A Seminar Paper
On

Combining Ability and Heterosis for Vegetables Improvement

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ABSTRACT

This review paper had been prepared on combining ability and heterosis for vegetables improvement to know the extent of combining ability and heterosis for economic trait improvement of different vegetables. All data and informations were collected from secondary sources. In this study good general combiner was found in parents of tomato (P3) for yield related trait; bitter gourd (P1, P2) for earliness; cabbage (P4, P1, P3) for antioxidant and nutritional value and tomato (P1) for pest resistance. Highest SCA effect was found in hybrids of brinjal (L3×T3, L4×T2) for yield related traits; bottle gourd (P1×P2) for earliness; cauliflower for ascorbic acid (L2×T2), anthocyanin (L3×T1), lycopene (L2×T1), carotenoid (L2×T4); tomato (L1×T3, L2×T2, L1×T4). In case of heterosis highest standard heterosis was found in hybrid of ridge gourd (L1×T1) for yield. Heterosis for earliness was found in squash hybrid (P7×P4) with lowest mean value. Economic heterosis for earliness was also found in sponge gourd hybrids (P1×P2, P4×P6). Highest economic heterosis for carotenoid was found in cabbage hybrid (P2×P6) and for ascorbic acid (P3×P9). Highest heterosis over mid-parent, better parent and check was found in cucumber hybrid (P1×P2). Study of GCA effects helps to select best performing parents and SCA effects help to select the best cross combination for utilization in breeding program. And Study of heterosis helps to utilize heterosis for developing improved cultivars of different vegetables through heterosis breeding and ultimately vegetables production can be increased.

Key words: GCA, SCA,Heterosis, Heterosis breeding.

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CHAPTER I

INTRODUCTION

Vegetable may be defined as "any plant part (roots, stems, leaves, flowers, fruits, and seeds) which is used for food. A textbook indicated that important self-pollinated vegetable crops that have been researched extensively include the legumes [bean (*Phaseolussp*.) and pea (*Pisumsativum* L.)], Solanaceae [eggplant (*Solanummelongena* L.), pepper (*Capsicum nigrum* L.), tomato (*Lycopersiconesculentum* Mill.)], and lettuce (*Lactuca sativa* L.) and important cross-pollinated vegetable crops include the cucurbits [cucumber, melon (*Cucumismelo* L.), squash (*Cucurbitasp*.), and watermelon], the cole crops [broccoli (*Brassica oleracea* L.), cabbage (*Brassica oleracea* L.), and cauliflower (*Brassica oleracea* L.)], root and bulb crops [carrot (*Daucuscarota* L.) and onion (*Allium cepa* L.),], asparagus (*Asparagus ojjicianalis* L.), and spinach (*Spinaciaoleracea* L.) Wehner, T. C. (1999). Vegetables can be eaten either raw or cooked and play an important role in human nutrition. Vegetables make up a major percentage of the human diet in many locations of the world and play a significant role in human nutrition, especially as sources of phytonutriceuticals: vitamins, minerals, dietary fiber and phytochemicals (Ryder, E., 2011). Some phytochemicals of vegetables are strong antioxidants and are thought to reduce the risk of chronic disease by protecting against free-radical damage, by modifying metabolic activation and detoxification of carcinogens, or even influencing processes that alter the course of tumor cells (Wargovich, M. J., 2000). Billions of people especially in developing countries suffer from micronutrient malnutrition ‘‘Hidden Hunger’’ caused by insufficient intake of micronutrients such as Vitamin-A, zinc and iron (Harvest Plus, 2007). More than 70% of malnourished children live in Asia. At least half of the preschool children and pregnant women are affected by micronutrient deficiencies in Bangladesh, Cambodia, Nepal and the Philippines (Talukder*et al*., 2010). Vegetables provide these micronutrients and regular consuming vegetables may reduce the incidence of being malnutrition and provide nutrition to the poor people at least cost.

Crop improvement involves strategies for enhancing yield potentiality and quality components (Singh *et al*., 2013). Heterosis and combining ability studies are prerequisite in any plant breeding programme, which provides the desired information regarding the varietal improvement or exploiting heterosis for commercial purposes (Singh *et al*., 2013). Identification of the best performing lines (for commercial release) and lines which can be used as parents in future crosses are two principal objects considering in most crop breeding programs (Oakey*et al*., 2006).The combining ability analysis is an important tool in preferring suitable parents for hybridization and superior cross combinations through general combining ability (GCA) and specific combining ability (SCA), respectively (Sharma *et al*., 2016). It can seldom be predicted just based on parental phenotype and hence it is measured by progeny testing. When parental plants produce potent offspring, they are said to have good combining ability (Vasal*et al*., 1999). Combining ability or productivity in crosses is defined as the cultivars or parents ability to combine among each other during hybridization process such that desirable genes or characters are transmitted to their progenies (Fasahat*et al*., 2016). Sprague and Tatum (1942) defined GCA as the average performance of a genotype in a series of hybrid combinations and SCA as those cases in which certain hybrid combinations perform better or poorer than would be expected on the basis of the average performance of the parental inbred lines. Parents showing a high average combining ability in crosses are considered to have good GCA while if their potential to combine well is bounded to a particular cross, they are considered to have good SCA (Fasahat*et al*., 2016). Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits (Muttappanavar*et al*., 2014).

Heterosis or hybrid vigour is a phenomenon that describes the survival and performance superiority of a hybrid offspring over the average of both its genetically distinct parents (Baranwal*et al*., 2012). According to Shull (1948) heterosis is “the increased vigor, size, fruitfulness, speed of development, resistance to diseases and insect pests manifested in cross-bred organisms as compared to corresponding inbred, as the specific result of unlikeness in the constitution of uniting parental gametes”. A textbook on “Genetics and exploitation of heterosis in crops” indicated that hybrid vigor, or heterosis, usually refers to the increase in size or rate of growth of offspring over parents; for example, hybrid vigor in crop plants can be observed as in increase in yield of grain, or reduction in number of days to flower (Duvick, 1999). Heterosis breeding provides an opportunity for achieving unique improvement in yield and other desirable attributes in one generation that would be more time consuming and difficult with other conventional breeding methods (Sherpa *et al*., 2014).Singh *et al*. (2017) indicated that it is a fast and convenient way to combine desirable characters of a vegetable together, for example fruit size and colour, plant type and disease resistance, and as a mean to control intellectual property rights through control and protection of the parental lines by the breeders. Combining ability study gives the best combiners which are used as parents of breeding program and utilizing these best combiners desired trait such as yield and yield related traits, earliness, antioxidant and nutrient quality can be improved in vegetables.

Objectives:

1. To review the extent of combining ability for improving various economic traits of different vegetables.
2. To highlight the extent of heterosis for various economic traits improvement of different vegetables.

CHAPTER II

MATERIALS AND METHODS

This paper is absolutely a review paper. With a view to preparing this paper, all informations were collected from secondary sources.The topic related findings have been reviewed by internet browsing, studying extensively various articles and research papers published in varied journals, books, proceedings, dissertation available in online. Valuable suggestion and information were received from honorable major professor and course instructors. After collecting information, these were compiled and organized chronologically for preparing this seminar manuscript.

