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Modifications of heterobeltiosis, heterosis, and hybrid vigour over check parent formulae to enhance judgment on hybrids

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Abstract

Many researchers are using the heterosis, heterobeltiosis and hybrid vigour over check parent value formulae to determine the hybrid vigour for animals, plants and silkworm breeding. These formulae are ideal for determine the hybrid vigour for the positive direction of single trait. It is difficult using these formulae for multiple traits. Suggested modification for cardinal formulae were made as well as suggestion new formula for determines hybrid vigour for multiple traits. Modifications of hybrid vigour were made to facilitate judgment of best hybrids under study for multiple traits. Nineteen local hybrids of mulberry silkworm were prepared for these investigations in addition the imported Bulgarian hybrid. Comparison between the cardinal and the modifications formulae were applied for thirteen economic characters. Nine positive and four negative direction characters were observed. Modified formulae make the judgment of heterobeltiosis, heterosis and hybrid vigour over check parent value very facilitate for positive and negative traits.

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Introduction

The mating or crossing of two different species is a process called hybridization, with the offspring known as hybrids. When a hybrid has characteristics superior to both parents it is said to have hybrid vigor or positive heterosis, which, of course, is the ultimate breeding goal. Genetic enhancement programs attempt to develop hybrids that are either superior to their parent species for individual traits or whose overall performance for several traits makes them economically more profitable than their parent species (Dunham and Masser, 2012).

In theory, heterosis may be "positive" or "negative". This is largely an artificial distinction. Positive heterosis is generally desired for traits like yield, while negative heterosis is desired for traits such as early maturity. Three kinds of heterosis may be distinguished as mid parent (heterosis), standard variety (check parent), and better parent (heterobeltiosis). Standard variety (check parent) heterosis is measured by comparing the hybrid to existing high yield commercial variety (Hallauer and Eberhard, 1966 & Hallauer and Miranda, 1988 and Acquaah 2019).

Evaluation of hybrids vigour formulae of heterobeltiosis, heterosis and check parents values are wildly used by many scientists and researches for plants (Gadag and Upadhyaya, 1995, Sekhar *et al*. 2010, Parameshwarappa *et al*. 2012, Abro *et*

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al. 2014, Ayano *et al.* 2015, Kumar *et al.* 2016 a & b, Kawamura *et al.* 2016, Bernardes *et al.* 2017, Kumar *et al.* 2017, Samayoa *et al.* 2017, Kanfany *et al.* 2018, Van Hulten *et al.* 2018, Adhikari *et al.* 2020 and Tyagi *et al.* 2020) ; animals (Proops *et al.* 2009, Wakchaure *et al.* 2015, Liu *et al.* 2017, Vandana *et al.* 2018, Getahun *et al.* 2019, Hanot *et al.* 2019) and silkworms (Ghazy, 1999 & 2005, Talebi and Subramanya 2009, Tiwari and Singh 2016, Sharma and Bali 2019).

These investigations are attempted to enhance the judgment of hybrid vigour by modifying the formulae of heterobeltiosis, heterosis and hybrid vigour over check parent values. Also, suggest formula for determine the best hybrid for multiple traits using heterobeltiosis, heterosis and hybrid vigour over check parent values.

Materials and Methods

Nineteen local hybrids in addition to the imported hybrid from Bulgaria of mulberry silkworm *Bombyx mori* L., were used in this study. The procedure of hybridization methods and hybrid codes were illustrated in Table 1.

Table 1. Hybridization procedures and codes of the hybrids.

NO	hybridization	Cods
1	J_{444} X P_{323}	Eg_1
2	L_{444} X J_{444}	Eg_2
3	P_{214} X L_{444}	Eg_3
4	P_{323} X P_{214}	Eg_4
5	$RBmch_1$X Z_{345}	Eg_5
6	Z_{345} X $RBmch_1$	Eg_6
7	L_{252} X Z_{345}	Eg_7
8	Z_{345} X L_{252}	Eg_8
9	$RBmj_1$ X Z_{345}	Eg_9
10	Z_{345} X $RBmj_1$	Eg_{10}
11	I_2pchX C_2pj	Eg_{11}
12	$RBmj_1$ X I_2pch	Eg_{12}
13	C_2pj X $RBpj_1$	Eg_{13}
14	$RBpj_1$ X I_2mch	Eg_{14}
15	C_2pj X I_2pch	Eg_{15}
16	$RBpj_1$ X I_2pch	Eg_{16}
17	I_2pj X M_{245}	Eg_{17}
18	Z_{345} X I_2pj	Eg_{18}
19	I_2pj X $RBpch_3$	Eg_{19}
20	H_1XUVX G_2X V_2	Im

The pervious hybrids resulted from hybridization some local strain. These strains were obtained from breeding program of Sericulture Research Department (SRD) - Plant Protection Research Institute- Agricultural Research Center- Egypt.

Three replicates of each hybrid were reared. Each replicate contains 500 larvae. Polythene sheets were used as bottom and cover for young instars (Ghazy, 2008). As well as wet foam strips were applied. Chopped leaves were offer four times daily for young instars. While, whole leaves and mulberry shoots offered for fourth and fifth instars, respectively. Collapsible frames provided for mature larvae for spinning cocoons.

Temperature and humidity inside rearing rooms were registered. Average of temperature is 24.038 ºC ± 0.144 and humidity percentage is 53.764 % ± 0.970. Thirteen economic characters were recorded for all hybrids. Nine of them are positive direction (high positive values desirable) and four are negative direction (negative and less values desirable). The positive characters were fresh cocoon weight (CW), fresh cocoon shell weight (CSW), fresh pupal weight (PW), cocoon shell ratio (CSR), silk productivity (SP), pupation ratio (PR), cocooning percentage (CP), cocoon crop for 10,000 fourth instar larvae/number (Crop/N) and cocoon crop by weight for 10,000 fourth instar larvae (Crop/W). Negative characters were fifth instar duration by days (Fd), total larval duration by days (LD), number of cocoon per liter (C/L) and mortality percentage (MP).

Many of researchers worked in plants, animals and beneficial insects…..etc used the equation of Hayes *et al.* (1955) for determined the heterobeltiosis, heterosis and standard hybrid vigour.

