branches per plant.	AVTS-06-5 x KYM-1, AVTS-06-5 x Soma , AVTS-06-5 x Tilak, AVTS-06-5 x VRI-2, AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, IVTS-06-2 x TMV-3, IVTS-06-6 x TMV-6	AVTS-06-5 x KYM-1, AVTS-06-7 x TMV-3, AVTS-06-10 x VRI-2, IVTS-06-6 x TMV-6, IVTS-06-12 x VRI-2
Capsule number	AVTS-06-3 x TMV-3, AVTS-06-5 x KYM-1, AVTS-06-7 x TMV-6, AVTS-06-10 x TMV-6, IVTS-06-2 x KYM-1, IVTS-06-6 x KYM-1, IVTS-06-6 x TMV-3, IVTS-06-12 x KYM-1, IVTS-06-12 x VRI-2, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x KYM-1, TCR-3279-A x Tilak, TCR-3279-A x VRI-2, TCR-3279-A x TMV-6	AVTS-06-3 x TMV-3, AVTS-06-5 x KYM-1, AVTS-06-5 x Soma , AVTS-06-7 x TMV-6, AVTS-06-10 x Tilak, AVTS-06-10 x TMV-6, IVTS-06-2 x Soma , IVTS-06-6 x Tilak, IVTS-06-6 x VRI-2, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x Tilak, TCR-3279-A x VRI-2

Table 32 Hybrids with desirable *per se* performance and *sca* effects contd.

Character	*Per se* performance	*sca* effects
Capsule length	AVTS-06-3 x VRI-2, AVTS-06-5 x Soma , AVTS-06-5 x Tilak, AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, AVTS-06-7 x TMV-3, AVTS-06-10 x Soma , AVTS-06-10 x Tilak, AVTS-06-10 x VRI-2, IVTS-06-2 x VRI-2, IVTS-06-2 x TMV-6, IVTS-06-6 x KYM-1, IVTS-06-6 x TMV-6, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6	AVTS-06-3 x Tilak, AVTS-06-5 x Soma , AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, AVTS-06-7 x TMV-3, AVTS-06-10 x Soma , AVTS-06-10 x Tilak, AVTS-06-10 x VRI-2, IVTS-06-2 x VRI-2, IVTS-06-6 x KYM-1, IVTS-06-6 x TMV-6, IVTS-06-12 x TMV-3, IVTS-06-11 x KYM-1
Test weight	AVTS-06-3 x KYM-1, AVTS-06-3 x Soma , AVTS-06-3 x Tilak, AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, AVTS-06-7 x KYM-1, AVTS-06-7 x Tilak, AVTS-06-7 x TMV-3, AVTS-06-10 x Soma , AVTS-06-10 x Tilak, IVTS-06-2 x KYM-1, IVTS-06-2 x TMV-6, IVTS-06-6 x Soma , IVTS-06-6 x Tilak, IVTS-06-12 x VRI-2, TCR-3279-A x Tilak	AVTS-06-3 x Soma , AVTS-06-3 x Tilak, AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, AVTS-06-7 x KYM-1, AVTS-06-7 x TMV-3, AVTS-06-10 x Soma, AVTS-06-10 x Tilak, IVTS-06-2 x KYM-1, IVTS-06-2 x Tilak, IVTS-06-12 x VRI-2, TCR-3279-A x VRI-2
Seed yield	AVTS-06-5 x KYM-1, AVTS-06-5 x Soma , AVTS-06-5 x TMV-3, AVTS-06-5 x TMV-6, AVTS-06-7 x KYM-1, AVTS-06-7 x TMV-3, AVTS-06-10 x Tilak, AVTS-06-10 x TMV-6, IVTS-06-2 x KYM-1, IVTS-06-6 x KYM-1, IVTS-06-6 x Tilak, IVTS-06-6 x TMV-3, IVTS-06-12 x KYM-1, IVTS-06-12 x VRI-1, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x KYM-1, TCR-3279-A x Tilak, TCR-3279-A x VRI-2, TCR-3279-A x TMV-3, TCR-3279-A x TMV-6	AVTS-06-3 x TMV-3, AVTS-06-5 x KYM-1, AVTS-06-5 x Soma, AVTS-06-10 x Soma , AVTS-06-10 x Tilak, IVTS-06-2 x Soma , IVTS-06-6 x Tilak, IVTS-06-6 x TMV-3, IVTS-06-12 x TMV-3, IVTS-06-12 x TMV-6, TCR-3279-A x Tilak, TCR-3279-A x VRI-2
Oil content	AVTS-06-3 x KYM-1, AVTS-06-3 x Tilak, AVTS-06-3 x VRI-2, AVTS-06-3 x TMV-3, AVTS-06-5 x Tilak, AVTS-06-5 x VRI-2, AVTS-06-5 x TMV-3, AVTS-06-7 x KYM-1, AVTS-06-7 x VRI-2, AVTS-06-6 x TMV-3, AVTS-06-10 x KYM-1, AVTS-06-10 x Soma , AVTS-06-10 x Tilak, AVTS-06-10 x TMV-3, AVTS-06-10 x TMV-6, IVTS-06-2 x Tilak, IVTS-06-6 x KYM-1, IVTS-06-6 x Soma , IVTS-06-12 x KYM-1, IVTS-06-12 x Soma , TCR-3279-A x TMV-3	AVTS-06-3 x VRI-2, AVTS-06-5 x Tilak, AVTS-06-5 x TMV-3, AVTS-06-7 x KYM-1, IVTS-06-12 x Tilak, TCR-3279-A x KYM-1, TCR-3279-A x Soma , TCR-3279-A x TMV-6

Figure 12. *Per se* performance and *sca* effects of hybrids for yield and yield contributing characters -1