CHAPTER III

REVIEW OF FINDINGS

3.1 Combing Ability

Combining ability is an estimation of the value of genotypes on the basis of their offspring performance in some definite mating design (Allard, 1960). From a statistical viewpoint, the GCA is a main effect and the SCA is an interaction effect (Kulembeka*et al*., 2012). Based on Sprague and Tatum (1942), GCA is owing to the activity of genes which are largely additive in their effects as well as additive × additive interactions. "Specific combining ability is regarded as an indication of loci with dominance variance (non-additive effects) and all the three types of epistatic interaction components if epistasis were present. They include additive × dominance and dominance × dominance interactions" (Griffing, 1956). Triveni*et al*. (2017) reported that "A knowledge of general combining ability (GCA) variances, reveals the existence of additive gene action while specific combining ability (SCA) variances reveals non additive gene action".

3.1.1 Combing Ability for Yield and Yield Related Traits

3.1.1(a) General combining ability effect

General combining ability of tomato parents for yield related traits is described in Table 1. According to Dharva*et al*. (2018), parent P3 were found to be good general combiners for fruit yield per plant, its other yield contributing characters. Dharva*et al*. (2018), mention that among parents, high GCA effect for fruit yield per plant was found in P3 were associated positive significant GCA effect for number of fruits per plant, average fruit weight. Almost identical results have been reported by Kumar *etal*. (2015), Bhattarai *et al*. (2016), Jaiprakashnarayan *et al.* (2016), Josna Jose *et al*. (2016) and Jadav*et al*. (2017).Dharva*et al*. (2018), also reported that high general combining ability of P3 for one or more yield attributing traits might be resulted in to higher combining ability for fruit yield. The parent could therefore effectively utilize in breeding programme for developing high yielding hybrids.

Table 1 Estimates of GCA effects of parents for yield related traits in tomato

Characters	Parental cultivars			
	P1	**P2**	**P3**	**P4**
No. of fruits per plant	3.13*	-0.91	1.18*	-0.89
Average fruit weight(g)	-6.61**	1.26	2.39*	2.90*
Fruit yield per plant(kg)	-0.02	-0.03	0.16*	0.03

*- Significant at 5% and **- Significant at 1%

P1=Avto-2, P2= Avto-3, P3= Avto-4, P4= Avto-7

(Source: Modified from Dharva*et al*., 2018)

3.1.1(b) Specific combining ability effect

Specific combing ability for brinjal crosses is described in Table 2.According to Khapte*et al*. (2013), SCA effect for per cent fruit set was highest in the cross L3 x T3 (9.61). Khapte*et al*. (2013) indicated that the cross L4 x T2 (1.90) recorded high SCA effect for fruit length and the cross L6 x T2 (1.73) for fruit diameter. Khapte*et al*. (2013) also indicated that SCA effect for average fruit weight was highest in the cross L2 x T3 (23.15).

Table 2 Estimates of SCA effect of crosses for yield related traits in brinjal

Characters	Cross				
	L2×T3	**L3×T3**	**L4×T2**	**L6×T2**	**L6×T3**
% Fruit set	4.87**	9.61**	-0.05	1.27	-7.06**
Fruit length (cm)	-0.09	1.41**	1.90**	1.65**	-0.95**
Fruit diameter (cm)	-0.47	1.23**	1.50**	1.73**	-1.19**
Average fruit weight(g)	23.15**	3.60**	13.00**	-4.33	-8.61*
No. of fruits per plant	-4.06**	-2.84**	3.26**	-0.28	5.38**
Fruit yield per plant(kg)	0.08	-0.16*	0.66**	0.15*	0.34*

*- Significant at 5% and **- Significant at 1%

(Source: Modified from Khapte*et al*., 2013)

For number of fruits per plant, the cross L6 x T3 (5.38) recorded highest SCA effect. Good specific combiner for yield per plant turned out to be the cross L4 xT2 (0.66).Among the crosses, L4 x T2 and L3 x T3 were good specific combiners for most of the yield attributing traits, and can be exploited for heterosis breeding and further subjected to selection to isolate desirable genotypes in Manjarigota type brinjal.

3.1.2 Combing Ability for Earliness

3.1.2(a) General combining ability effect

General combining ability of bitter gourd parents for earliness is described in Table 3.According to Bhatt *et al*. (2017), parents P1 showed highest significant negative GCA value for days to first flowering followed by P2 and P4. Bhatt *et al*. (2017), also indicated that P1, and P2 were found good general combiner for earliness.

Table 3 Estimates of GCA effects of parents for earliness in bitter gourd

Characters	**Parents**			
	P1	**P2**	**P3**	**P4**
Days to first female flowering	-2.87**	-2.14**	0.13	-2.14**
Days to first fruit set	-2.56**	-1.83**	-0.19	-1.92**
Days to first harvest	0.30	-3.24**	5.12**	-1.33

*- Significant at 5% and **- Significant at 1%

P1=Punjab-14, P2=ArkaHarit, P3=Panipat Local, P4=KalyanpurSona

(Source: Modified from Bhatt *et al*., 2017)

3.1.2(b) Specific combining ability effect

Specific combining ability for earliness of bottle gourd crosses is described in Figure 1. According to Shinde*et al*. (2016)' the cross combination P1×P2 showed highest significant negative SCA effect for both days to first female flower (-8.73) and days to first harvest (-9.09)respectively followed by P1×P4, P1×P5, P2×P3, P3×P6, P3×P7. Shinde*et al*. (2016) also reported that these crosses can be exploited for further heterosis breeding for improvement in bottle gourd.

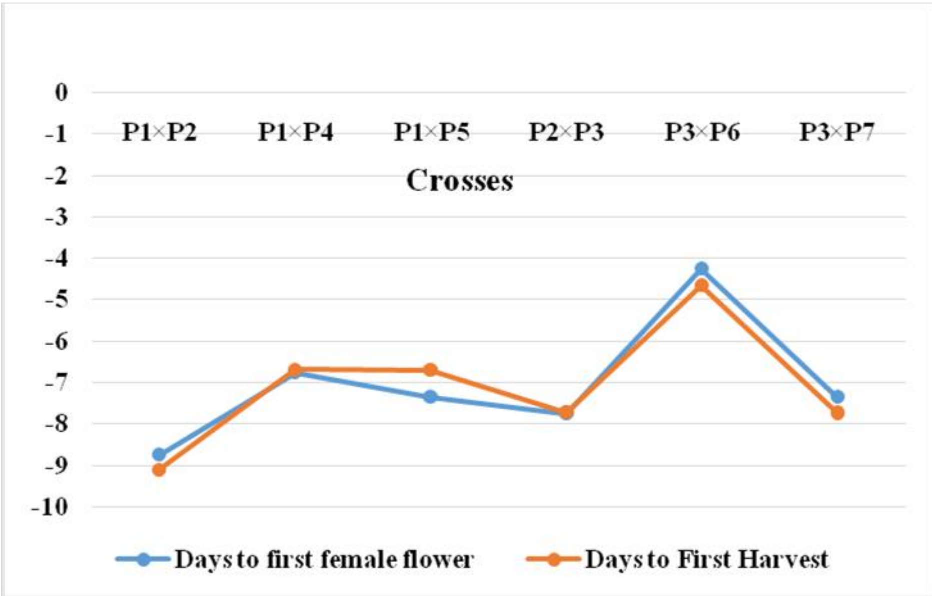

Figure 1: SCA effect of crosses for earliness in bottle gourd.