It is good determine the hybrid vigour for positive direction trait. While it caused confused for determine the hybrid vigour for negative direction traits. In addition the equations determine the hybrid vigour for traits separately. So, it is difficult to determine the best hybrids for multiple characters especially when the evaluation involved positive and negative direction traits.

1. Cardinal equations of heterobeltiosis, heterosis and hybrid vigour over check value were as follows Hayes *et al.* (1955):

$$\text{Heterobeltiosis} = \frac{\overline{F}_1 - BPV}{BPV} X100$$

$$\text{Heterosis} = \frac{\overline{F}_1 - MPV}{MPV} X100$$

$$\text{Hybrid vigour over CPV} = \frac{\bar{F}_1 - CPV}{CPV} X100$$

Where: average of F1 hybrid

B P V: $\bar{F}_1$ Better Parent Value

MPV: Mid Parent Value $(P_1+P_2)/2$

CPV: Check Parent Value

Suggested equations

It is suggested that; the cardinal equations of Hayes *et al.* (1955) will multiply by 1 followed by the direction of the character. So in case of positive direction will multiply by +1. And the negative direction will multiply by -1.

Suggested modification for the heterobeltiosis, heterosis and hybrid vigour over check parent value equations for positive direction Characters:

$$\text{Heterobeltiosis} = +1 \ X \ (\frac{\bar{F}_1 - BPV}{BPV})X100$$

$$\text{Heterobeltiosis} = (\frac{\bar{F}_1 - BPV}{BPV})X100$$

$$\text{Heterosis} = +1 \ X \ (\frac{\bar{F}_1 - MPV}{MPV})X100$$

$$\text{Heterosis} = (\frac{\bar{F}_1 - MPV}{MPV})X100$$

$$\text{Hybrid vigour over CPV} = +1 \ X \ (\frac{\bar{F}_1 - CPV}{CPV})X100$$

$$\text{Hybrid vigour over CPV} = (\frac{\bar{F}_1 - CPV}{CPV})X100$$

Where: $\bar{F}_1$ average of F_1 hybrid

BPV: Better Parent Value

MPV: Mid Parent Value $(P_1+P_2)/2$

CPV: Check Parent Value

Suggested modification for heterobeltiosis, heterosis and hybrid vigour over check parent value equations for negative direction Characters:

$$\text{Heterobeltiosis} = -1 \ X \ (\frac{\bar{F}_1 - BPV}{BPV})X100$$

$$\text{Heterobeltiosis} = \frac{BPV - \bar{F}_1}{BPV} X100$$

$$\text{Heterosis} = -1 \ X \ (\frac{\bar{F}_1 - MPV}{MPV})X100$$

$$\text{Heterosis} = \frac{MPV - \bar{F}_1}{MPV} X100$$

$$\text{Hybrid vigour over CPV} = -1 \ X \ (\frac{\bar{F}_1 - CPV}{CPV})X100$$

$$\text{Hybrid vigour over CPV} = \frac{CPV - \bar{F}_1}{CPV} X100$$

Estimation of hybrid vigour for multiple traits:

Formulae of heterobeltiosis, heterosis and hybrid vigour over check parent value did not apple determined the best hybrids for multiple characters together especially when some of characters are positive direction and others are negative direction. So that the next formulae were suggested to be facilitate judgment the best hybrids for multiple characters together.

Suggestion of new formula:

$$\text{Ratio of positive value (RPV)} = \frac{NPC}{TNC} X\,100$$

Where; NPC: Number of positive value characters

TNC: Total Number of Characters

It is easy to judge the best hybrid which owns 50% or more of ratio of positive value (RPV). After that the selected hybrids will arrangement according to total of hybrid vigour for all traits. The best hybrid is the higher values for RPV and total hybrid vigour values. Cardinal formulae and the suggested modifications were applied the collected data.

Results and Discussion

Performance of imported and nineteen local single hybrids for thirteen economic characters are mention in Table 2. It is so difficult to determine the best hybrid depending on the performance. There is no single hybrid superior for all characters together.

Cardinal and modified hybrid vigour formulae of heterobeltiosis (hybrid vigour over better parent value).

Data found in Tables of 3 to 5 represented hybrid vigour over better parent value estimated by the cardinal and modified

Table 2. Performance of imported and nineteen local single hybrids for thirteen economic characters.

Character Hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)
Eg_1	0.877	0.188	0.627	21.637	2.007	9.375	36.375	93.520	90.000	84.962	33.500	8496.200	7570.114
Eg_2	1.129	0.233	0.834	20.773	2.594	9.000	36.688	88.480	94.000	84.118	15.000	8411.800	9501.128
Eg_3	0.991	0.199	0.730	20.130	2.051	9.688	36.688	95.200	98.000	81.768	9.500	8176.800	8100.510
Eg_4	1.558	0.279	1.216	17.882	2.795	10.000	37.000	105.840	95.000	72.727	28.500	7272.700	11327.230
Eg_5	1.617	0.387	1.168	24.409	4.300	9.000	36.000	112.560	93.000	92.105	5.000	9210.500	14897.984
Eg_6	1.171	0.249	0.860	21.606	2.390	10.344	37.344	115.360	96.500	65.171	6.250	6517.070	7295.549
Eg_7	1.535	0.307	1.165	20.118	3.278	9.375	36.375	105.280	98.000	71.181	4.000	7118.100	10926.284
Eg_8	1.460	0.275	1.123	18.977	3.168	8.688	35.688	104.720	94.500	81.712	6.301	8171.150	11997.159
Eg_9	1.426	0.250	1.114	17.733	2.414	10.375	38.000	104.720	100.000	76.705	5.000	7670.500	10938.133
Eg_{10}	1.572	0.340	1.169	21.770	3.631	9.375	36.375	94.640	95.000	55.714	30.000	5571.400	8758.241
Eg_{11}	1.618	0.330	1.226	20.595	3.298	10.000	37.000	97.440	98.000	87.895	1.000	8789.500	14221.411
Eg_{12}	1.021	0.245	0.714	24.297	2.921	8.375	35.375	135.520	99.000	65.574	1.000	6557.400	6695.105
Eg_{13}	1.553	0.278	1.212	18.040	2.784	10.000	37.000	114.240	94.000	89.286	2.000	8928.600	13866.116
Eg_{14}	1.282	0.246	0.974	19.347	2.935	8.375	35.375	120.960	96.000	52.000	1.000	5200.000	6666.400
Eg_{15}	1.270	0.246	0.963	19.536	2.619	9.375	36.375	106.400	94.000	65.104	2.500	6510.400	8274.718
Eg_{16}	1.600	0.323	1.215	20.340	3.277	10.375	38.375	102.480	98.000	84.211	1.000	8421.100	13473.760
Eg_{17}	0.998	0.214	0.722	21.689	2.285	9.375	36.375	109.760	99.000	82.915	5.000	8291.500	8274.917
Eg_{18}	1.370	0.245	1.064	17.951	2.923	8.375	36.375	106.960	98.889	96.875	4.167	9687.500	13281.563
Eg_{19}	1.266	0.257	0.947	20.260	2.481	10.375	37.375	108.080	96.000	58.974	2.500	5897.400	7466.108
Im	1.209	0.234	0.913	19.416	2.124	11.000	38.000	117.600	98.000	72.333	27.667	7233.300	8745.060

