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Performance Estimation of Mulberry Silkworm Double Hybrids Using Novel Check Parent Assessment Equations

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Abstract
Selecting the suitable silkworm, *Bombyx mori* L. hybrids, for rearing and highest productivity is the first step for increasing the commercial production. Twenty silkworm double hybrids obtained from the hybridization system of the sericulture research department were selected to evaluate. In addition, an imported hybrid from Bulgaria was used as a check parent. There were hy_1, hy_2, hy_3, hy_4, hy_5, hy_6, hy_7, hy_8, hy_9, hy_{10}, hy_{11}, hy_{12}, hy_{13}, hy_{14}, hy_{15}, hy_{16}, hy_{17}, hy_{18}, hy_{19}, hy_{20}, and the hyB (Bulgarian imported hybrid as check parent hybrid). Fourteen economic traits were tested: fifth and whole duration of larva, percentage of mortality, double cocooning percentage, cocooning %, pupation rate, and cocoon numbers per liter were registered. Cocoon weight, cocoon shell weight, weight of pupa, shell ratio, silk productivity, crop by number, and crop by weight. Data reveal that there is no hybrid acquired the better outcome for all traits together. Generally, hy_{13} and hy_9 hybrids have superior data of eleven traits to gather. Whilst, hybrids of hy_6, hy_{14}, and hy_{17} have good averages for nine traits together. Also, hybrids of hy_7, hy_{11}, and hy_{18} have good averages over the check parent value for eight traits together.

Keywords: *Silkworm Bombyx mori L*, double hybrids, check parent, larvae characters, economic characters, local hybrids

Introduction

The quality and viability of silkworm eggs (*Bombyx mori* L.) are critical determinants in sericulture, as healthy embryonic development directly influences larval growth rates, silk gland maturation, and ultimately the quantum and goodness of silk fibers produced during cocoon formation. Amendments of silkworm races/hybrids have long been key factor in increasing productivity of the sericulture output. The key to raising the quantum and goodness of silk is ongoing development, assessment, renovation, and interchange of current breeds and hybrids with new, superior types, as well as their commercialization (Kumari and Tripathi, 2017 & Nasirillayev *et al*. 2025) [1, 2] There is an enormous variety of silkworm , *B. mori* , originating from races that are Japanese, Chinese, European, and Indian, there are about 3000 genotypes,worldwide, including mutants, parthenoclones, polyploids, and geographical races Nagaraju and Goldsmith, (2002) [3]. Studies of cross breeding have been extremely applied as averges of exercising heterosis in silkworm, hybridization have participated significantly to the enhance the silk production. Studies are being conducted on silkworm strains/hybrids and their relationship to climatic conditions and the suitability of each hybrid for each region or climatic zone (Fouad, 2020a; Manimegalai *et al*. 2023 & Attri *et al*. 2024) [4, 5, 6].

The interactions of genotype with environment can be a very serious problem for the breeder, and their effects may be uncontrollable. However, certain kinds of environmental effects, such as variations in microclimate, other experimental bias, and the like, can be controlled through careful design and analytical techniques and through careful attention to detail and planning (Sharma and Bukhari, 2020)[7]. It is more challenging for breeders to put all the improved characters together in a single variety (Fouad, 2020b)[8]. Breeders must endlessly struggle to maintain silkworm pure lines themselves, or pure lines for a superior hybrid, at the level once achieved for certain characters that are of interest in specific combinations Bukhari *et al*. (2021) [9].

Breeding of hybrids in silkworm, *Bombyx mori* L. has gained considerable attentiveness because its effect on cocoon production and, silk quality. The combination of polyvoltine female parents and bivoltine male parents leads to commercially viable hybrids. Specifically, the hybridization of polyvoltine strains, which are adapted to local climatic conditions, with high-quality bivoltine strains has proven effective as these hybrids exhibit enhanced adaptability and silk quality (Rao *et al*. 2016 & Chandrakanth *et al*. 2015) [10, 11]. The first-generation F_1 hybrids with high-temperature tolerance and nutritional efficiency are crucial for sustainable silk yield production (Verma & Sajgotra, 2017; Kumari *et al*. 2011 & Lokesh *et al*. 2013) [12, 13, 14]. Double hybrids are more resilient to adverse climatic conditions and guarantee crop stability, demonstrating increased genetic flexibility and are suitable for Autumn and Spring seasons with sustainable silk production (watanab, 2002) [15]. Double silkworm hybrid showed superior performance in economic traits such as weight of cocoon, shell, and filament. As well as shell ratio, filament length, and denier over other hybrids, CSR_{46} X CSR_{47}, CSR_2 X CSR_4, and breed PMXCSR$_2$. Moreover, the ability to tolerate unstable environments is a characteristic of double hybrids (Manimegalai *et al*. 2023) [16].