P1×P2= Samrat X Pusa Summer Prolific Long, P1×P4= Samrat X NDBG 619, P1×P5= Samrat X NDBG 129, P2×P3= Pusa Summer Prolific Long X PusaSamrudhi, P3×P6= PusaSamrudhi X DBG 5, P3×P7= PusaSamrudhi X Bhagirathi.

(Source: Modified from Shinde*et al*., 2016)

3.1.3 Combing Ability for Antioxidant and Nutritional Value

3.1.3(a) General combining ability effect

General combining ability of Cabbage CMS lines for antioxidants is described in Table 4. According to Singh *et al*. (2018), the CMS lines P4, P1 and P3 were good general combiner and CMS line P2 was poor general combiner for majority of traits.Singh *et al*. (2018) also indicated that line P4 was found significantly good general combiner for all the antioxidants except FRAP and the line P3 exhibited highly positive significant GCA effects at P ≤ 0.001 for all the traits except lycopene, b-carotene. Singh *et al*. (2018) also reported that P1 exhibited significantly positive GCA effects for FRAP, ascorbic acid, lycopene, total carotenoids respectively.

Table 4 Estimates of GCA effects of CMS lines for antioxidants in cabbage

Characters	**Parents**			
	P1	**P2**	**P3**	**P4**
CUPRAC	0.04***	-.07***	0.18***	0.10***
FRAP	1.07***	-0.06***	0.05***	0.00
Ascorbic acid	1.76***	-2.60***	1.73***	1.55***
Phenols	-76.84***	-89.92***	223.67***	39.74***
Anthocyanin	-0.06***	-0.02	0.20***	0.24***
Lycopene	-0.02***	-0.02***	-0.01*	0.00
Beta carotene	0.07***	-0.02*	-0.04***	0.04***

* = significant at 5% probability, ** = significant at 1% probability, *** = significant at 0.1%

P1=Ogu122-5A, P2=Ogu118-6A, P3=Ogu119-1A, P4=Ogu33-1A

(Source: Modified from Singh *et al*., 2018)

3.1.3(b) Specific combining ability effect

Specific combining ability effects for Ascorbic acid and Anthocyanin of crosses in cauliflower is described in Figure 2. According to Dey*et al*. (2014), highest SCA effect in positive direction was found in the cross combination L2×T2 (24.21)for ascorbic acid concentration andfor anthocyanin content cross combination L3×T1 (0.25) exhibited highest SCA effect in positive direction.

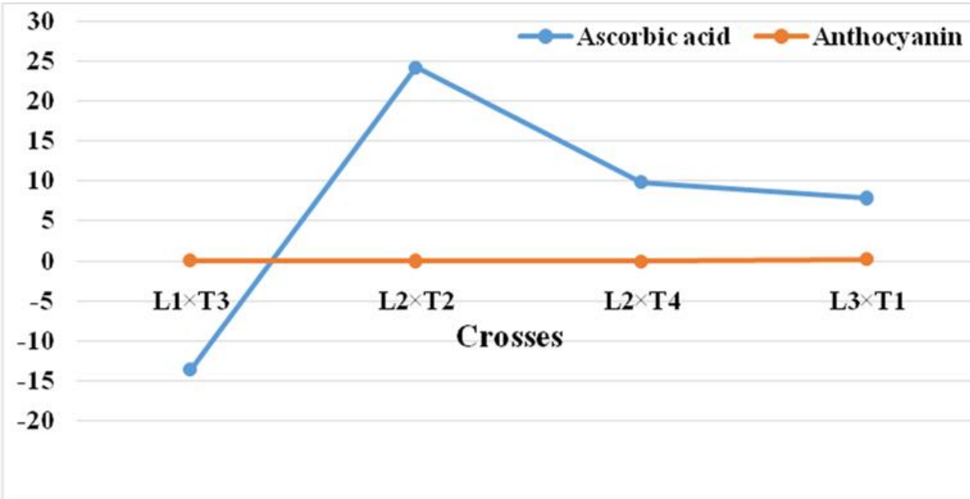

Figure 2: SCA effect of crosses for ascorbic acid and anthocyanin in cauliflower.

L1×T3=Ogu13A×Kt-2, L2×T2= Ogu14A×Sel-27, L2×T4= Ogu14A×PSBK-1, L3×T1= Ogu33A×HLSRO5

(Source: Modified from Dey*et al*., 2014)

Specific combining ability effects for Lycopene and β-carotene of crosses in cauliflower is described in Figure 3. Dey*et al*. (2014), mention that the highest SCA effect for lycopene content was recorded in the hybrid L2×T4 (0.41), followed by hybrid L1×T3 (0.40). Dey*et al*. (2014), also reported that the hybrid L2×T4 (39.93) followed by hybrid L1×T3 (32.62) showed high SCA for β-carotene content.

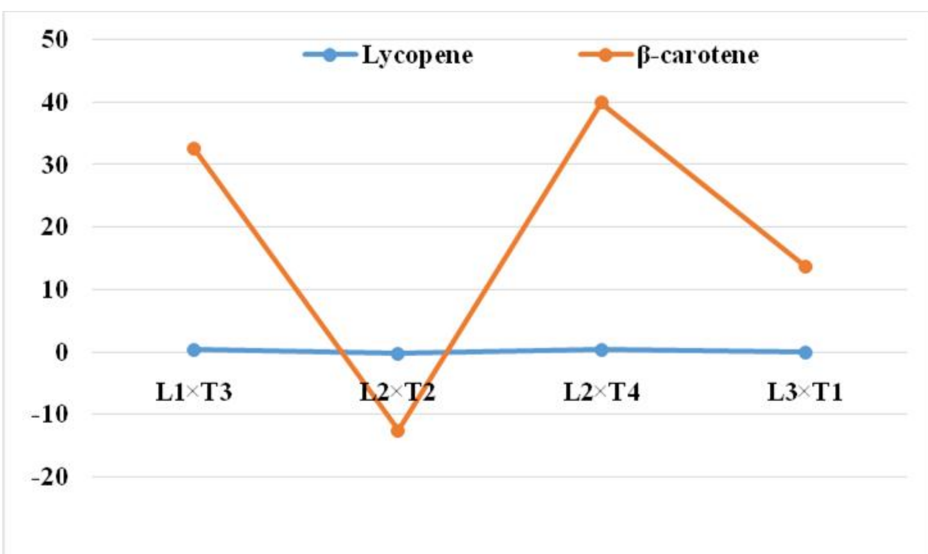

Figure 3: SCA effect of crosses for lycopene and β-carotene in cauliflower.