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight.& Eg_1= J_{444} X P_{323}, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$, Im= H_1XUVX G_2X V_2.

formulae.

Cardinal heterobeltiosis (hybrid vigour formula over better parent value).

Table 3 Showed the estimation of heterobeltiosis using the cardinal formulae. Regarding to CW, CSW, PW, CSR, SP, PR, CP, Crop/N and Crop/W characters positive hybrid vigour were desirable. While characters of Fd, LD, C/L and MP the negative hybrid vigour are desirable.

Hybrids of Eg_5 and Eg_{16} observed hybrid vigour for CW, CSW, PW, CSR, SP, CP, Crop/N and Crop/W. Also, the previous hybrids showed negative hybrid vigour for Fd, C/L and MP. Eg_5 and Eg_{16} hybrids are promising.

These results are coincidence with those founded by Rahman *et al*. (2015) who estimated heterosis over better parent value among indigenous and newly developed bivoltine silkworm, *Bombyx mori* L. Eighteen combinations were evaluated. They stated that, $P_2×P_9$, $P_1×P_9$, $P_3×P_9$, $P_4×P_9$, $P_5×P_9$, $P_6×P_9$ exhibited positive hybrid vigour over better value for single cocoon weight, single shell weight and cocoon shell ratio.

Also Talebi *et al*. (2010) investigated the heterosis of silkworm (*Bombyx mori* L.) to define heterosis in the four silkworm races namely C_{108}, NB_4D_2, Pure Mysore and Nistari for four important characters including larval weight, cocoon weight, shell weight and shell percentage. The traits of larval weight and cocoon weight showed highly significant heterosis in F_1 hybrids ranging

Table 3. Estimation of heterobeltiosis (Hybrid vigour over better parent value) using the cardinal formulae.

Character hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)
Eg_{1}	-25.580	-7.905	-31.275	24.424	-7.905	0.000	-1.689	-35.271	76.316	-8.163	-3.452	-3.452	-27.005
Eg_{2}	-14.010	-5.541	-16.863	12.215	-5.541	0.000	-0.843	-17.708	-21.053	-4.082	-4.411	-4.411	-8.386
Eg_{3}	-25.495	-27.737	-27.226	-2.953	-32.869	7.644	-0.843	-11.458	-34.483	-2.000	5.537	5.538	-21.359
Eg_{4}	17.150	1.655	22.513	-21.144	-8.510	11.111	0.000	-7.805	96.552	-5.000	-6.699	-6.699	9.966
Eg_{5}	20.243	41.068	15.825	19.495	72.417	-18.182	-2.703	5.236	-76.190	-3.125	39.999	39.998	89.814
Eg_{6}	-12.919	-9.256	-14.709	5.773	-4.175	-5.964	0.930	7.853	-70.238	0.521	-0.942	-0.941	-7.048
Eg_{7}	9.348	12.045	7.779	-1.513	11.166	4.167	-1.689	3.867	-68.000	2.083	-14.152	-14.152	-6.107
Eg_{8}	4.046	0.232	3.893	-7.097	7.437	-21.023	-3.547	3.315	-49.592	-1.563	-1.451	-1.451	3.096
Eg_{9}	6.017	-8.702	10.390	-13.187	-3.202	-5.682	2.703	-2.094	-80.000	0.000	6.535	6.535	79.702
Eg_{10}	16.855	24.107	15.920	6.576	45.619	-14.773	-1.689	-17.157	20.000	-5.000	-22.619	-22.619	43.889
Eg_{11}	38.880	49.644	38.924	-10.932	43.703	11.111	-5.128	-22.667	-66.667	0.000	-12.105	-12.105	57.952
Eg_{12}	-12.389	10.989	-21.357	26.937	45.776	-23.864	-7.818	7.556	-95.833	10.000	5.765	5.765	-14.176
Eg_{13}	72.452	34.806	91.868	-21.981	21.325	11.111	-2.632	0.000	-33.333	-6.000	-10.714	-10.714	54.006
Eg_{14}	7.291	-1.462	10.197	-8.299	17.657	-16.250	-4.392	5.882	-95.238	-4.000	-27.778	-27.778	-7.035
Eg_{15}	9.032	11.423	9.070	-15.513	14.133	4.167	-6.731	-15.556	-16.667	-4.082	-34.896	-34.896	-8.096
Eg_{16}	37.334	46.446	37.681	2.813	63.541	-5.682	0.987	-10.294	-96.500	-2.000	16.960	16.960	86.523
Eg_{17}	-18.124	-6.621	-22.264	13.334	-0.396	3.786	-1.777	12.000	-61.718	-1.000	16.189	16.189	-4.870
Eg_{18}	1.877	-10.769	5.431	-12.122	17.199	-16.250	-1.689	9.143	-68.096	-1.111	35.752	35.752	52.687
Eg_{19}	3.857	12.195	1.943	5.436	1.324	15.278	1.014	10.286	0.000	-4.000	-41.026	-41.026	-25.893