Silkworm breeding efforts emphasize the need to test silkworm strains and hybrids produced in the field under natural conditions. Diverse environmental conditions are necessary to improve production, seasonal responsiveness, and adaptation to the local environment (Talebi *et al*. 2010) [17]. Therefore, a study conducted by Pereira *et al*. (2013) [18] studied 14 silkworm strains by quantitative and qualitative traits, DNA markers correlating to sensitivity to the *B. mori* nucleopolyhedrovirus. Silkworm races from diversely geographical descents were found to have various characters like larval weight, larval duration, cocoon weight, raw silk Percentage. The C_{37} (Chinese race) have the better performance in most of the quantitative traits.

The effects of genotype-environment interactions are unpredictable and pose a major challenge for breeders. Nonetheless, with careful planning and design and rigorous analytical methods, some types of environmental influences, such as microclimate fluctuations and other experimental biases, can be managed Chandrakanth *et al*. (2018) [19]. (Bajwa, 2023) [20] Evaluated ten bivoltine silkworm hybrids for heterosis the hybrids get better vigour for biological characters and silk output of 5.6% - 27.5% over respective midparents averages. Heterosis of 4.2% to 23.0% averages was detected compared to the respective better parents. PO_{206}×J_{101} recorded the better better-parents heterosis for shell weight. MKD_{206}×C_{102} recorded negative better-parent heterosis for egg hatching, larva weight, and ratio of pupation. Ghazy *et al*. (2017) [21] studied check parent value for 15 local double hybrids, almost local double hybrids gained the best above imported hybrid for (cocoon, shell, and pupa) weights, silk productivity, cocoon numbers/liter, fifth period, larvae period and crop by weight. For every examined character, no hybrids showed heterosis over the check parent.

H_3, H_6 and H_{15} hybrids earned best averages than imported hybrid for all traits except percentage of mortality. The present experiments aim to evaluate twenty local double hybrids of silkworm, *Bombyx mori* L. and compare them with the Bulgarian imported hybrid using a modified check-parent hybrid formula.

Materials and Methods

- **Techniques of hybrid crossing**

Thirty-one of the silkworms, *Bombyx mori* L. races are selected for this study from the Sericulture Research Department (SRD) breeding program -Plant Protection Research Institute - Agriculture Research Center. Freshly hatched larvae of selected races were brushed off and reared in the spring season up to cocoon formation to obtain the twenty-two single hybrids by the hybridization schedule (Table 1). Eggs of resulting single hybrids were applied to artificial hatching methods according to Eid *et al*. (2007) [22]. Silkworm larvae reared in the autumn season to be used in creating twenty double hybrids as described in Table 2.

Table 1: Single hybrids hybridizations and codes.

No	Hybrids codes	Single hybrids names
1	HC_3	J_{444} X P_{323}
2	HC_4	L_{444} X P_{323}
3	HC_{16}	C_{137} X K_{462}
4	HC_{34}	Z_{345} X L_{252}
5	HC_{37}	$RBmj_1$ X I_2pch
6	HC_{38}	I_2pch X C_2pj
7	HC_{40}	C_2pj X $RBpj_1$
8	HC_{43}	$RBpj_1$ X I_2pch
9	HC_{45}	I_2pch X M_{245}
10	CH_2	K_{341} X F_{272}
11	CH_{12}	C_2pch X $RBpch_3$
12	CH_{16}	MAK_1 X E_{144}
13	CH_{17}	P_{444}X L_{232}
14	CH_{19}	H_{245} X J_{444}
15	CH_{22}	Z_{345} X $RBPJ_1$
16	CH_{26}	I_2mch X $RBpj_1$
17	CH_{32}	Y_{165} X O_{323}
18	Giza C	$RBpch_4$ X $RBpch_3$
19	Giza D	O_{323} X A_{468}
20	Giza N	B_{214} X M_{444}
21	Giza O	A_{422} X D_{262}
22	Giza T	E_{144} X L_{444}