L1×T3=Ogu13A×Kt-2, L2×T2= Ogu14A×Sel-27, L2×T4= Ogu14A×PSBK-1, L3×T1= Ogu33A×HLSRO5

(Source: Modified from Dey*et al.*, 2014)

3.1.4 Combing Ability for Disease and Pest Resistance

3.1.4(a) General combing ability effect

General combining ability of parents for pest resistance in tomato is described in Table 5. According to Izge and Garba (2012), the general combining ability effect for number of fruits/plant showed that P1 had the highest positive and significant value (40.04**), followed by P2 (21.46**) and P3 (20.63**). P4 showed insignificant negative GCA values. Izge and Garba (2012) also reported that all the remaining traits of which some were positive and negative did not show any significant values in their GCA effects.

Table 5 Estimates of GCA effects of parents for pest resistance in tomato

Characters	**Parents**			
	P1	**P2**	**P3**	**P4**
Trichome count	0.24	0.60	-0.07	-0.49
No. of fruits per plant	40.04**	21.46*	20.63*	-4.29
Weight of fruits per plant(g)	1.26	0.61	0.75	0.13
% damaged fruits	-4.81	-5.01	-4.50	-0.95

*- Significant at 5% and **- Significant at 1%

P1=Cherry, P2=US, P3=Roma VF, P4=Tandino

(Source: Modified from Izge and Garba, 2012)

3.1.4(b) Specific combining ability effect

Specific combining ability (SCA) effect of hybrids for pest resistance in tomato is described in Table 6. According to Izge and Garba (2012), the four cross combinations L1×T3 (15.21**), L2×T2 (14.38**), L1×T4 (12.38**) and L2×T1 (9.88**) showed highly significant and positive values for number of fruits/plant. Mahendrakar (2004), Premalkshmin*et al*. (2006) and Asati*et al*. (2007) also indicated positive and significant SCA effects for number of fruits/plant in tomatoes. Izge and Garba (2012) reported that these same sets of hybrids parenthetically had the highest number of trichome count and could mean that some level of resistance consequential due to the presence of the glandular trichome was at display and these give rise to high number of fruits/plant. Heinz and Zalom (1995) reported similar result. Izge and Garba (2012) suggested that these hybrids or cross combinations could be exploited for the improvement of tomato to fruit worm resistance, number of fruits/plant and yield as per they have displayed some levels of stability in their specific combining abilities.

Table 6 Estimates of SCA effect of hybrids for pest resistance in tomato

Characters	**Crosses**			
	L1×T3	**L1×T4**	**L2×T1**	**L2×T2**
Trichome count	0.51	0.10	0.15	0.32
No. of fruits per plant	15.21**	12.38**	9.88**	14.38**
Weight of fruits per plant(g)	0.55	0.37	0.31	0.44
% damaged fruits	-7.58	-4.41	-3.95	-3.72

*- Significant at 5% and **- Significant at 1%

L1×T3=Cherry × Hong Large, L1×T4=Cherry × Golden Roma L2×T1=Current × UC, L2×T2=Current × Roma VF

(Source: Modified from Izge and Garba, 2012)

3.2 Heterosis

Genetic basis of heterosis in crops is explain by two hypotheses that is, the dominance hypothesis (Davenport, 1908) and the overdominance hypothesis (East, 1908). The dominance hypothesis states that deleterious alleles at different loci in parental genomes are countered in the F1, producing a better phenotype. The overdominance hypothesis states that improved performance of an F1 hybrid, in relation to its inbred parents, is a result of favorable allelic interactions at heterozygous loci that outperform either homozygous parent. Utilization of heterosis increases productivity and contributes to increase of agricultural production (Huang *et al*., 2006; Stuber, 1994; Yuan, 1998) and quality (Gwanama*et al*., 2001). Heterosis has been utilized to exploit dominance variance through production of hybrids (Ahmed et al., 2003; Olfati*et al*., 2011).

3.2.1 Heterosis for Yield and Yield Related Traits

Heterosis for yield and yield related traits is described in Figure 4, Figure 5 and Table 7. In Figure 4 (a) showed whole plants of parents (P1, Black leaf succession; P2, Early summer) and their F1 hybrid on the 83rd day after transplanting and (b) showed vertically divided heads (Tanaka and Niikura, 2006).

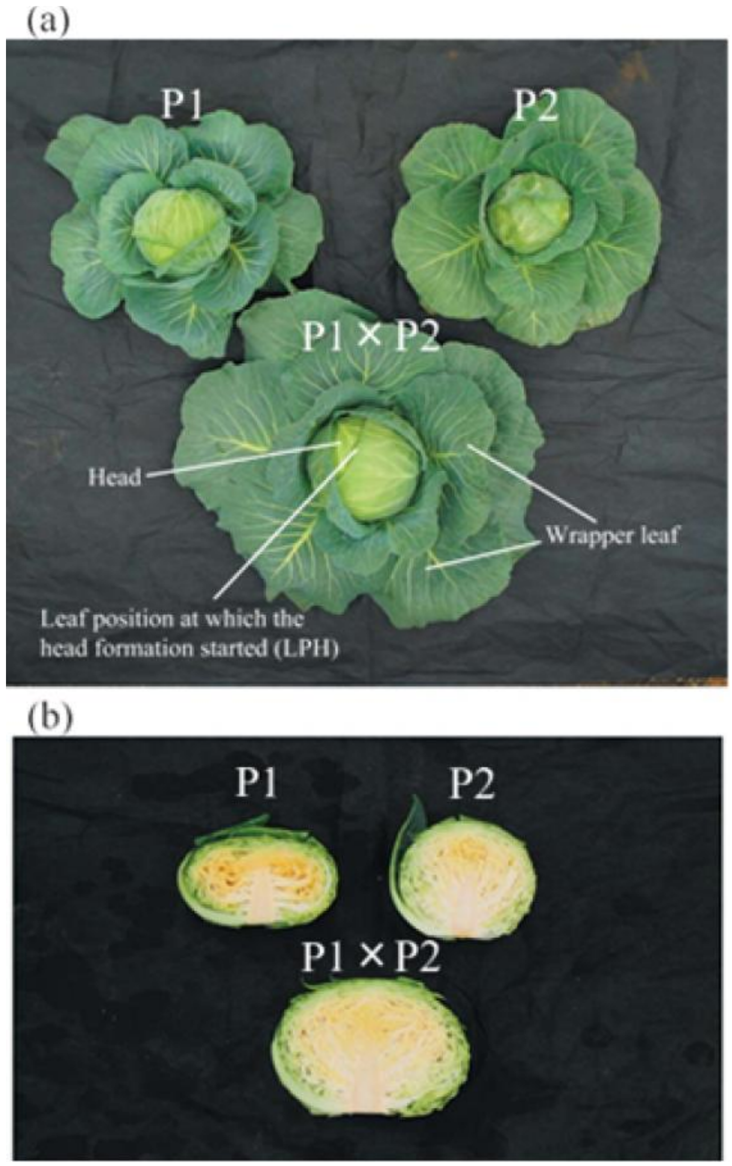

Figure: 4 An example of heterosis in cabbage.