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight.& Eg_{1}= J_{444} X P_{323}, Eg_{2}= L_{444} X J_{444}, Eg_{3}= P_{214} X L_{444}, Eg_{4}= P_{323} X P_{214}, Eg_{5}= $RBmch_{1}$X Z_{345}, Eg_{6}= Z_{345} X $RBmch_{1}$, Eg_{7}= L_{252} X Z_{345}, Eg_{8}= Z_{345} X L_{252}, Eg_{9}= $RBmj_{1}$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_{1}$, Eg_{11}= $I_{2}pch$X $C_{2}pj$, Eg_{12}= $RBmj_{1}$ X $I_{2}pch$, Eg_{13}= $C_{2}pj$ X $RBpj_{1}$, Eg_{14}= $RBpj_{1}$ X $I_{2}mch$, Eg_{15}= $C_{2}pj$ X $I_{2}pch$, Eg_{16}= $RBpj_{1}$ X $I_{2}pch$, Eg_{17}= $I_{2}pj$ X M_{245}, Eg_{18}= Z_{345} X $I_{2}pj$, Eg_{19}= $I_{2}pj$ X $RBpch_{3}$, Im= H_{1}XUVX G_{2}X V_{2}.

from 11 to 23% and 14 to 27% respectively. Shell weight showed low level of heterosis in F_1 hybrids (14 to 20 %).

In addition, Ghazy (2012) used fifteen races resulted from silkworm breeding program at Sericulture Research Department (SRD) for hybridization. Fourteen hybrids were obtained and coded as; Giza C, Giza D, Giza R, Giza S, Giza T, Giza U, Giza A, Giza V, Giza W, Giza P, Giza H, Giza L , Qanater 1 and Qanater 2. Data were analyzed by using formula of heterosis over better values. For positive direction traits, most hybrids exhibited positive hybrid vigour. And about the negative direction traits of fifth instar duration, larval duration and number of cocoons per liter all hybrid have negative values. Hybrids of Giza V, Giza C, Qanater 1 and Qanater 2 proved promising and could be used for commercial cocoon production.

Modified heterobeltiosis (formula hybrid vigour over better parent value)

Estimation of Heterobeltiosis (Hybrid vigour over better parent value) using the suggested modifications formulae were founded in Table 4. The results were not changed except the sign of negative direction character negative values turn on positive values and vice versa. Hybrids of Eg_{5}, Eg_{16}, Eg_{11}, Eg_{13}, Eg_{18}, Eg_{12}, Eg_{9}, Eg_{10}, Eg_{8}, Eg_{7} and Eg_{15} showed highest RPV over 50. Table 5 represented the arrangements of selected hybrids of total heterobeltiosis and ratio of positive value. Hybrid Eg_{5} took the first order followed by Eg_{16}, Eg_{11}, Eg_{13}, Eg_{18}, Eg_{12}, Eg_{9} , Eg_{10} , Eg_{8} , Eg_{7} and Eg_{15} hybrids.

Table 4. Estimation of Heterobeltiosis (Hybrid vigour over better parent value) using the suggested modifications formulae.

Character hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/ day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)	Positive character No.	RPV %	Total hybrid vigour
Eg_1	-25.580	-7.905	-31.275	24.424	-7.905	0.000	1.689	35.271	-76.316	-8.163	-3.452	-3.452	-27.005	4	30.769	-129.670
Eg_2	-14.010	-5.541	-16.863	12.215	-5.541	0.000	0.843	17.708	21.053	-4.082	-4.411	-4.411	-8.386	5	38.462	-11.427
Eg_3	-25.495	-27.737	-27.226	-2.953	-32.869	-7.644	0.843	11.458	34.483	-2.000	5.537	5.538	-21.359	5	38.462	-89.424
Eg_4	17.150	1.655	22.513	-21.144	-8.510	-11.111	0.000	7.805	-96.552	-5.000	-6.699	-6.699	9.966	6	46.154	-96.626
Eg_5	20.243	41.068	15.825	19.495	72.417	18.182	2.703	-5.236	76.190	-3.125	39.999	39.998	89.814	11	84.615	427.574
Eg_6	-12.919	-9.256	-14.709	5.773	-4.175	5.964	-0.930	-7.853	70.238	0.521	-0.942	-0.941	-7.048	4	30.769	23.723
Eg_7	9.348	12.045	7.779	-1.513	11.166	-4.167	1.689	-3.867	68.000	2.083	-14.152	-14.152	-6.107	7	53.846	68.153
Eg_8	4.046	0.232	3.893	-7.097	7.437	21.023	3.547	-3.315	49.592	-1.563	-1.451	-1.451	3.096	8	61.538	77.987
Eg_9	6.017	-8.702	10.390	-13.187	-3.202	5.682	-2.703	2.094	80.000	0.000	6.535	6.535	79.702	9	69.231	169.161
Eg_{10}	16.855	24.107	15.920	6.576	45.619	14.773	1.689	17.157	-20.000	-5.000	-22.619	-22.619	43.889	9	69.231	116.345
Eg_{11}	38.880	49.644	38.924	-10.932	43.703	-11.111	5.128	22.667	66.667	0.000	-12.105	-12.105	57.952	9	69.231	277.310
Eg_{12}	-12.389	10.989	-21.357	26.937	45.776	23.864	7.818	-7.556	95.833	10.000	5.765	5.765	-14.176	9	69.231	177.267
Eg_{13}	72.452	34.806	91.868	-21.981	21.325	-11.111	2.632	0.000	33.333	-6.000	-10.714	-10.714	54.006	8	61.538	249.902
Eg_{14}	7.291	-1.462	10.197	-8.299	17.657	16.250	4.392	-5.882	95.238	-4.000	-27.778	-27.778	-7.035	6	46.154	68.791
Eg_{15}	9.032	11.423	9.070	-15.513	14.133	-4.167	6.731	15.556	16.667	-4.082	-34.896	-34.896	-8.096	7	53.846	-19.039
Eg_{16}	37.334	46.446	37.681	2.813	63.541	5.682	-0.987	10.294	96.500	-2.000	16.960	16.960	86.523	11	84.615	417.747
Eg_{17}	-18.124	-6.621	-22.264	13.334	-0.396	-3.786	1.777	-12.000	61.718	-1.000	16.189	16.189	-4.870	5	38.462	40.146
Eg_{18}	1.877	-10.769	5.431	-12.122	17.199	16.250	1.689	-9.143	68.096	-1.111	35.752	35.752	52.687	9	69.231	201.587
Eg_{19}	3.857	12.195	1.943	5.436	1.324	-15.278	-1.014	-10.286	0.000	-4.000	-41.026	-41.026	-25.893	6	46.154	-113.767

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight. RPV= = ratio positive value & Eg_1= J_{444} X P_{323}, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$, Im= H_1XUVX G_2X V_2.