Table 2: Hybridization system of double hybrids

No	Hybrids codes	Double hybrids
1	hy_1	HC_{16} X Giza T
2	hy_2	Giza T X Giza O
3	hy_3	Giza O X HC_{16}
4	hy_4	HC_{45} X CH_{19}
5	hy_5	CH_{19} X HC_{45}
6	hy_6	CH_{16} X Giza D
7	hy_7	Giza D X Giza N
8	hy_8	HC_{40} X HC_{38}
9	hy_9	HC_{38} X HC_{40}
10	hy_{10}	CH_{17} X CH_{26}
11	hy_{11}	CH_{12} X CH_{17}
12	hy_{12}	CH_{26}X CH_{12}
13	hy_{13}	CH_{22}X CH_2
14	hy_{14}	CH_2X CH_{22}
15	hy_{15}	Giza C X HC_{43}
16	hy_{16}	HC_3X HC_{37}
17	hy_{17}	HC_{37}X HC_3
18	hy_{18}	CH_{32} X HC_4
19	hy_{19}	HC_{34} X HC_4
20	hy_{20}	HC_4 X HC_{34}
Imported	hy B (Bulgaria)	G_2X V_2 X H_1 X kk

Silkworm double hybrids obtained from the hybridization system of (SRD) were reared in the next year in the Spring Season. The investigation was carried out in the Branch of Plant Protection Research Institute, Sericulture Breeding Station in El-Qanater, Elkhyria City, and Qalubiya Governorate. One imported hybrid from Bulgaria was used as a check parent for evaluation.

- **Mulberry Silkworm Rearing Techniques**

The experiment was conducted under normal temperature laboratory 22.653±1.688 °C and 59.083±5.753 % relative humidity. All the tested hybrid eggs were incubated until hatching with three replications. Every replicate counted five hundred larvae. The hatched larva was brushed on plastic trays (60X90X5) cm and enclitic with clammy foam on polyethylene sheets under and above the silkworm larvae (Ghazy, 2008) [23]. The mulberry leaf of *Morus alba* var. Kokuso-27 were cut in young silkworm instars. The larvae were dusted with Serilim disinfectant (from SRD) after every moult in young instars and applied as described by Hosny *et al*. (2002) [24] in grown instars. The whole mulberry leaf and shoots were used for the 4^{th} and 5^{th} silkworm instars, and the larvae were fed three times a day. Collapsible frames were used for mountage. The cocoons were collected after seven days.

- **Mulberry silkworm traits**

The fifth (FD) and total larvae duration (LD), mortality % (MP), double cocooning percentage (DCP), percentage of cocooning (CP), pupation ratio (PR), and cocoon numbers/liter (C/L) were registered. Cocoon weight (CW), cocoon shell weight (CSW), pupa weight (PW), cocoon shell ratio (CSR), silk productivity (SP), crops by number (Crop/N), and crops by weight (Crop/W) were calculated and tabulated. Heterosis and heterobeltiosis are calculated for each combination based on the average values of the tested double hybrids according to Ghazy and Fouad, (2021) [25].

a. Hybrid vigour estimation

1. Formula of positive characters

$$\text{Hybrid Vigour} = \left(\frac{\overline{F1} - \text{CPV}}{CPV}\right) X\ 100$$

2. Formula of negative characters

$$\text{Hybrid Vigour} = \left(\frac{\text{CPV} - \overline{F1}}{CPV}\right) X\ 100$$

Where: average of $\overline{F1}$hybrid

CPV: Check Parent Value

b. Ratio of positive Value

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

Where;

NPC: Numbers of positive value characters

TNC: Total numbers of characters

The better hybrid that gains 50% or more of the ratio positive value (RPV). Then, resulted selected hybrids will be arrayed according to total hybrid vigour for all characters. The better hybrid is highest means for RPV and total hybrid vigour values. Both of averages and check parent values data were analyzed by using SAS program (1998) [26].