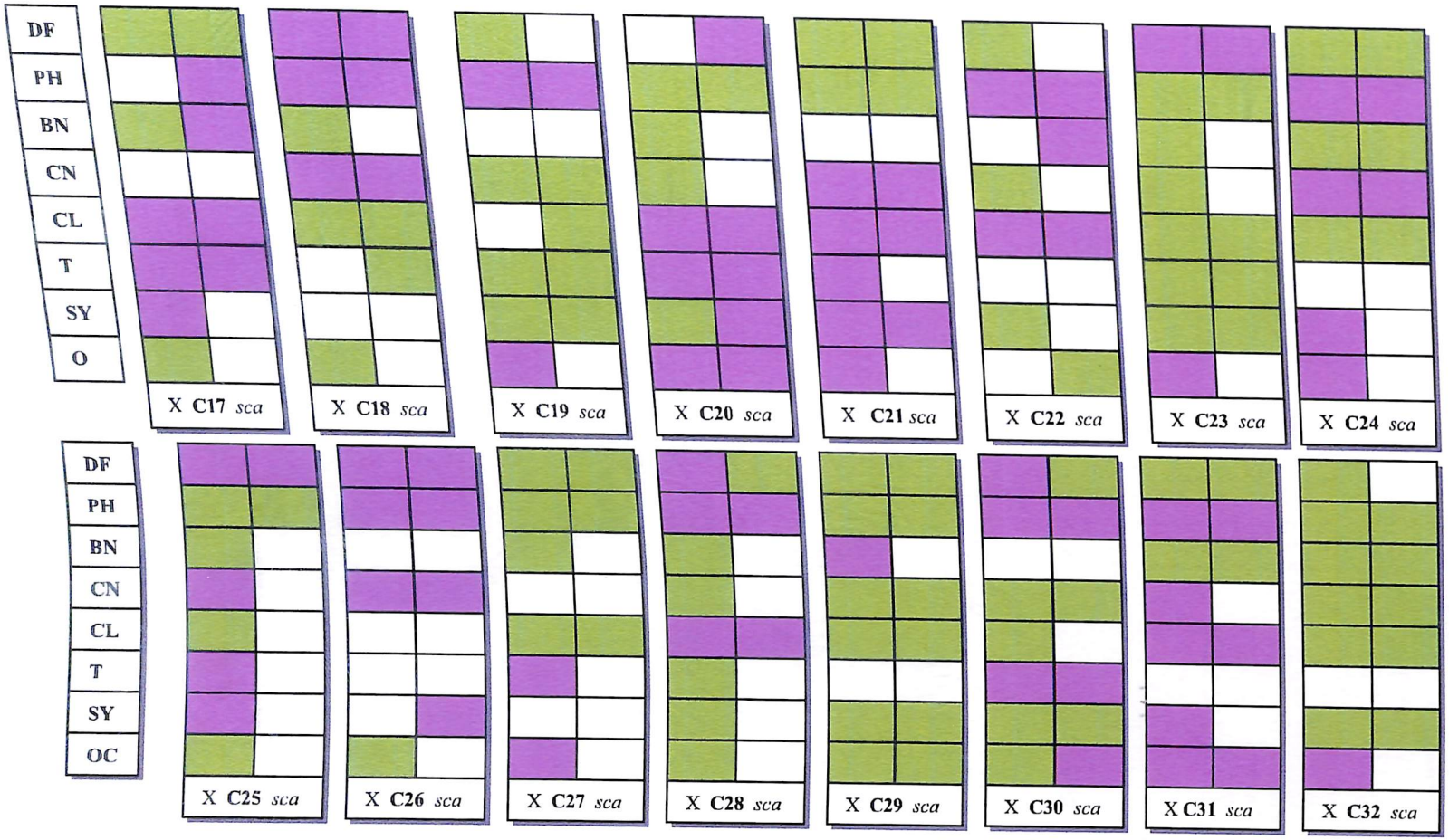


DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

Figure 13. ***Per se*** **performance and** ***sca*** **effects of hybrids for yield and yield contributing characters -2**