Cardinal and modified heterosis formulae (hybrid vigour over mid parent value).

Tables of 6 to 8 showed the hybrid vigour over mid parent value estimated using the cardinal and modified formulae:

Cardinal heterosis (hybrid vigour over mid parent value) formula.

Estimation of heterosis using the cardinal formulae (Table 6). Most of local hybrids obtained positive hybrid vigour over mid parent value for positive direction characters and negative values for the negative direction characters.

Eg_{16} showed hybrid vigour over mid parent value for all characters under study. While, hybrid of Eg_5 have hybrid vigour over mid parent value for twelve characters.

The previous results are in accordance that found by Sajgotra *et al*. (2017) studied the heterosis on thermotolerant hybrids of bivoltine silkworm, *Bombyx mori* L. of twenty-eight silkworm bivoltine hybrids for some positive and negative characters. Some hybrids exhibited heterosis over mid parent value. The used the evaluation index equation to determine the best hybrids.

Hybrid vigour over mid parent value two bivoltine and three monovoltine inbred have been evaluated. Four hybrids were crossed during Autumn seasons. It could be concluded that, hybrid C was the best for cocoon weight, cocoon shell weight, pupal weight, cocoon shell ratio, while hybrid D was the better for cocoon weight, cocoon shell weight, pupal weight over the

Table 5. Arrangements of selected hybrids of total heterobeltiosis and ratio of positive value.

Character hybrid	RPV %	Total of hybrid vigour	Serial No.
Eg_5	84.615	427.574	1
Eg_{16}	84.615	417.747	2
Eg_{11}	69.231	277.310	3
Eg_{13}	61.538	249.902	4
Eg_{18}	69.231	201.587	5
Eg_{12}	69.231	177.267	6
Eg_9	69.231	169.161	7
Eg_{10}	69.231	116.345	8
Eg_8	61.538	77.987	9
Eg_7	53.846	68.153	10
Eg_{15}	53.846	-19.039	11

Where: RPV= ratio positive value, Eg5= RBmch1X Z_{345}, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{18}= Z_{345} X I_2pj.

mid parent values (Ghazy and Fouda 2006).

Modified heterosis (hybrid vigour over mid parent value) formulae.

Data in Table 7. Observed the estimation of heterosis (Hybrid vigour over mid parent value) using the suggested modifications formulae. No differentiation caused in results of positive direction characters. Also the values of negative direction characters did not change, while the signs were reversed. So, positive values were preferred for both positive and negative direction characters. Eg_5 and Eg_{16} hybrids showed hybrid vigour for thirteen and twelve traits together, respectively. Eighteen hybrids acquired over 50 percent for RPV.

Arrangements of selected hybrids of total heterosis and ratio of positive value were founded in Table 8. Hybrid Eg_5 was the highest total of hybrid vigour for all traits, followed by Eg_{16}, Eg_{11}, Eg_{13}, Eg_{18}, Eg_9, Eg_{10}, Eg_{12}, Eg_8, Eg_7, Eg_{14}, Eg_{15}, Eg_{17}, Eg_6, Eg_2, Eg_4 and Eg_{19} hybrids.

Cardinal and modified hybrid vigour formulae over check parent value

Hybrid vigour over check parent value were evaluated according to cardinal and modified hybrid vigour formulae founded in Tables of 9 to 11.

Cardinal hybrid vigour formula over check parent value

Estimation of hybrid vigour over check parent value using the cardinal formula was represented in Table 9. Hybrids of Eg_5 and Eg_{11} obtained hybrid vigour for twelve characters and hybrid Eg_{16} for eleven characters.

These results are in agreement with the findings of Ghazy (2007) & Rajalakshmi *et al*. (1998) who studied heterosis on rearing and cocoon characters of some hybrids of silkworm, *Bombyx mori* L. Data revealed that some hybrids were highly promising over the existing checks hybrid.

Also, Ghazy (2012) used fifteen races resulted from silkworm breeding program at Sericulture Research Department (SRD) for hybridization. Fourteen hybrids were obtained and coded as; Giza C, Giza D, Giza R, Giza S, Giza T, Giza U, Giza A, Giza V, Giza W, Giza P, Giza H, Giza L, Qanater 1 and Qanater 2. The traits of cocoon weight, cocoon shell weight, pupal weight, cocoon shell ratio, silk productivity, fifth instar duration, number of cocoon per liter and pupation ratio were evaluated. Data were analyzed by using three formulae of heterosis over check parent values. Only K X D hybrid showed hybrid vigour over check hybrid Bulgaria 2 for all characters except pupal weight trait. Also, most of single hybrid represented hybrid vigour over check hybrid Bulgaria 2 for fifth instar duration, total larval duration and pupation ratio.

Modified hybrid vigour formulae over check parent value.

Estimation of hybrid vigour over check parent value using the suggested modifications formulae (Table, 10). No changes happen in results except the sign of negative direction traits become positive instead of negative vice versa.

Arrangements of selected hybrids of total hybrid vigour over check parent values and ratio of positive value were appeared in Table 11. Hybrid Eg_5 took the first order followed by Eg_{11}, Eg_{16}, Eg_{13}, Eg_{18}, Eg_8, Eg_7, Eg_9, Eg_{10}, Eg_4, Eg_2, Eg_{15}, Eg_{17}, Eg_{12}, Eg_{14}, Eg_{19}, Eg_6 and Eg_3 hybrids.

Conclusion

Applications of cardinal formulae of heterobeltiosis, heterosis and hybrid vigour over check parent value are good

Table 6. Estimation of heterosis (Hybrid vigour over mid parent value) using the cardinal formulae.