(Source:Tanaka and Niikura, 2006)

According to MH and Jadav (2018), the cross L1×T1 exhibited the highest standard heterosis for fruit yield per vine (26.25), no. of fruits per vine (38.61) and fruit weight (27.05) followed by cross L1×T2, L1×T3 and cross L2×T3 exhibited higher standard heterosis. MH and Jadav (2018) also indicated that cross L2×T3 exhibited highest standard heterosis (12.17) for fruit length and cross L1×T2 exhibited highest standard heterosis (52.17) for girth of fruit.

Table 7 Comparative study of four most standard heterotic crosses for fruit yield per vine along with their heterotic effects for component characters in ridge gourd

Characters	Crosses			
	L1×T1	L1×T2	L1×T3	L2×T3
Fruit yield per vine	26.55**	17.23**	17.11**	14.23**
No. of fruits per vine	38.61**	30.38**	27.85**	20.25**
Fruit weight	27.05**	17.23**	16.83**	14.23**
Fruit length	4.41**	-8.03	0.33	12.17*
Girth of fruit	18.34**	52.17**	25.41**	8.70

*- Significant at 5% and **- Significant at 1%

L1×T1= JRG-13-04 x Jaipur Long, L1×T2= JRG-13-04 x ArkaSujat, L1×T3= JRG-13-04 x PusaNasdar, L2×T3= JRG-13-07 x PusaNasdar

(Source: Modified from MH and Jadav, 2018)

MH and Jadav (2018) reported that crosses L1×T1, L1×T2, L1×T3 exhibited high per se fruit yield per vine (Figure 5) and these crosses also showed significant and desirable heterobeltiosis and standard heterosis. MH and Jadav (2018) suggested that these three cross combinations might be exploited as commercial hybrids, after testing on large scale as well as for its reaction to major diseases and pests.

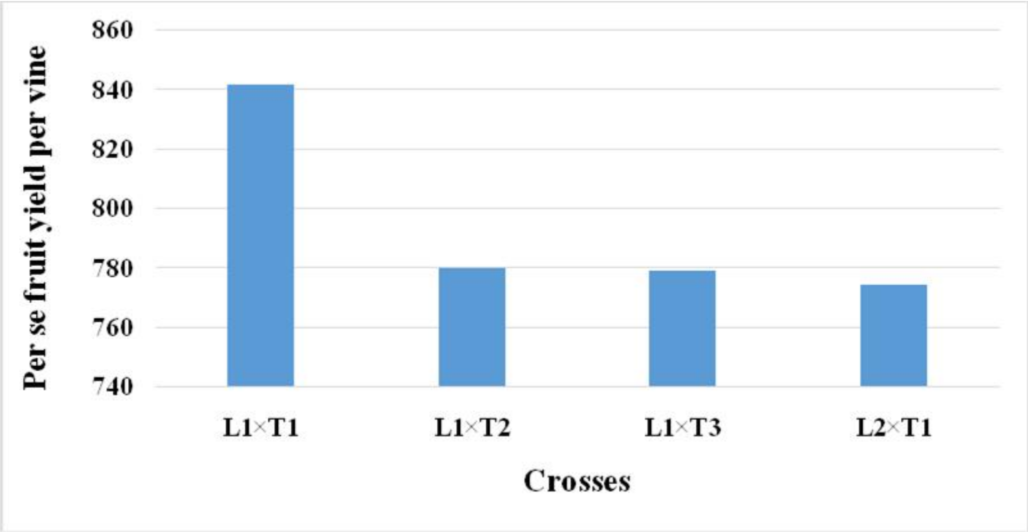

Figure: 5 Per se fruit yield per vine in crosses in ridge gourd.

L1×T1= JRG-13-04 x Jaipur Long, L1×T2= JRG-13-04 x ArkaSujat, L1×T3= JRG-13-04 x PusaNasdar, L2×T1= JRG-13-07 x Jaipur Long

(Source: Modified from MH and Jadav, 2018)

3.2.2 Heterosis for Earliness

Earliness is an important economic character, as it gives earliest yield and at the same time may widen the flowering and fruiting span of the plants, which ultimately result in higher fruit yield. Heterosis for earliness is described in Figure 6 and Table 8. According to El-Adl*et al*. (2014), (Figure 6) the highest mean value for days to 1st female flower exhibited by P6 × P2 (34.93) which was undesirable. El-Adl*et al*. (2014) reported that hybrid P7 × P4 exhibited the lowest mean value for both days to 1st female flower (26.37) and days to 1st harvest which was desirable for earliness.

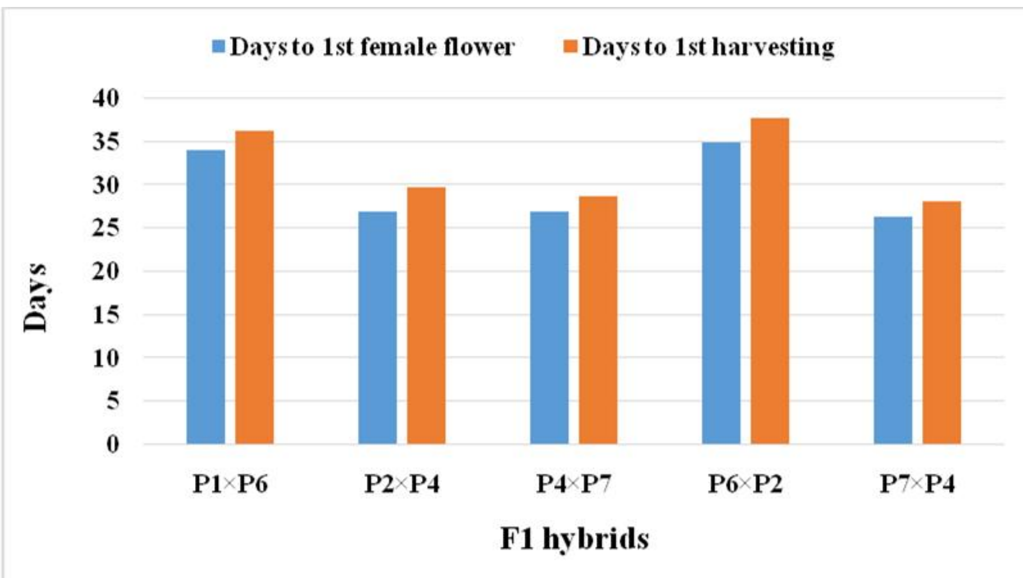

Figure: 6 The mean performances of the F1 hybrids for earliness traits in squash.

(Source: Modified from El-Adl*et al*., 2014)

According to Venugopala*et al*. (2019), the F1 hybrids P1×P2 (-14.42%) and P4 ×P6 (-11.54%) exhibited (Table 8) the highest economic heterosis for days to first female flower appeared. Venugopala*et al*. (2019) also indicate that P1×P2 and P1×P7 exhibited highest standard heterosis for days to 1st fruit harvest. The heterosis for earliness has also been reported by Maurya and

Singh (1994) and Singh *et al*. (1996) in bottle gourd; Munsi and Sirohi (1993) in bitter gourd; Tyagi (1997) and Sharma *et al*. (2002) in ridge gourd.