Results and Discussions

Results in the Table 3 represented the average of twenty hybrids and check parent hybrids for fourteen silkworm, *Bombyx mori* characters.

Table 3: Average of twenty hybrids and imported check parent hybrid for fourteen silkworm, *Bombyx mori* L. characters.

character Hybrid	FD	LD	MP	DCP	C/L	CP	PR	CW	CSW	PW	CSR	SP	Crop/N	Crop/W
hy_1	9.000	33.000	5.000	2.667	197.613	95.000	85.000	1.434	0.239	1.125	16.959	2.652	9500.000	13622.700
hy_2	9.000	32.000	10.000	2.667	198.400	84.333	86.000	1.489	0.256	1.162	17.459	2.851	8433.300	12556.600
hy_3	9.125	33.292	5.000	2.000	184.000	79.667	93.000	1.520	0.269	1.181	17.905	2.951	7966.700	12108.900
hy_4	9.958	34.125	16.667	1.333	201.600	54.667	90.000	1.411	0.260	1.081	18.710	2.614	5466.700	7715.900
hy_5	9.958	34.125	14.667	1.333	177.600	33.333	89.167	1.504	0.261	1.174	17.512	2.619	3333.300	5014.000
hy_6	9.125	34.208	16.667	0.000	177.600	83.333	90.833	1.557	0.281	1.206	18.336	3.077	8333.300	12974.000
hy_7	9.000	33.000	17.000	2.000	175.200	49.667	95.000	1.554	0.272	1.210	17.702	3.030	4966.700	7716.200
hy_8	9.000	33.167	14.333	4.667	192.000	76.333	76.000	1.552	0.271	1.213	17.693	3.008	7633.300	11848.700
hy_9	9.000	33.000	21.667	3.333	184.200	81.000	90.000	1.641	0.300	1.271	18.659	3.340	8100.000	13293.700
hy_{10}	9.125	34.208	6.667	8.667	195.200	78.667	89.000	1.693	0.308	1.315	18.274	3.374	7866.700	13315.600
hy_{11}	9.125	34.208	2.333	3.333	185.600	87.333	98.000	1.646	0.271	1.306	16.626	2.967	8733.300	14379.600
hy_{12}	9.125	34.208	21.667	2.000	184.000	58.333	99.000	1.069	0.210	0.790	19.747	2.295	5833.300	6235.900
hy_{13}	9.125	33.292	6.333	8.667	177.600	86.333	97.000	1.719	0.305	1.344	18.003	3.342	8633.300	14837.900
hy_{14}	9.125	33.292	10.000	6.000	170.400	85.000	98.000	1.672	0.282	1.320	17.254	3.092	8500.000	14183.100
hy_{15}	9.000	33.000	13.333	6.000	202.400	60.667	100.000	1.643	0.263	1.310	16.167	2.921	6100.000	10024.300
hy_{16}	9.958	34.125	16.667	0.667	195.200	91.000	91.000	1.572	0.272	1.230	17.520	2.730	9100.000	14303.800
hy_{17}	9.958	34.125	0.667	5.333	198.400	89.000	87.000	1.690	0.313	1.308	18.944	3.145	8900.000	15046.900
hy_{18}	9.958	34.125	7.667	2.667	196.800	69.000	100.000	1.689	0.306	1.313	18.253	3.074	6900.000	11654.200
hy_{19}	9.000	33.000	13.333	4.000	189.600	78.333	100.000	1.571	0.280	1.221	18.028	3.114	7833.300	12304.400
hy_{20}	9.000	33.000	10.333	0.000	189.600	77.333	94.000	1.516	0.264	1.182	17.556	2.936	7733.300	11725.000
Hy B (check hybrid)	9.000	31.000	6.600	3.333	146.222	91.667	100.000	1.096	0.195	0.831	17.878	2.163	9166.700	10047.200
F	0.190	0.270	23.090**	14.670**	81.460**	35.430**	7.620**	4.130**	19.820**	2.870**	0.500	19.070**	37.930**	48.950**
LSD 0.05	-	-	3.567	1.835	4.214	7.624	6.529	0-.244	0.019	0.247	-	0.207	736.100	1171.000

Where: FD (fifth duration); LD (larval duration); MP (Larval mortality percentage); DCP (double cocooning percentage); C/L (number of cocoons per liter); CP (cocooning percentage); PR (pupation ratio); CW (cocoon weight); CSW (cocoon shell weight); CSR (cocoon shell ratio); SP (silk productivity); crop/N (cocoon crop by number) and crop/w (cocoon crop by weight).