Character hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)
Eg_1	-13.271	-4.513	-16.658	8.005	-6.391	2.041	-1.689	-27.862	63.212	-9.091	2.395	2.395	-10.676
Eg_2	-9.364	3.437	-12.932	15.720	5.344	-2.041	-0.843	-29.778	-26.829	4.444	7.844	7.844	-1.553
Eg_3	-25.038	-23.897	-26.848	2.562	-29.302	7.644	-0.843	-18.072	-47.945	7.692	12.413	12.413	-15.759
Eg_4	43.312	20.287	53.450	-17.629	8.259	11.111	0.000	-11.682	55.946	-5.000	-6.417	-6.416	34.213
Eg_5	27.467	54.716	22.124	24.102	91.955	-19.553	-4.478	-6.729	-78.261	-2.105	69.847	69.846	119.290
Eg_6	-7.687	-0.477	-10.070	9.850	6.684	-7.540	-0.911	-4.408	-72.826	1.579	20.178	20.178	7.387
Eg_7	11.669	13.890	11.512	1.970	20.467	-6.250	-1.689	1.075	-78.667	8.889	13.362	13.362	25.766
Eg_8	6.254	1.883	7.491	-3.812	16.426	-13.125	-3.547	0.538	-66.395	5.000	30.133	30.133	38.092
Eg_9	30.205	14.011	36.878	-11.798	16.172	-5.682	1.333	-5.316	-81.333	2.041	33.787	33.787	84.992
Eg_{10}	43.515	54.982	43.735	8.281	74.764	-14.773	-3.000	-14.430	12.001	-3.061	-2.825	-2.825	48.124
Eg_{11}	56.681	54.494	61.938	-2.542	53.447	0.000	-5.128	-25.000	-94.667	4.255	8.512	8.512	75.278
Eg_{12}	-11.702	23.140	-20.242	41.463	64.146	-25.140	-8.562	0.363	-96.581	15.116	9.290	9.290	-10.878
Eg_{13}	77.882	49.874	93.931	-15.909	40.734	0.000	-3.896	-7.901	-87.330	-5.051	3.821	3.821	83.773
Eg_{14}	25.672	18.606	29.687	-5.351	41.217	-20.238	-5.667	-2.262	-95.965	-2.538	-21.212	-21.212	0.567
Eg_{15}	23.007	15.035	27.138	-7.554	21.872	-6.250	-6.731	-18.103	-86.667	0.000	-19.625	-19.625	1.985
Eg_{16}	59.173	67.487	61.927	4.510	78.780	-5.682	-0.325	-14.685	-96.829	3.158	25.688	25.688	102.454
Eg_{17}	-5.729	6.837	-9.454	14.353	8.929	-1.487	-3.043	-1.754	-74.350	1.538	22.108	22.108	14.230
Eg_{18}	6.891	-2.816	9.801	-8.469	22.084	-20.238	-3.000	4.372	-78.104	0.907	69.913	69.913	83.990
Eg_{19}	6.710	14.453	5.119	6.599	4.621	9.211	-0.333	-14.790	-67.868	0.524	-31.170	-31.170	-20.461

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight.& Eg_1= J_{444} X P_{323}, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$, Im= H_1XUVX G_2X V_2.

for determine the hybrid vigour for single trait, especially for positive direction characters. Using these formulae are difficult to determine the hybrids vigour for all traits together. Suggested modification made the judgment of hybrid vigour for multiple traits easy, also determine the best hybrids facilitated. Hybrids of Eg_5, Eg_{16}, Eg_{11}, Eg_{13}, Eg_{18}, Eg_{12}, Eg_9, Eg_{10}, Eg_8, Eg_7 and Eg_{15} were the best hybrids for heterobeltiosis. For heterosis, hybrid of Eg_5 was the highest total of heterosis for all traits, followed by Eg_{16}, Eg_{11}, Eg_{13}, Eg_{18}, Eg_9, Eg_{10}, Eg_{12}, Eg_8, Eg_7, Eg_{14}, Eg_{15}, Eg_{17}, Eg_6, Eg_2, Eg_4 and Eg_{19} hybrids. According to hybrid vigour over check parent value, hybrid Eg_5 took the first order followed by Eg_{11}, Eg_{16}, Eg_{13}, Eg_{18}, Eg_8, Eg_7, Eg_9, Eg_{10}, Eg_4, Eg_2, Eg_{15}, Eg_{17}, Eg_{12}, Eg_{14}, Eg_{19}, Eg_6 and Eg_3 hybrids.

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Table 7. Estimation of heterosis (hybrid vigour over mid parent value) using the suggested modifications formulae.

Character Hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/ day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)	Positive character No.	RPV %	Total hybrid vigour
Eg_1	-13.271	-4.513	-16.658	8.005	-6.391	-2.041	1.689	27.862	-63.212	-9.091	2.395	2.395	-10.676	5	38.462	-83.505
Eg_2	-9.364	3.437	-12.932	15.720	5.344	2.041	0.843	29.778	26.829	4.444	7.844	7.844	-1.553	10	76.923	80.274
Eg_3	-25.038	-23.897	-26.848	2.562	-29.302	-7.644	0.843	18.072	47.945	7.692	12.413	12.413	-15.759	7	53.846	-26.547
Eg_4	43.312	20.287	53.450	-17.629	8.259	-11.111	0.000	11.682	-55.946	-5.000	-6.417	-6.416	34.213	7	53.846	68.683
Eg_5	27.467	54.716	22.124	24.102	91.955	19.553	4.478	6.729	78.261	-2.105	69.847	69.846	119.290	12	92.308	586.261
Eg_6	-7.687	-0.477	-10.070	9.850	6.684	7.540	0.911	4.408	72.826	1.579	20.178	20.178	7.387	10	76.923	133.307
Eg_7	11.669	13.890	11.512	1.970	20.467	6.250	1.689	-1.075	78.667	8.889	13.362	13.362	25.766	12	92.308	206.417
Eg_8	6.254	1.883	7.491	-3.812	16.426	13.125	3.547	-0.538	66.395	5.000	30.133	30.133	38.092	11	84.615	214.128
Eg_9	30.205	14.011	36.878	-11.798	16.172	5.682	-1.333	5.316	81.333	2.041	33.787	33.787	84.992	11	84.615	331.073
Eg_{10}	43.515	54.982	43.735	8.281	74.764	14.773	3.000	14.430	-12.001	-3.061	-2.825	-2.825	48.124	9	69.231	284.893
Eg_{11}	56.681	54.494	61.938	-2.542	53.447	0.000	5.128	25.000	94.667	4.255	8.512	8.512	75.278	12	92.308	445.371
Eg_{12}	-11.702	23.140	-20.242	41.463	64.146	25.140	8.562	-0.363	96.581	15.116	9.290	9.290	-10.878	9	69.231	249.543
Eg_{13}	77.882	49.874	93.931	-15.909	40.734	0.000	3.896	7.901	87.330	-5.051	3.821	3.821	83.773	11	84.615	432.005
Eg_{14}	25.672	18.606	29.687	-5.351	41.217	20.238	5.667	2.262	95.965	-2.538	-21.212	-21.212	0.567	9	69.231	189.568
Eg_{15}	23.007	15.035	27.138	-7.554	21.872	6.250	6.731	18.103	86.667	0.000	-19.625	-19.625	1.985	10	76.923	159.985
Eg_{16}	59.173	67.487	61.927	4.510	78.780	5.682	0.325	14.685	96.829	3.158	25.688	25.688	102.454	11	84.615	546.386
Eg_{17}	-5.729	6.837	-9.454	14.353	8.929	1.487	3.043	1.754	74.350	1.538	22.108	22.108	14.230	11	84.615	155.554
Eg_{18}	6.891	-2.816	9.801	-8.469	22.084	20.238	3.000	-4.372	78.104	0.907	69.913	69.913	83.990	10	76.923	349.185
Eg_{19}	6.710	14.453	5.119	6.599	4.621	-9.211	0.333	14.790	67.868	0.524	-31.170	-31.170	-20.461	9	69.231	29.007