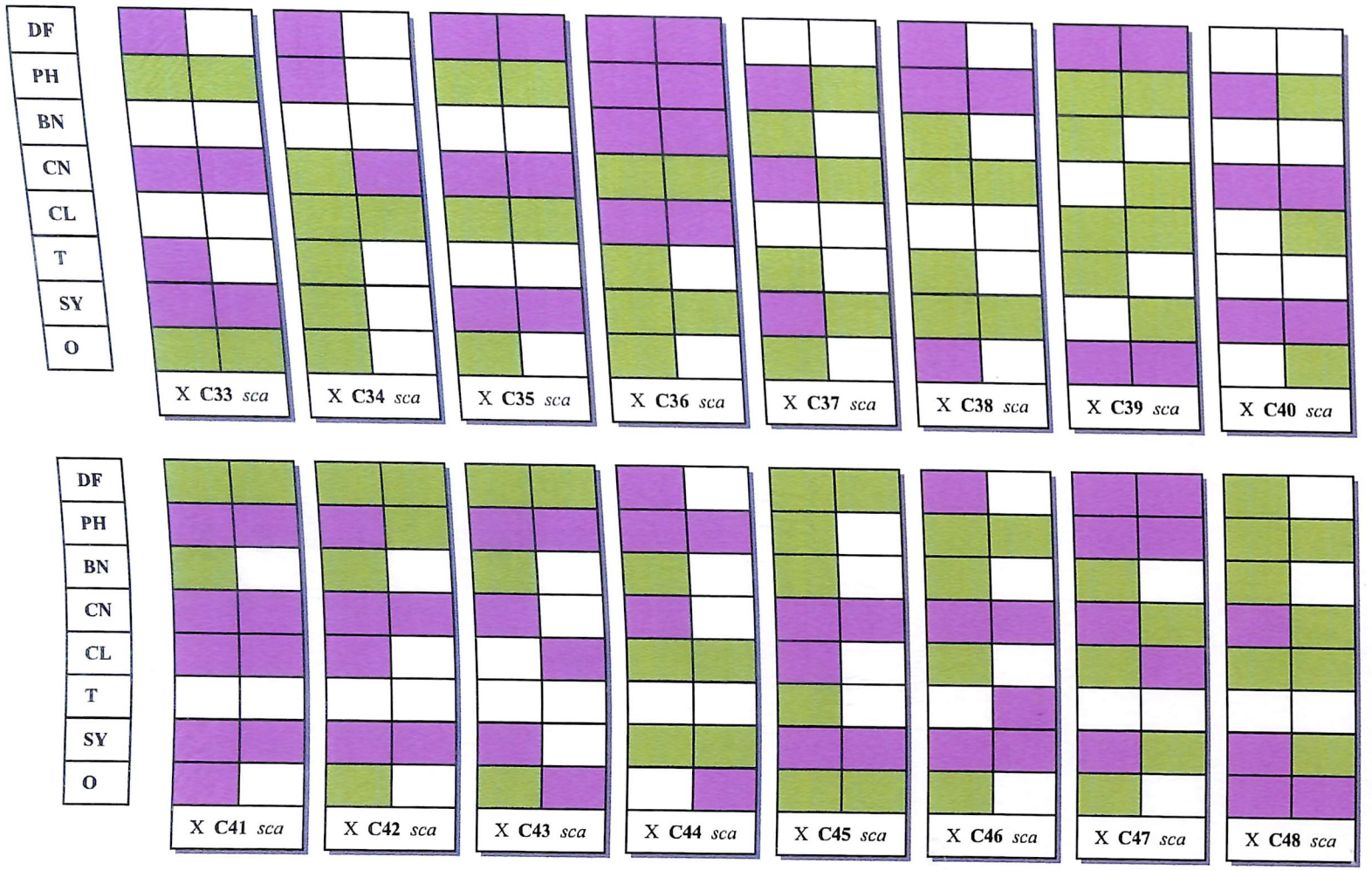


DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

Figure 14. *Per se* performance and *sca* effects of hybrids for yield and yield contributing characters -3



DF – Number of days to flowering
PH- Plant Height
BN- Number of branches per plant

CN – Number of capsules per plant
CL- Length of capsule

TW – 1000 seed weight
SY- Seed yield per plant
OC- Oil content

5.4.11.*sca* effects and standard heterosis

It is predicted that generally hybrids with high standard heterosis would have higher values of *sca* effects as observed in the present study. AVTS-06-5 X KYM-1 and IVTS-06-12 x TMV-3 had significant *sca* effects and standard heterosis for plant height, number of capsules per plant and seed yield per plant. In contrast, not all crosses with high heterotic effects exhibited significant *sca* effects. There were crosses of high heterosis and low *sca* effects and vice versa. This showed inconsistent relationship between the heterosis and *sca* effects.

5.4.12. *Per se* performance, *sca* effects and heterosis

In the present investigation, an attempt was also made to choose hybrid combinations for high order of expression for all the three genetic parameters *viz. per se* performance, *sca* effects and standard heterosis to give more validity for selection. The hybrids AVTS-06-5 X KYM-1 and IVTS-06-12 X TMV-3 for plant height, number of capsules per plant and seed yield per plant (Plate 9) clearly indicate this combination and the hybrids presented in Table 33 are the best for exploiting hybrid vigour for the respective characters. However, this is not uniform for all the characters and all the crosses. There are crosses at low and high levels for *per se* performance, *sca* effects and standard heterosis in different combinations. Therefore, the study had clearly indicated that the *sca* effects may not always lead to correct choice of hybrid combinations. Hence selection of hybrids based on high *per se* performance and heterotic expression would be more useful than based on *sca* effects alone as reported by Pethani and Kapoor (1984) and Rogbell *et al.* (1998b).

5.4.13. *sca* effects and *gca* effects

The combinations of parents with high *gca* effects for hybridisation will be more useful in the improvement of autogamous plants (Raghavaiah and Joshi, 1986). In the present study, the cross combinations involving parents with high *gca* effects namely IVTS-06-12 x TMV-3 and IVTS-06-12 x TMV-6 for plant height, number of capsules per plant and seed yield per plant had high *sca* effects for these