Hybrids of hy_1, hy_2, hy_7, Hy_8, hy_9, hy_{15}, hy_{19} and hy_{20} earned the best data for fifth duration, and whole larvae duration. The characters of mortality percentage registered best results for hy_1, hy_3, hy_{10}, hy_{11}, hy_{13} and hy_{17} hybrids. The most of tested hybrids earned best data for the character double cocoon percentage except hy_{10}, hy_{13}, hy_{14}, hy_{15} and hy_{17}.The hybrids of hyB, hy_6, $hy_{13}$and hy_1 have the superior number for C/L and good percentage for CP together. Whereas; hybrids of hy_6, hy_7, hy_{13}, hy14 and hy_{18} earned the better data for pupation ratio, cocoon and shell weight. While, the hybrids of hy_{10}, hy_{13}, hy_{17}, and hy_{18} acquired the best results for pupa weight, shell ratio, and productivity of silk. The characters of crop by number and weight have the best data for the hybrids of hy_1, hy_9, hy_{11}, hy_{13}, hy_{16}, and hy_{17}. As general, only hybrid of hy_{13} and hy_9 has better data for eleven characters to gather. While, hybrids of hy_6 hy_{14} and hy_{17} have good averages for nine traits together. Also, hybrids of hy_7, hy $_{11}$ and hy_{18} have good averages for eight traits together. Whereas, hybrids of hy_1, hy_{10}, and hy_B earned best means for seven characters together. It could be concluded that there are no single hybrids showed superior averages for all characters together included the check hybrid.

These results are agreement with founded by Lakshmanan and SureshKumar (2012) [27] tested hybrid vigour of ten double hybrids, none of selected hybrids are better in all characters together. Ambilwade *et al.* (2022) [28] examine 30 F_1 silkworm hybrids resulted from crossing six parental strains and coincide the most auspicious hybrids by examined four economic traits by heterosis over mid and better parent, three crosses, BL_{67}×CSR_5, BL_{67}×HosaMysore and CSR_5×HosaMysore and their respective reciprocals are promising. Also, Sahaf *et al.* (2019) [29] evaluated eight silkworm bivoltine hybrids SKAU-R-6xSKAU-R-1, SK_{30}xSK_{28}, SKAU-R-1xSK_{28}, SKAU-R-6xSK_{31}, SKAU-R-1xSKAU-R-6, CSR_2xCSR_4, SH_6xNB_4D_2, and DUN_6xDUN_{22} for their performance, high-yielding hybrids suitable for Spring season. Four hybrids exhibited better performance with respect to economic traits to improve the cocoon productivity. Rao *et al.* (2012) [30] evaluated thirty-one silkworms, *B. mori* lines under different seasons for various economically important traits high-yielding races that have been identified will act as the starting for the creation of better breeds and hybrids.

Results in the Table.4 showed the average values of twenty hybrids over the check parent hybrid for fourteen silkworm, *Bombyx mori* L. characters.

Table 4: Average values of twenty hybrids over check parent hybrid for fourteen silkworm, *Bombyx mori* L. characters.