Table 8 Estimation of standard heterosis for earliness traits in sponge gourd

Characters	**F1 hybrids**			
	P1×P2	**P1×P7**	**P4×P6**	**P5×P3**
Days to female flower appearance	-14.42**	-5.77	-11.54**	-8.65
Days to 1st harvest	-10.45*	-8.21*	-3.73	-9.70
Days to last harvest	11.01	4.40	1.26	5.66

*- Significant at 5% and **- Significant at 1%

P1×P2=Kulgodlocal×Pusachikini, P1×P7=Kulgod local×KRCCH-1, P4×P6=SG-4×SG-6, P5×P3= SG-5×SG-3

(Source: Modified from Venugopala*et al*., 2019)

3.2.3 Heterosis for AntioxidantandNutritional value

According to Singh *et al*. (2009), (Figure 7) hybrid P2×P6 (1865.3) showed high amount of carotenoid followed by P1×P8 (913.3) and exhibited significant and high economic heterosis for carotenoid content in cabbage head.

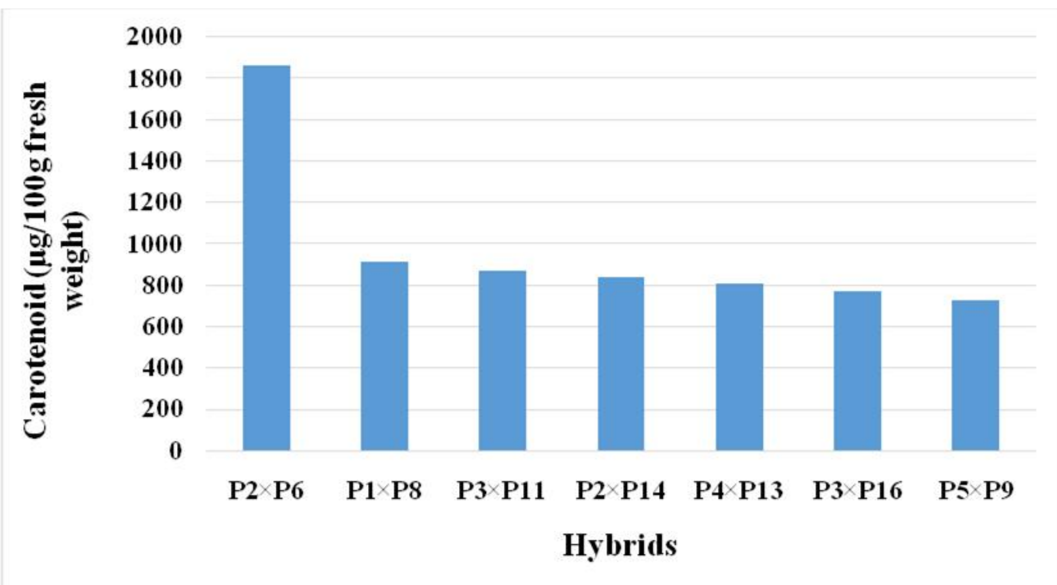

Figure: 7 Carotenoid content in hybrids of cabbage.

P2 × P6=Golden Acre × AC-204, P1 × P8=CMS-GA × PusaMukta, P3 × P11=83-1 × C 2, P2 × P14= Golden Acre × MR 1, P4 × P13= 83-2 × EC 490192, P3 × P16= 83-1 × AC 1021, P5 × P9= Pride of Asia × C 4.

(Source: Modified from Singh *et al*., 2009)

According to Singh *et al*. (2009), the highest amount of ascorbic acid content (Figure 8) found in hybrid P3×P9 (54.3) followed by P2×P9 (53.6), P5×P8 (52.7), P5×P9 (52.7) and exhibited significant and high economic heterosis for ascorbic acid content in cabbage head. According to Singh *et al*. (2009) also indicated the superior hybrids in cabbage those were the best for Fe, Zn, Mn and Cu content. Singh *et al*. (2009) also reported that the three hybrids (CMS-GA× AC-1021, Golden Acre × EC-490192 and Golden Acre × PusaMukta) have the potential to improve the macronutrient content in cabbage head through heterosis breeding.

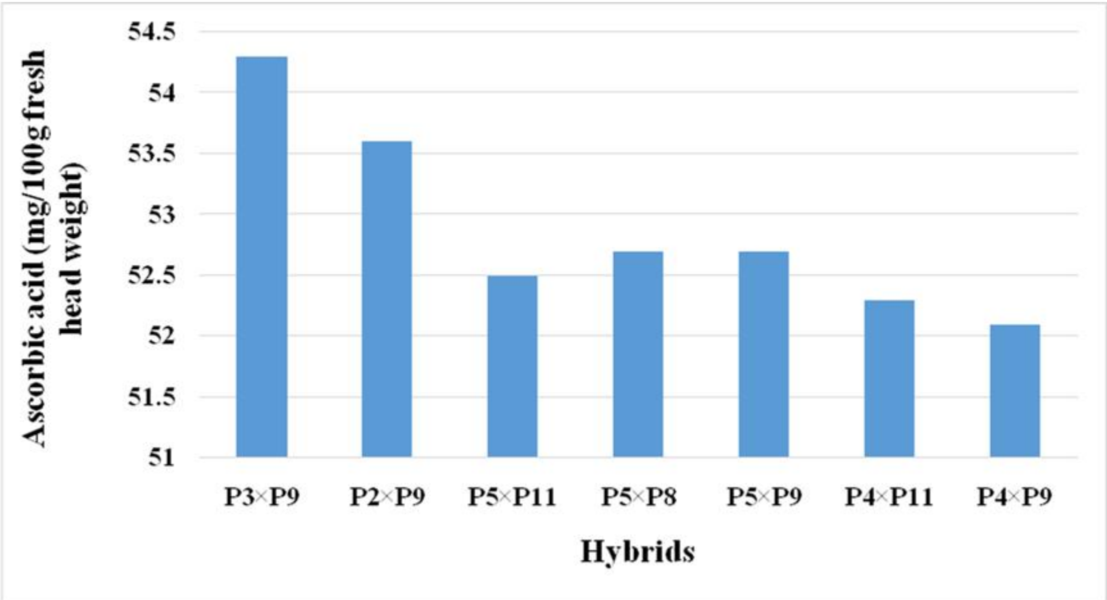

Figure: 8 Ascorbic acid content in hybrids of cabbage.

P3×P9= 83-1× C 4, P2×P9= Golden Acre× C 4, P5×P11= Pride of Asia ×C 2, P5×P8= Pride of Asia× PusaMukta, P5×P9= Pride of Asia× C 4, P4×P11= 83-2× C 2, P4×P9= 83-2× C 4.