Table 33 Hybrids identified for direct exploitation of heterotic vigour

Character	Hybrid	Mean	SCA	Standard heterosis
Number of days to flowering	IVTS-06-6 x TMV-3	29.70**	-2.758**	-5.71**
	IVTS-06-12 x Tilak	29.60**	-3.458**	-6.03**
Plant height	AVTS-06-5 x KYM-1	143.50**	59.80**	16.679**
	AVTS-06-5 x VRI-2	146.60**	19.917**	63.25**
	AVTS-06-7 x TMV-6	140.30**	17.008**	56.24**
	AVTS -06-10 x KYM-1	147.60**	19.112**	64.37**
	AVTS-06-10 x VRI-2	135.10**	6.75**	50.45**
	IVTS-06-2 x VRI-2	147.80**	17.417**	64.59**
	IVTS-06-2 x TMV-6	139.90**	9.242**	55.79**
	IVTS-06-6 x TMV-6	179.00**	42.992**	99.33**
	IVTS-06-12 x Soma	161.10**	24.588**	79.40**
	IVTS-06-12 x TMV-3	151.40**	9.975**	68.60**
	TCR-3279-A x KYM-1	139.10**	5.729**	54.90**
	TCR-3279-A x Soma	151.30**	27.354**	68.49**
	TCR-3279-A x TMV-3	140.80**	11.942**	56.79**
Number of capsules per plant	AVTS-06-5 x KYM-1	67.40**	14.254**	46.52**
	IVTS-06-12 x TMV-3	60.00**	3.721**	30.43**
	IVTS-06-12 x TMV-6	61.60**	6.633**	33.91**
	TCR-3279-A x Tilak	61.80**	5.017**	34.35**
	TCR-3279-A x VRI-2	60.70**	6.804**	31.96**
Capsule length	AVTS-06-5 x Soma	2.31**	0.095**	16.67**
	AVTS-06-5 x TMV-3	2.34**	0.127**	18.18**
	AVTS-06-7 x TMV-3	2.41**	0.318**	21.72**
	AVTS-06-10 x Soma	2.39**	0.162**	20.71**
	AVTS-06-10 x Tilak	2.38**	0.084**	20.20**
1000 Seed weight	AVTS-06-3 x Soma	3.19**	0.040**	1.48**
	AVTS-06-3 x Tilak	3.21**	0.038**	1.79**
	AVTS-06-5 x TMV-6	3.20**	0.072**	2.27**
	AVTS-06-7 x KYM-1	3.20**	0.036**	1.48**
	AVTS-06-7 x TMV-3	3.17**	0.032**	1.16*
	AVTS-06-10 x Soma	3.19**	0.053**	1.48**
	AVTS-06-10 x Tilak	9.68**	1.394**	81.57**
Seed yield per plant	IVTS-06-6 x Tilak	9.14**	0.541**	71.26**
	IVTS-06-6 x TMV-3	9.69**	0.929**	81.66**
	AVTS-06-5 x KYM-1	11.72**	2.115**	119.63**
	IVTS-06-12 x TMV-3	10.43**	0.796**	95.54**
	IVTS-06-12 x TMV-6	10.72**	1.071**	100.88**
	TCR-3279-A x Tilak	10.65**	0.748**	99.57**
	TCR-3279-A x VRI-2	10.60**	1.417**	98.82**
Oil content	AVTS-06-3 x VRI-2	50.60**	0.737**	2.85**
	AVTS-06-5 x Tilak	50.60**	0.494*	3.06**
	AVTS-06-5 x TMV-3	50.10**	0.781**	2.55**

Plate 9. Hybrids identified for direct exploitation of heterotic vigour

AVTS-06-5 x KYM-1

IVTS-06-12 x TMV-3

IVTS-06-12 x TMV-6

characters. When these parents are involved in the hybridization programme, they will express high heterotic vigour as reported by Bhandari (1978). Raghavaiah and Joshi (1986) opined that significant *gca* effects are due to additive effect. The hybrid combinations involving high *gca* effects can also be utilized in the breeding programme as the additive genes are fixable (Shinde and Kulkarni, 1984). However, like other parameters the *sca* effects was also expressed when two parents are at low and high, high and low and low and low *gca* effects. Vijayabaskarareddy *et al.* (1986) reported that there was no specific trend of nicking among the parents to produce desirable combinations. The lack of consistent specific relationship between the *gca* effects and *sca* effects might be due to complimentary interaction of genes as suggested by Griffings (1956), Matzinger and Kempthrone (1956) and Hayman (1958). Hence for the improvement of self pollinated crops like sesame, *sca* of a particular cross will be useful if it is accompanied by high *gca* of respective parents as suggested by Raghavaiah and Joshi (1986).

5.4.14. Hybrids for recombination breeding

The genetic architecture of the progenies will be improved by the effective recombination of parents in a cross combination. Recombination breeding makes use of fixable additive gene action. To get outstanding recombinants in segregating generations, the parents of the hybrids must be good general combiners for the characters to which improvement is sought. In case of hybrids with significant *sca* effects, selection in early segregating generations is likely to fail as the *sca* effects mask the true performance of the selected plants. As suggested by Nadarajan and Sreerangaswamy (1990) it will be useful to select only those hybrids having parents with high *gca* effects and non significant *sca* effects for recombination breeding since it is likely to throw segregants with favourable genes derived from both parents.

In the present investigation, the evaluation of hybrids based on this criterion for all the traits (Table 34 and Plate 10) revealed that the combinations AVTS-06-5 x VRI- 2 and IVTS-06-12 x Soma for earliness, AVTS-06-10 x TMV-3, IVTS-06-2 x TMV-3 and IVTS-06-6 x TMV-3 for plant height, AVTS-06-5 x Tilak for capsule length, AVTS-06-3 x KYM-1 for 1000 seed weight and AVTS-06-5 x TMV-6 and

Table 34 Hybrids identified for recombination breeding

Character	Good combining line	GCA effect of line	Good combining tester	GCA effect of tester	Possible cross combination	Sca effect of hybrid	Promising combinations for recombination breeding
Days to flowering	AVTS-06-5	-1.675**	Soma	-0.504**	AVTS-06-5 x Soma	0.337	AVTS-06.5 x VRI-2 IVTS-06-12 x Soma
	IVTS-06-6	-0.642**	VRI-2	-0.267**	AVTS-06.5 x VRI-2	-0.600	
	IVTS-06-12	-0.492*	TMV-3	-0.242*	AVTS-06-5 x TMV-3	0.975	
					IVTS-06-6 x Soma	4.404**	
					IVTS-06-6 x VRI-2	0.167	
					IVTS-06-6 x TMV-3	-2.758**	
					IVTS-06-12 x Soma	-0.046	
					IVTS-06-12 x VRI-2	0.517	
					IVTS-06-12 x TMV-3	1.392**	
Plant height	AVTS-06-10	1.038**	KYM-1	5.904**	AVTS-06-10 x KYM-1	147.60**	AVTS-06-10 x TMV-3 IVTS-06-2 x TMV-3 IVTS-06-6 x TMV-3 TCR -3279-A x VRI-2 TCR -3279-A x TMV-6
	IVTS-06-2	0.996**	VRI-2	5.767**	AVTS-06-10 x VRI-2	135.10**	
	IVTS-06-6	6.346**	TMV-3	1.392	AVTS-06-10 x TMV-3	109.90	
	IVTS-06-12	16.413**	TMV-6	6.042	AVTS-06-10 x TMV-6	134.50**	
	TCR-3279-A	3.846**			IVTS-06-2 x KYM-1	-18.321**	
					IVTS-06-2 x VRI-2	147.80**	
					IVTS-06-2 x TMV-3	111.60	
					IVTS-06-2 x TMV-6	139.90**	
					IVTS-06-6 x KYM-1	146.70**	
					IVTS-06-6 x VRI-2	134.50**	
					IVTS-06-6 x TMV-3	112.70	
					IVTS-06-6 x TMV-6	179.00**	
					IVTS-06-12 x KYM-1	140.70**	
					IVTS-06-12 x VRI-2	144.70**	
					IVTS-06-12 x TMV-3	151.40**	
					IVTS-06-12 x TMV-6	133.90**	
					TCR -3279-A x KYM-1	139.10**	
					TCR -3279-A x VRI-2	110.80	
					TCR -3279-A x TMV-3	140.80**	
					TCR -3279-A x TMV-6	110.80	