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight. RPV= = ratio positive value & Eg_1= J_{444} X P_{323}, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$, Im= H_1XUVX G_2X V_2.

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Table 8. Arrangements of selected hybrids of total heterosis and ratio of positive value.

Character hybrid	RPV %	Total of hybrid vigour	Serial No.
Eg_5	92.308	586.261	1
Eg_{16}	84.615	546.386	2
Eg_{11}	92.308	445.371	3
Eg_{13}	84.615	432.005	4
Eg_{18}	76.923	349.185	5
Eg_9	84.615	331.073	6
Eg_{10}	69.231	284.893	7
Eg_{12}	69.231	249.543	8
Eg_8	84.615	214.128	9
Eg_7	92.308	206.417	10
Eg_{14}	69.231	189.568	11
Eg_{15}	76.923	159.985	12
Eg_{17}	84.615	155.554	13
Eg_6	76.923	133.307	14
Eg_2	76.923	80.274	15
Eg_4	53.846	68.683	16
Eg_{19}	69.231	29.007	17
Eg_3	53.846	-26.547	18

Where: RPV= ratio positive value, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, , Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$.

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Table 9. Estimation of hybrid vigour over check parent value using the cardinal formulae.

Character Hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)
Eg_1	-27.418	-19.493	-31.308	11.441	-5.538	-14.773	-4.276	-20.476	21.083	-8.163	17.460	17.460	-13.436
Eg_2	-6.554	-0.080	-8.656	6.987	22.125	-18.182	-3.453	-24.762	-45.784	-4.082	16.293	16.293	8.646
Eg_3	-18.035	-14.979	-20.042	3.675	-3.465	-11.927	-3.453	-19.048	-65.663	0.000	13.044	13.044	-7.370
Eg_4	28.879	19.603	33.215	-7.899	31.563	-9.091	-2.632	-10.000	3.011	-3.061	0.545	0.545	29.527
Eg_5	33.826	65.608	27.988	25.717	102.410	-18.182	-5.263	-4.286	-81.928	-5.102	27.335	27.335	70.359
Eg_6	-3.082	6.530	-5.752	11.280	12.495	-5.964	-1.726	-1.905	-77.410	-1.531	-9.902	-9.902	-16.575
Eg_7	26.978	31.536	27.643	3.615	54.335	-14.773	-4.276	-10.476	-85.542	0.000	-1.593	-1.593	24.942
Eg_8	20.820	17.668	23.041	-2.261	49.159	-21.023	-6.086	-10.952	-77.226	-3.571	12.966	12.966	37.188
Eg_9	17.993	7.180	21.982	-8.667	13.637	-5.682	0.000	-10.952	-81.928	2.041	6.044	6.044	25.078
Eg_{10}	30.055	45.696	28.093	12.125	70.950	-14.773	-4.276	-19.524	8.432	-3.061	-22.976	-22.976	0.151
Eg_{11}	33.880	41.142	34.322	6.071	55.257	-9.091	-2.632	-17.143	-96.386	0.000	21.514	21.514	62.622
Eg_{12}	-15.543	4.683	-21.775	25.140	37.495	-23.864	-6.908	15.238	-96.386	1.020	-9.344	-9.344	-23.441
Eg_{13}	28.468	19.163	32.783	-7.086	31.079	-9.091	-2.632	-2.857	-92.771	-4.082	23.437	23.437	58.559
Eg_{14}	6.076	5.183	6.717	-0.356	38.150	-23.864	-6.908	2.857	-96.386	-2.041	-28.110	-28.110	-23.770
Eg_{15}	5.106	5.093	5.457	0.616	23.309	-14.773	-4.276	-9.524	-90.964	-4.082	-9.994	-9.994	-5.378
Eg_{16}	32.389	38.127	33.120	4.760	54.250	-5.682	0.987	-12.857	-96.386	0.000	16.421	16.421	54.073
Eg_{17}	-17.425	-8.318	-20.940	11.707	7.573	-14.773	-4.276	-6.667	-81.928	1.020	14.630	14.630	-5.376
Eg_{18}	13.385	4.753	16.503	-7.547	37.586	-23.864	-4.276	-9.048	-84.939	0.907	33.929	33.929	51.875
Eg_{19}	4.743	10.156	3.680	4.348	16.792	-5.682	-1.645	-8.095	-90.964	-2.041	-18.469	-18.469	-14.625

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight.& Eg_1= J_{444} X P_{323}, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$.

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Table 10. Estimation of hybrid vigour over check parent value using the suggested modifications formulae.