(Source: Modified from Singh *et al*., 2009)

3.2.4 Heterosis for DiseaseandPest Resistance

According to Pradhan *et al*. (2017) only hybrid P1×P2 exhibited significant negative heterosis over mid parent (-63.64%), better parent (-75%) and standard check (-60%) and was found to be the best among the hybrids. Pradhan *et al*. (2017) reported that hybrid P1×P3 exhibited significant negative heterosis over better parent (-54.55%) and standard check (-50.00*). Pradhan *et al*. (2017) also indicated that hybrids P1×P4 (-57.14%), P1×P3 (-54.55%) and P1×P5 (-41.67%) exhibited significant negative better parent heterosis. Heterosis for pest and disease resistance also reported by Thakur *et al*. (2019) in cucumber hybrids. Pradhan *et al*. (2017) suggested that there is a good opportunity for developing disease resistance competency of plants especially hybrid cucumbers by means of heterosis breeding.

Table 9 Heterosis % over mid-parent, better parent and check for downy mildew scoring in cucumber

Hybrids	**Heterosis % over**		
	Mid-parent	Better parent	Check
P1×P2	-63.64**	-75.00**	-60.00*
P1×P3	-41.18	-54.55*	-50.00*
P1×P4	-40.00	-57.14**	-40.00
P1×P5	-22.22	-41.67*	-30.00

*- Significant at 5% and **- Significant at 1%

P1×P2= Hot Season × White Long, P1×P3= Hot Season × PusaSanyog, P1×P4= Hot Season × PCO-2, P1×P5= Hot Season × Priya.

(Source: Modified fromPradhan *et al*., 2017)

CHAPTER IV

CONCLUSIONS

- GCA effect helps to select best performing parents of different vegetables those possess higher yield, earliness, higher nutritional value, antioxidant and biotic stress resistance and SCA effect help to select the best cross combination having those characters.
- Proper utilization of heterosis will give improved cultivars of different vegetables possess higher yield, earliness, higher mineral content, antioxidant and fetching biotic stress resistance through heterosis breeding.

REFERENCES

Ahmed, E. A., Oaf, H. I., & El Jack, A. E. (2003). Combining ability and heterosis in line x tester crosses of summer squash (cucurbitapepo l.). *Cucurbit Genetics Cooperative Report*, *26*, 54-56.

Allard, R. W. (1960). Principies of Plant Breeding John Wiley. *New York*.

Baranwal, V. K., Mikkilineni, V., Zehr, U. B., Tyagi, A. K., & Kapoor, S. (2012). Heterosis: emerging ideas about hybrid vigour. *Journal of experimental botany*, *63*(18), 6309-6314.

Bhatt, L., Singh, S. P., Soni, A. K., &Samota, M. K. (2017). Combining Ability Studies in Bitter Gourd (Momordicacharantia L.) for Quantitative Characters. *Int. J. Curr. Microbiol. App. Sci*, *6*(7), 4471-4478.

Bhattarai, U., Sharma, A., Das, R., &Talukdar, P. (2016). Genetic analysis of yield and yield-attributing traits for high temperature resistance in tomato. *International Journal of Vegetable Science*, *22*(6), 585-597.

Davenport, C. B. (1908). Degeneration, albinism and inbreeding. *Science*, *28*(718), 454-455.

Dey, S. S., Singh, N., Bhatia, R., Parkash, C., &Chandel, C. (2014). Genetic combining ability and heterosis for important vitamins and antioxidant pigments in cauliflower (Brassica oleracea var. botrytis L.). *Euphytica*, *195*(2), 169-181.

Dharva, P. B., Patel, A. I., Vashi, J. M., &Chaudhari, B. N. (2018). Combining ability analysis for yield and yield attributing traits in tomato (Solanumlycopersicum L.). *Int. J. Chem. Studies*, *6*, 2342-48.

Duvick, D. N. (1999). Heterosis: feeding people and protecting natural resources. *Genetics and exploitation of heterosis in crops*, 19-29.

East, E. (1908). Inbreeding in corn, pp: 419-428 in Reports of the Connecticut Agricultural Experiment Station for Years 1907-1908. *Inbreeding in corn. p. 419–428. In Reports of the Connecticut Agricultural Experiment Station for Years 1907–1908.*

El-Adl, A. M., El-Hadi, A. A., Fathy, H. M., &Abdein, M. A. (2014). Heterosis, Heritability and Combining Abilities for some Earliness Traits in Squash (Cucurbitapepo, L.). *Alexandria Science Exchange Journal*, *35*(3), 203-214.

Fasahat, P., Rajabi, A., Rad, J. M., &Derera, J. (2016). Principles and utilization of combining ability in plant breeding. *BiomBiostatInt J*, *4*(1), 1-24.

Griffing, B. (1956). A generalised treatment of the use of diallel crosses in quantitative inheritance. *Heredity*, *10*(1), 31-50.

Gwanama, C., Botha, A. M., &Labuschagne, M. T. (2001). Genetic effects and heterosis of flowering and fruit characteristics of tropical pumpkin. *Plant Breeding*, *120*(3), 271-272.

Harvest Plus, 2007. <http://www.harvestplus.org/micronut.html>.

Heinz, K. M., &Zalom, F. G. (1995). Variation in trichome-based resistance to Bemisiaargentifolii (Homoptera: Aleyrodidae) oviposition on tomato. *Journal of Economic Entomology*, *88*(5), 1494-1502.

Huang, Y., Zhang, L., Zhang, J., Yuan, D., Xu, C., Li, X., ...& Zhang, Q. (2006). Heterosis and polymorphisms of gene expression in an elite rice hybrid as revealed by a microarray analysis of 9198 unique ESTs. *Plant molecular biology*, *62*(4-5), 579-591.

Izge, A. U., &Garba, Y. M. (2012). Combining ability for fruit worm resistance in some commercially grown tomatoes in parts of north eastern Nigeria. Int J AgricSci, 2, 240-244.

Jaiprakashnarayan, R. P., Mallesh, S. B., &Patil, M. G. (2016). Development of F1 hybrids resistance to bacterial wilt incidence in tomato (Solanumlycopersicum L.). *Electronic Journal of Plant Breeding*, *7*(4), 911-918.

Jose, J., Patel, A. I., & PATEL, H. B. (2016). Heterosis studies for yield and yield attributing traits in tomato (Solanumlycopersicum L.). *Advances Life Sci*, *5*(3), 908-913.

Khapte, P. S., Singh, T. H., Sadashiva, A. T., & Reddy, K. M. (2013). Combining ability for yield and yield-related traits in Manjarigota type brinjal (Solanummelongena L.). *Journal of Horticultural Sciences*, *8*(2), 176-180.

Kulembeka, H. P., Ferguson, M., Herselman, L., Kanju, E., Mkamilo, G., Masumba, E., ...&Labuschagne, M. T. (2012). Diallel analysis of field resistance to brown streak disease in cassava (ManihotesculentaCrantz) landraces from Tanzania. *Euphytica*, *187*(2), 277-288.

Kumar, V., Jindal, S. K., Dhaliwal, M. S., &Meena, O. P. (2015). Hybrid development for resistance to late blight and root knot nematodes in tomato (Solanumlycopersicum L.). *SABRAO Journal of Breeding and Genetics*, *47*(4), 340-354.