Table 34 Hybrids for recombination breeding contd.

Character	Good combining line	GCA effect of line	Good combining tester	GCA effect of tester	Possible cross combination	Sca effect of hybrid	Promising combinations for recombination breeding
Branches number	AVTS-06-5	1.348**	KYM-1	0.102**	AVTS-06-5 x KYM-1	0.715**	
	IVTS-06-6	0.431**	TMV-6	0.290**	AVTS-06-5 x TMV-6	-0.473*	
					IVTS-06-6 x KYM-1	-0.669**	
					IVTS-06-6 x TMV-6	1.744**	
Capsules number	IVTS-06-12	4.317**	KYM-1	3.696**	IVTS-06-12 x KYM-1	-3.529**	
	TCR 3279A	7.233**	TMV-3	2.346**	IVTS-06-12 x TMV-3	3.721**	
			TMV-6	1.033**	IVTS-06-12 x TMV-6	6.633**	
					TCR -3279-A x KYM-1	-0.146	
					TCR -3279-A x TMV-3	-7.196**	
					TCR- 3279-A x TMV-6	-2.883*	
Capsules length	AVTS-06-5	0.116**	Tilak	0.053**	AVTS-06-5 x Tilak	0.057	AVTS-06-5 x Tilak
	AVTS-06-10	0.130**	TMV-6	0.056**	AVTS-06-5 x TMV-6	0.134**	
					AVTS-06-10 x Tilak	0.084**	
					AVTS-06-10 x TMV-6	-0.22**	
1000 Seed weight	AVTS-06-3	0.016**	KYM-1	0.006*	AVTS-06-3 x KYM-1	0.004	AVTS-06-3 x KYM-1
			Tilak	0.007*	AVTS-06-3 x Tilak	0.038**	
			TMV-6	0.006*	AVTS-06-3 x TMV-6	-0.056**	

Table 34 Hybrids for recombination breeding contd.

Character	Good combining line	GCA effect of line	Good combining tester	GCA effect of tester	Possible cross combination	Sca effect of hybrid	Promising combinations for recombination breeding
Seed yield	AVTS-06-5	0.295**	KYM-1	0.628*	AVTS-06-5 x KYM-1	2.115**	AVTS-06-5 x TMV-6
	IVTS-06-12	0.692**	Tilak	0.098*	AVTS-06-5 x Tilak	-2.141**	TCR- 3279-A x KYM-1
	TCR-3279-A	1.122**	TMV-3	0.265**	AVTS-06-5 x TMV-3	-0.088	
			TMV-6	0.275**	AVTS-06-5 x TMV-6	0.162	
			Soma	0.655*	AVTS-06-5 x Soma	1.242**	
					IVTS-06-12 x KYM-1	-0.607**	
					IVTS-06-12 x Tilak	-0.837**	
					IVTS-06-12 x TMV-3	0.796**	
					IVTS-06-12 x TMV-6	1.071**	
					IVTS-06-12 x Soma	-0.704**	
					TCR-3279-A x KYM-1	0.063	
					TCR-3279-A x Tilak	0.748**	
					TCR-3279-A x TMV-3	-1.024**	
					TCR-3279-A x TMV-6	-0.509*	
Oil content	AVTS-06-5	0.300**	Tilak	0.373**	AVTS-06-5 x Tilak	0.494*	
	AVTS-06-10	0.567**	VRI-2	0.204**	AVTS-06-5 x VRI-2	0.781**	
	IVTS-06-12	0.192*			AVTS-06-10 x Tilak	0.721**	
					AVTS-06-10 x VRI-2	-0.554*	
					IVTS-06-12 x Tilak	-0.004	
					IVTS-06-12 x VRI-2	-0.679**	

Plate 10. Hybrids identified for recombination breeding

AVTS-06-5 x TMV-3

AVTS-06-5 x TMV-6

TCR-3279-A x KYM-1

TCR 3279-A x KYM-1 for seed yield per plant had non-significant *sca* effects for respective characters with favourable *gca* effects of parents. Hence these hybrids may serve as a better source for deriving superior segregants by recombination breeding for the improvement of the respective traits.

5.5. Interspecific hybridization

Cytoplasmic - genetic male sterility (CGMS) results from nuclear- cytoplasm interaction in which higher plants fail to produce functional pollen, but maintain female fertility. In several species, CGMS is associated with rearrangements in the mitochondrial DNA (mt.DNA). These rearrangements result in the expression of gene(s) whose protein products are considered to interfere, by unknown mechanism(s), with normal pollen development (Newton, 1988). CGMS has been commercially exploited for the production of F_1 hybrid seed in a number of crops such as rice, maize, sorghum, sunflower and sugarbeet. The yield superiority of these hybrids over inbred cultivars or open pollinated varieties has been an important factor in the adoption and cultivation of hybrid varieties.