Character Hybrid	CW (g)	CSW (g)	PW (g)	CSR (%)	SP (Cg/ day)	Fd (day)	LD (day)	C/L (No)	PR (%)	CP (%)	Mort (%)	Crop/N (No)	Crop/W (g)	Positive charac-ter No.	RPV %	Total hybrid vigour
Eg_1	-27.418	-19.493	-31.308	11.441	-5.538	14.773	4.276	20.476	-21.083	-8.163	17.460	17.460	-13.436	6	46.154	-40.554
Eg_2	-6.554	-0.080	-8.656	6.987	22.125	18.182	3.453	24.762	45.784	-4.082	16.293	16.293	8.646	9	69.231	143.151
Eg_3	-18.035	-14.979	-20.042	3.675	-3.465	11.927	3.453	19.048	65.663	0.000	13.044	13.044	-7.370	8	61.538	65.961
Eg_4	28.879	19.603	33.215	-7.899	31.563	9.091	2.632	10.000	-3.011	-3.061	0.545	0.545	29.527	10	76.923	151.628
Eg_5	33.826	65.608	27.988	25.717	102.410	18.182	5.263	4.286	81.928	-5.102	27.335	27.335	70.359	12	92.308	485.134
Eg_6	-3.082	6.530	-5.752	11.280	12.495	5.964	1.726	1.905	77.410	-1.531	-9.902	-9.902	-16.575	7	53.846	70.565
Eg_7	26.978	31.536	27.643	3.615	54.335	14.773	4.276	10.476	85.542	0.000	-1.593	-1.593	24.942	11	84.615	280.932
Eg_8	20.820	17.668	23.041	-2.261	49.159	21.023	6.086	10.952	77.226	-3.571	12.966	12.966	37.188	11	84.615	283.262
Eg_9	17.993	7.180	21.982	-8.667	13.637	5.682	0.000	10.952	81.928	2.041	6.044	6.044	25.078	12	92.308	189.894
Eg_{10}	30.055	45.696	28.093	12.125	70.950	14.773	4.276	19.524	-8.432	-3.061	-22.976	-22.976	0.151	9	69.231	168.198
Eg_{11}	33.880	41.142	34.322	6.071	55.257	9.091	2.632	17.143	96.386	0.000	21.514	21.514	62.622	13	100.000	401.574
Eg_{12}	-15.543	4.683	-21.775	25.140	37.495	23.864	6.908	-15.238	96.386	1.020	-9.344	-9.344	-23.441	7	53.846	100.809
Eg_{13}	28.468	19.163	32.783	-7.086	31.079	9.091	2.632	2.857	92.771	-4.082	23.437	23.437	58.559	11	84.615	313.111
Eg_{14}	6.076	5.183	6.717	-0.356	38.150	23.864	6.908	-2.857	96.386	-2.041	-28.110	-28.110	-23.770	7	53.846	98.038
Eg_{15}	5.106	5.093	5.457	0.616	23.309	14.773	4.276	9.524	90.964	-4.082	-9.994	-9.994	-5.378	9	69.231	129.670
Eg_{16}	32.389	38.127	33.120	4.760	54.250	5.682	-0.987	12.857	96.386	0.000	16.421	16.421	54.073	12	92.308	363.500
Eg_{17}	-17.425	-8.318	-20.940	11.707	7.573	14.773	4.276	6.667	81.928	1.020	14.630	14.630	-5.376	9	69.231	105.144
Eg_{18}	13.385	4.753	16.503	-7.547	37.586	23.864	4.276	9.048	84.939	0.907	33.929	33.929	51.875	12	92.308	307.447
Eg_{19}	4.743	10.156	3.680	4.348	16.792	5.682	1.645	8.095	90.964	-2.041	-18.469	-18.469	-14.625	9	69.231	92.502

Where: CW= fresh cocoon weight, CSW= fresh cocoon shell weight, PW= fresh pupal weight, CSR= cocoon shell ratio, SP= silk productivity, FD = fifth larvae duration, Fd= fifth larvae duration, LD= total larval duration, C/L= number of cocoons per liter, PR= pupation ratio, CP = cocooning percentage, Mort= moratlity percentage, Crop/N=cocoon crop by number , Crop/W= cocoon crop by weight ¡RPV= ratio positive value, . & Eg_1= J_{444} X P_{323}, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$.

Table 11. Arrangements of selected hybrids of total hybrid vigour over check parent values and ratio of positive value.

Character Hybrids	RPV %	Total of hybrid vigour	Serial No.
Eg_5	92.308	485.134	1
Eg_{11}	100.000	401.574	2
Eg_{16}	92.308	363.500	3
Eg_{13}	84.615	313.111	4
Eg_{18}	92.308	307.447	5
Eg_8	84.615	283.262	6
Eg_7	84.615	280.932	7
Eg_9	92.308	189.894	8
Eg_{10}	69.231	168.198	9
Eg_4	76.923	151.628	10
Eg_2	69.231	143.151	11
Eg_{15}	69.231	129.670	12
Eg_{17}	69.231	105.144	13
Eg_{12}	53.846	100.809	14
Eg_{14}	53.846	98.038	15
Eg_{19}	69.231	92.502	16
Eg_6	53.846	70.565	17
Eg_3	61.538	65.961	18

Where: RPV= ratio positive value, Eg_2= L_{444} X J_{444}, Eg_3= P_{214} X L_{444}, Eg_4= P_{323} X P_{214}, Eg_5= $RBmch_1$X Z_{345}, Eg_6= Z_{345} X $RBmch_1$, Eg_7= L_{252} X Z_{345}, Eg_8= Z_{345} X L_{252}, Eg_9= $RBmj_1$ X Z_{345}, Eg_{10}= Z_{345} X $RBmj_1$, Eg_{11}= I_2pchX C_2pj, Eg_{12}= $RBmj_1$ X I_2pch, Eg_{13}= C_2pj X $RBpj_1$, Eg_{14}= $RBpj_1$ X I_2mch, Eg_{15}= C_2pj X I_2pch, Eg_{16}= $RBpj_1$ X I_2pch, , Eg_{17}= I_2pj X M_{245}, Eg_{18}= Z_{345} X I_2pj, Eg_{19}= I_2pj X $RBpch_3$.