Mahendrakar, P. (2004). *Development of F1 hybrids in tomato (Lycopersiconesculentum Mill.)* (Doctoral dissertation, UNIVERSITY OF AGRICULTURAL SCIENCES GKVK, DHARWAD).

Maurya, I. B., & Singh, S. P. (1994). Studies on gene action in long fruited bottlegourd. *Crop Res*, *8*, 100-104.

MH S., Jadav k. (2018). Heterosis for fruit yield and its component traits in ridge gourd (Luffaacutangula (Roxb.) L.).

Munshi, A. D., &Sirohi, P. S. (1994). Combining ability estimates in bitter gourd (Momordicacharantia L.). *Veg. Sci*, *21*(2), 132-136.

Muttappanavar, R. D., Sadashiva, A. T., Vijendrakumar, R. C., Roopa, B. N., &Vasantha, P. T. (2014). Combining ability analysis of growth, yield and quality traits in Cherry Tomato (Solanumlycopersicum var. cersiforme). *Molecular Plant Breeding*, *5*.

Oakey, H., Verbyla, A., Pitchford, W., Cullis, B., &Kuchel, H. (2006). Joint modeling of additive and non-additive genetic line effects in single field trials. *Theoretical and Applied Genetics*, *113*(5), 809-819.

Olfati, J. A., Samizadeh, H., Peyvast, G. A., Rabiel, B., &Khodaparast, S. A. (2012). Relationship between genetic distance and heterosis in cucumber. *International Journal of plant breeding*, *6*, 21-26.

Pradhan, S. R., Dharmattiand, P. R., & Jena, R. (2017). Study of Heterosis and Combining Ability Pattern for Downy Mildew Resistance in Local Cucumbers of Northern Karnataka. *Research Journal of Agricultural Sciences*, *8*(2), 506-509.

Premalakshmi, V., Thyagaraj, T., Veeraragavathatham, D., &Arumugam, T. (2006). Heterosis and combining ability analysis in tomato (Lycopersiconesculentum Mill.) for yield and yield contributing traits. *Vegetable Sci*, *33*, 120-122.

Ryder, E. (2011). World vegetable industry: production, breeding, trends. *Hortic Rev*, *38*, 299.

Sharma, N., Sharma, N. K., & Malik, Y. S. (2002). Combining ability in long-fruited bottle gourd. *Haryana Journal of Horticultural Sciences*, *31*(1/2), 79-81.

Sharma, T. K., Pant, S. C., Kumar, S., Paliwal, A., Bahuguna, P., &Badhani, H. C. (2016). Combining ability studies in brinjal (Solanummelongena L.). *International Journal of Bio-resource and Stress Management*, *7*(6), 1225-1231.

Sherpa, P., Seth, T., Shende, V. D., Pandiarana, N., Mukherjee, S., &Chattopadhyay, A. (2014). Heterosis, dominance estimate and genetic control of yield and postharvest quality traits of tomato. *Journal of Applied and Natural Science*, *6*(2), 625-632.

Shinde, S., Supe, V. S., Bhalekar, M. N., &Gaikwad, S. S. (2016). Combining ability studies for earliness and yield in bottle gourd (Lagenarariasiceraria (Mol.) standl.) in kharif season. *Asian Journal of Science and Technology*, *7*, 2846-2849.

Shull, G. H. (1948). What is" heterosis"?. *Genetics*, *33*(5), 439.

Singh, A. K., Pan, R. S., &Bhavana, P. (2013). Heterosis and combining ability analysis in bittergourd (Momordicacharantia L.). *The Bioscan*, *8*(4), 1533-1536.

Singh, B. K., Sharma, S. R., & Singh, B. (2009). Heterosis for antioxidants and horticultural traits in single cross hybrids of cabbage (Brassica oleracea var. capitata). *Indian Journal of Agricultural Sciences*, *79*(9), 703.

Singh, B. K., Sharma, S. R., & Singh, B. (2009). Heterosis for mineral elements in single cross-hybrids of cabbage (Brassica oleracea var. capitata L.). *ScientiaHorticulturae*, *122*(1), 32-36.

Singh, B., Prasanna, H. C., Singh, P. M., Pandey, S., Kumar, R., Mishra, G. P., ...& Singh, B. K. Harnessing Heterosis in Vegetable Crops: A Means for Achieving High Productivity and Profitability.

Singh, I., Sharma, J. R., & Kumar, J. C. (1996). Heterosis studies in long fruited genotypes of bottlegourd. *Indian Journal of Horticulture*, *53*(1), 64-67.

Singh, S., Bhatia, R., Kumar, R., Sharma, K., Dash, S., &Dey, S. S. (2018). Cytoplasmic male sterile and doubled haploid lines with desirable combining ability enhances the concentration of important antioxidant attributes in Brassica oleracea. *Euphytica*, *214*(11), 207.

Sprague, G. F., & Tatum, L. A. (1942). General vs. specific combining ability in single crosses of corn 1. *Agronomy Journal*, *34*(10), 923-932.

Talukder, A., Haselow, N. J., Osei, A. K., Villate, E., Reario, D., Kroeun, H., ...& Quinn, V. (2010). Homestead food production model contributes to improved household food security and nutrition status of young children and women in poor populations. Lessons learned from scaling-up programs in Asia (Bangladesh, Cambodia, Nepal and Philippines). *Field Actions Science Reports. The journal of field actions*, (Special Issue 1).

Tanaka, N., &Niikura, S. (2006). Genetic analysis of the developmental characteristics related to the earliness of head formation in cabbage (Brassica oleracea L.). *Breeding science*, *56*(2), 147-153.

Thakur, M., Kumar, R., &Kansal, S. (2019). Heterosis, combining ability and gene action studies in cucumber for different biotic stresses to develope resistant hybrids. *Genetika*, *51*(1), 199-212.

Triveni, D., Saidaiah, P., & Reddy, K. R. (2017). Studies on combing ability and gene action for growth and quality characters in tomato (Solanumlycopersicum L.). *Int. J. Pure App. Biosci*, *5*(4), 1835-1840.

Tyagi, S. V. S. (1997). *Studies on combining ability and stability parameters in ridge gourd (LuffaacutangulaRoxb.)* (Doctoral dissertation, Ph. D. Thesis, Rajasthan Agriculture University, Bikaner, Rajasthan).

Vasal, S. K., Cordova, H., Pandey, S., & Srinivasan, G. (1999). Tropical maize and heterosis. *Genetics and Exploitation of Heterosis in Crops*, 363-373.

Venugopala Reddy, M., Patil, M. G., Kurubar, A. R., Das, U., & Patil, S. (2019). Heterosis studies in sponge gourd for Earliness and qualitative traits. *Journal of Pharmacognosy and Phytochemistry*, *8*(1), 2132-2138.

Wargovich, M. J. (2000). Anticancer properties of fruits and vegetables. *HortScience*, *35*(4), 573-574.

Wehner, T. C. (1999). Heterosis in vegetable crops. *Genetics and Exploitation of Heterosis in Crops*, 387-397.