Major progress has been made recently in developing high yielding rice based on the CGMS system, occupying over 18 million ha. in China. About 95 per cent of the total area of hybrid rice in China and in the tropics, thus has wild abortive (WA) type of cytoplasm derived from *Oryza sativa f. spontanea* (Yuan, 1993).

5.5.2. Interspecific hybridization using *S.indicum* and *S.malabaricum*

In the present study which aimed at producing male sterile lines through interspecific hybridization, there was difficulty in germinating seeds of wild species of *Sesamum malabaricum* even after undertaking several seed treatment practices like mechanical scarification, hot water treatment, acid treatment, GA treatment and others which was also reported by Bedigian (2003) who attributed such failure to chemical inhibitors present in the seed.

Personal exploration revealed the presence of *S.malabaricum* plants on the roadsides of Alleppey and Ernakulam districts. Hence these were collected and used for further studies. Bedigian (2003) has opined that *S.malabaricum* grows in the wild in tracts of South India.

Sesamum malabaricum was crossed with KYM-1, Soma, Surya, Tilak, Tilatara, Tilarani, Co-1, SVPR-1, VRI-1, VRI-2, TMV-3, TMV-4, TMV-5 and TMV-6 and success was obtained in crosses with KYM-1, Soma, Surya and CO-1.

Attempts initiated by Prabakaran (1992) followed by Bhuyan (1996) and Kavitha (1998) resulted in identification of four male sterile lines each from *S. indicum* cv.CO-1, TMV-3, TMV-4 and TMV-6. Vighneshwaran (2001) reported that cytoplasm of *S.malabaricum* may be the factor, which induced the sterility system in the cross with *Sesamum indicum.*

As the hybrid seeds failed to germinate after repeated seed treatments like hot water treatment, mechanical scarification, acid treatment, GA application, the seed was dissected and observed at maturity and it was found that the interspecific crossed seeds of *S.malabaricum* x *S.indicum* had shrivelled embryo at maturity (Plate11) which is in accordance with the reports of Amirthadevarathinam (1965) and Sundaram (1968).

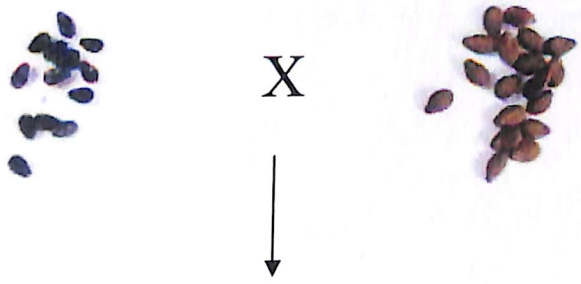
Embryo rescue was attempted to develop seedlings from the interspecific cross namely *S.malabaricum* x KYM-1, *S.malabaricum* x Soma and *S.malabaricum* x Surya through *in vitro* culture in MS medium. Earlier attempts in embryo rescue of interspecific crosses of sesame have been reported by Kulkarni (2007) when the hybrid seeds failed to germinate.

Suggestions for future studies

Sesame is grown on residual soil moisture with low inputs, and is a good crop for rotations with an extensive tap root system. Though India ranks first in area and production in sesame, the productivity of the crop is very low. Hybrid breeding is one of the best methods to increase productivity in sesame. Despite its nutritional value

Plate 11. Interspecific hybridisation

S.malabaricum X *S.indicum* var.KYM-1

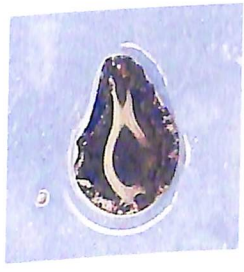


Interspecific hybrid seed

L.S. of seeds

S.malabaricum

S.indicum



Interspecific hybrid

and its historic and cultural importance, research on sesame is scarce. Different studies have indicated that exploitation of hybrid vigour is possible in sesame. Commercial exploitation of hybrid vigour could be achieved through hybrids with high *per se* performance along with *sca* for yield and yield contributing characters.

The project was envisaged to evolve heterotic combinations of sesame from the available genetic diversity and to develop a male sterile line to be used for producing hybrids.

Eight promising hybrids have been identified as heterotic for seed yield per plant as well as with good *per se* performance in field conditions with a potential for commercial exploitation. This is based on evaluation over one location and one season. To release a commercial hybrid, extensive yield trials over locations and seasons is inevitable. Since such studies could not be done within the time frame of this study, the combinations with consistent yield performance may be adjudged over locations and seasons in the future.

Although the major objective was to develop heterotic combinations, in the present study, five hybrids with non significant *sca* were obtained from parents having high *gca* effects. Hence these F_1' s could be used in recombination breeding since it is likely to throw segregants with favorable genes derived from both the parents.

Utilisation of male sterility in producing hybrids is highly useful in reducing the price of hybrid seeds. Hence it is a breeder's dream to develop male sterile lines. Development of male sterile lines has been attempted for the past three decades. Both GMS and CGMS have been reported by many workers but so far success has been minimal. Hence the plantlets developed in this study using tissue culture techniques may be hardened, field planted and assessed for its pollen sterility. They may be back crossed with the *S.indicum* parent to develop male sterile lines.

Summary

SUMMARY

The present study entitled 'Heterosis breeding in sesame (*Sesamum indicum* L.)' was undertaken at the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara during 2007-2010 to study the extent of variability and identify potential parents and superior crosses for heterosis breeding and to impart male sterility to cultivated sesame through interspecific hybridization with *Sesamum malabaricum*.

The experimental material consisted of 40 genotypes of sesame for variability and divergence studies and eight lines and six testers for hybridization studies. Three accessions of *S.malabaricum* were used for interspecific hybridization studies.

The salient findings are presented below.

1. Analysis of variance of diversity studies of forty genotypes of sesame revealed highly significant differences among genotypes with respect to number of days to flowering, plant height and number of capsules per plant.

2. High GCV and PCV were observed for plant height, number of branches per plant, number of capsules per plant and seed yield per plant.

3. High heritability with high genetic advance as per cent of mean was recorded for number of days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant.

4. Number of days to flowering, plant height, number of branches per plant, number of capsules per plant, locules per capsule and oil content showed positive and significant association with seed yield per plant.

5. Path coefficient analysis indicated maximum positive direct effect by number of capsules per plant, capsule length, plant height and 1000 seed weight on seed yield per plant.

6. Forty genotypes of sesame were grouped into six clusters where Cluster I contained thirty genotypes, Cluster II had six genotypes and four genotypes formed separate clusters each which included KYM-1, Soma and SVPR-1.

7. Eight lines from cultures and six testers from released varieties were selected based on *per se* performance in the field for Line X Tester mating design and crossed.

8. SCA variance was found to be higher than GCA variance for all characters except number of branches per plant.

9. Among lines IVTS-06-2 was identified as best parent for plant height, number of branches per plant, number of capsules per plant, capsule length, 1000 seed weight, seed yield per plant and oil content and AVTS-06-03 for number of days to flowering, number of branches per plant, number of capsules per plant, capsule length, seed yield per plant and oil content based on *per se* performance.

10. Among testers Soma and Tilak were identified as best for plant height, number of branches per plant, number of capsules per plant, seed yield per plant and oil content based on *per se* performance.

11. Based on *gca* effects, the lines AVTS-06-5, AVTS-06-10 and IVTS-06-12 and the testers KYM-1, Tilak and TMV-6 were identified as high combiners.

12. Among hybrids, AVTS-06-3 X Tilak had good *per se* performance for plant height, capsule length, 1000 seed weight and oil content; AVTS-06-5 X KYM-1 for number of days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant.

13. AVTS-06-7 X KYM-1 recorded good *per se* performance for number of days to flowering, number of capsules per plant, 1000 seed weight, seed yield per plant and oil content

14. IVTS-06-12 X TMV-3 had good *per se* performance for plant height, number of capsules per plant, capsule length, seed yield per plant and oil content.

15. All the hybrids were found to be overall heterotic compared to better parent.

16. Two hybrids found to possess desirable standard heterosis for earliness indicating the possibility of developing early hybrids.

17. Seven hybrids registered desirable standard heterosis for number of capsules per plant.

18. Nineteen hybrids recorded significant standard heterosis for seed yield per plant.

19. AVTS-06-5 x KYM-1 had high *sca* effects for number of days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant.

20. AVTS-06-5 x KYM-1 and IVTS-06-12 x TMV-3 had significant *sca* effects and standard heterosis for plant height, number of capsules per plant and seed yield per plant.

21. The crosses AVTS-06-5 x VRI- 2 and IVTS-06-12 x Soma for earliness, AVTS-06-10 x TMV-3, IVTS-06-2 x TMV-3 and IVTS-06-6 x TMV-3 for plant height, AVTS-06-5 x Tilak for capsule length AVTS-06-3 x KYM-1 for 1000 seed weight and AVTS-06-5 x TMV-6 and TCR-3279-A x KYM-1for seed yield per plant had non significant *sca* but favourable *gca* of parents for the respective characters and could be taken up for recombination breeding.

22. *S.malabaricum* accessions were collected and evaluated for their morphological characteristics.

23. Interspecific hybridization was successful with the crosses *S.malabaricum* x CO-1, *S.malabaricum* x KYM-1, *S. malabaricum* x Soma and *S. malabaricum* x Surya.

24. Embryo rescue techniques using *in vitro* culture methods were adopted to raise the interspecific crosses.

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APPENDIX 1. MEAN PERFORMANCE OF TRAITS FOR 40 GENOTYPES IN SESAME

Sl No:	Genotype	Number of days to flowering	Plant Height	Number of branches per plant	Number of capsules per plant	Capsule length	Locules per capsule	1000 seed weight	Seed yield per plant	Oil content
1.	KYM – 1	18.73	95.60	5.00	26.07	1.99	4	3.15	4.79	50.17
2.	Surya	25.87	82.40	4.27	19.53	1.96	4	3.15	2.76	49.10
3.	Soma	25.73	107.97	10.80	41.20	2.09	8	3.14	5.77	49.23
4.	Tilak	31.73	90.00	12.13	46.60	1.98	4	3.16	5.48	49.27
5.	Tilatara	31.27	77.27	10.80	50.93	2.00	4	3.17	6.12	49.80
6.	Tilarani	34.80	88.80	6.60	29.00	2.00	4	3.14	4.27	49.77
7.	CO-1	30.93	82.47	8.00	40.53	2.19	4	3.15	5.11	49.73
8.	SVPR-1	28.13	59.30	4.73	45.43	2.07	4	3.17	7.02	49.53
9.	VRI-1	28.40	50.20	11.13	30.80	1.99	4	3.13	4.04	49.90
10	VRI-2	29.40	49.20	5.87	27.27	2.02	4	3.18	3.75	48.60
11.	TMV-3	30.00	68.53	8.53	29.80	2.06	4	3.17	3.82	49.60
12	TMV-4	30.20	57.47	5.47	26.27	1.86	4	3.14	3.91	48.60
13.	TMV-5	31.27	58.40	5.67	23.77	2.10	4	3.18	3.27	48.13
14.	TMV-6	31.87	61.20	5.73	25.87	1.82	4	3.15	3.47	48.30
15.	AVTS-06-1	23.53	32.40	5.67	27.00	1.89	4	3.15	4.05	48.90
16.	AVTS-06-3	21.80	34.00	5.73	22.67	1.87	4	3.15	3.33	49.23
17.	AVTS-06-4	28.80	36.27	5.40	21.93	2.04	4	3.17	3.35	48.50
18.	AVTS-06-5	25.20	35.33	4.47	20.47	2.07	4	3.15	3.15	49.50
19.	AVTS-06-6	26.20	41.20	4.47	23.93	1.91	4	3.15	3.43	46.76
20.	AVTS-06-7	27.07	38.93	4.93	18.27	1.97	4	3.21	2.79	45.53
21.	AVTS-06-9	30.60	32.67	5.00	21.00	2.11	4	3.15	3.14	46.57
22.	AVTS-06-10	26.37	36.26	4.93	21.47	1.99	4	3.16	3.19	47.23
23.	IVTS-06-2	25.76	43.38	4.93	24.16	1.91	4	3.16	3.21	48.67
24.	IVTS-06-3	25.22	42.69	4.80	23.67	1.95	4	3.15	3.27	49.33
25	IVTS-06-6	23.27	49.39	4.77	20.57	1.90	4	3.13	2.77	48.63
26.	IVTS-06-8	24.63	50.07	4.72	20.78	1.95	4	3.11	2.80	48.13
27.	IVTS-06-12	27.10	31.40	4.66	13.15	1.84	4	3.16	1.67	46.10
28	IVTS-06-13	27.53	32.53	4.48	12.76	1.95	4	3.17	1.75	47.83
29.	IVTS-06-15	27.94	39.53	4.80	14.85	2.01	4	3.16	2.12	48.73
30.	IVTS-06-16	28.03	44.97	5.09	15.76	2.02	4	3.15	2.26	48.33
31.	IVTS-06-22	21.41	61.33	7.33	9.96	2.01	4	3.12	1.35	49.33
32.	IVTS-06-26	29.28	59.30	4.61	23.50	2.26	4	3.15	3.79	49.47
33.	IVTS-06-27	27.15	54.01	4.87	19.46	2.23	4	3.16	3.20	47.70
34.	IVTS-06-28	27.05	52.66	5.25	18.34	2.20	4	3.14	3.15	48.83
35.	TCR-2511	22.13	32.07	4.93	12.87	1.90	4	3.14	1.71	48.40
36.	TCR-2527-C	26.07	37.53	4.53	18.40	2.02	4	3.15	2.62	49.53
37.	TCR-3279-A	30.40	55.53	5.07	25.53	2.23	4	3.19	3.70	48.60
38.	TCR-3105	29.13	40.60	4.93	20.47	2.04	4	3.16	3.01	48.37
39.	TCR-4865	28.27	45.93	4.40	24.27	1.99	4	3.11	3.28	49.37
40.	YLM-17	25.53	48.93	4.60	23.33	2.01	4	3.15	3.03	48.70
	Mean	**27.3452**	**53.4423**	**5.8527**	**24.5407**	**2.0098**	**6.0500**	**3.1535**	**3.4685**	**48.6508**
	C.V.	**2.4412**	**1.8296**	**5.7936**	**4.8701**	**2.1223**	**0.0000**	**1.0358**	**3.9742**	**0.8513**
	S.E.	**0.3854**	**0.5645**	**0.1958**	**0.6900**	**0.0246**	**0.0000**	**0.0189**	**0.0796**	**0.2391**

HETEROSIS BREEDING IN SESAME

(*Sesamum indicum* L.)

By

GAYATHRI, G.

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy

(PLANT BREEDING AND GENETICS)

Faculty of Agriculture

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DEPARTMENT OF PLANT BREEDING AND GENETICS

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ABSTRACT

The study entitled 'Heterosis breeding in sesame (*Sesamum indicum* L.)' was undertaken at the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara. The objectives of the study were to collect and evaluate different genotypes of sesame for morphological traits and yield attributes, to identify useful parents producing heterotic crosses and developing hybrids in sesame. The study also intended to develop male sterile lines in sesame through interspecific hybridization with *Sesamum malabaricum.*

Sesamum indicum and *Sesamum malabaricum* accessions were collected from Kerala and Tamil Nadu and evaluated for their morphological traits. Wide range of variation was noticed for characters like plant height, number of days to flowering and seed yield per plant which contributed maximum to genetic divergence. The genotypes studied were grouped into six clusters.

High genotypic coefficient of variation (GCV) was recorded for number of capsules per plant, plant height, seed yield per plant and number of branches per plant. High heritability with high genetic advance as per cent of mean was recorded for number of days to flowering, plant height, number of branches per plant, number of capsules per plant and seed yield per plant. This indicates that the characters are governed by additive gene effects and selection for these traits will be effective.

Association analysis revealed that seed yield per plant was correlated to plant height, number of capsules per plant and number of days to flowering. Path coefficient analysis indicated maximum positive direct effect by number of capsules per plant, capsule length, plant height and 1000 seed weight on seed yield per plant.

In order to develop hybrids, fourteen parents were selected based on the *per se* performance of the genotypes. They were crossed in line X tester mating design. Forty eight hybrid combinations obtained were raised in the field along with the parents and evaluated for their heterosis and combining ability effects.

Parental genotypes AVTS-06-5, AVTS-06-10, IVTS-06-12, KYM-1, Tilak and TMV-6 were identified as high combiners based on general combining ability (*gca)* effects. Two combinations viz. AVTS-06-5 X KYM-1 and IVTS-06-12 X TMV-3 had significant values of *per se* performance, specific combining ability (*sca)* effects and standard heterosis for seed yield per plant. They can be evaluated for their hybrid vigour over locations and seasons.

The crosses AVTS-06-5 X TMV-3, AVTS-06-5 X TMV-6 and TCR 3279A X KYM-1 have been identified as potential cross combinations for isolation of promising segregants as the parents involved in these crosses had high significant *gca* effects for seed yield per plant but the hybrids recorded non significant *sca* effects.

Interspecific hybridization between *S.malabaricum* and *S.indicum* was attempted to develop male sterile lines. Seed set was noticed in three interspecific hybrids which failed to germinate due to embryo abortion. Hence these embryos were rescued and raised *in vitro* to obtain the hybrids.