HY \ Ch	FD	LD	MP	DCP	C/L	CP	PR	CW	CSW	PW	CSR	SP	Crop/N	Crop/W	NPC	RPV%	THV
hy_1	-0.833	-6.888	24.62	21.14	-35.151	3.652	-15.00	30.941	22.680	35.501	-5.260	22.680	3.636	35.588	9	64.286	137.306
hy_2	-0.833	-3.022	-46.06	19.94	-35.688	-8.001	-14.00	36.222	31.886	40.384	-2.372	31.886	-8.072	24.879	6	42.857	67.149
hy_3	-2.234	-6.300	16.79	39.36	-25.836	-13.163	-7.00	38.684	38.319	42.073	0.111	36.425	-13.164	20.420	8	57.143	164.485
hy_4	-11.566	-10.390	-156.48	60.58	-37.876	-40.367	-10.00	29.048	33.803	30.404	4.522	20.931	-40.367	-23.207	6	42.857	-150.965
hy_5	-11.566	-10.390	-125.66	60.04	-21.456	-63.637	-10.833	37.257	34.043	41.119	-2.236	21.148	-63.636	-50.095	5	35.714	-165.902
hy_6	-2.234	-10.670	-153.35	99.99	-21.456	-9.108	-9.167	41.707	44.151	44.640	2.450	42.176	-9.092	29.130	7	50.000	89.167
hy_7	-0.833	-6.470	-166.31	39.36	-19.815	-45.814	-5.00	42.106	40.224	46.133	-1.088	40.224	-45.815	-23.196	5	35.714	-106.294
hy_8	-0.833	-5.152	-100.26	-46.71	-19.641	-16.729	-24.00	41.688	39.148	45.770	-1.255	39.148	-16.737	17.918	5	35.714	-47.645
hy_9	-0.833	-7.166	-233.27	0.00	-25.975	-11.638	-10.00	49.603	54.508	52.546	4.105	54.508	-11.622	32.335	7	50.000	-52.899
hy_{10}	-2.234	-10.670	-2.55	-160.13	-33.497	-14.167	-11.00	54.800	58.285	58.642	2.112	56.116	-14.175	32.542	6	42.857	14.074
hy_{11}	-2.234	-10.670	64.08	-0.060	-26.931	-4.800	-2.00	50.128	39.112	56.925	-7.112	37.206	-4.712	43.144	6	42.857	232.076
hy_{12}	-2.234	-10.670	-233.27	39.36	-25.845	-36.439	-1.00	-2.208	7.714	-4.757	10.268	6.238	-36.367	-37.936	4	28.571	-327.146
hy_{13}	-2.234	-7.721	-2.98	-158.99	-21.452	-5.814	-3.00	56.796	56.677	61.618	0.555	54.531	-5.812	47.693	6	42.857	69.867
hy_{14}	-2.234	-7.693	-46.06	-78.32	-16.543	-7.226	-2.00	52.493	45.071	58.602	-3.672	43.084	-7.345	41.056	5	35.714	69.213
hy_{15}	-0.833	-6.470	-105.18	-79.53	-38.417	-33.801	0.000	49.814	35.117	57.398	-9.788	35.117	-33.458	-0.231	5	35.714	-130.262
hy_{16}	-11.566	-10.401	-156.48	79.98	-33.500	-0.712	-9.000	43.508	39.666	48.105	-2.115	26.229	-0.728	42.367	6	42.857	55.353
hy_{17}	-11.566	-10.109	89.78	-60.08	-35.686	-2.910	-13.00	54.962	61.126	58.218	5.885	45.625	-2.910	49.762	7	50.000	229.097
hy_{18}	-11.566	-10.401	-16.42	19.94	-34.599	-24.801	0.00	54.268	57.291	58.201	2.076	42.159	-24.801	15.882	8	57.143	127.229
hy_{19}	-0.833	-6.609	-104.87	-18.88	66.350	-14.555	0.00	66.350	43.968	46.868	0.735	43.968	-14.547	22.464	8	57.143	130.409
hy_{20}	0.833	-6.052	-58.86	99.99	-29.667	-15.631	-6.00	38.492	35.841	42.347	-1.956	35.841	-15.646	16.687	7	50.000	136.219
F	0.480	0.300	14.550**	16.290**	68.780**	40.130**	7.620**	9.480**	14.660**	6.590**	1.080	14.330**	45.950**	58.920**			
LSD 0.05	-	-	68.770	52.220	7.675	7.817	6.529	14.690	11.460	19.560	12.320	11.060	7.295	10.620			

Where: RPV= ratio positive value, FD (fifth duration); LD (larval duration); MP (Larval mortality percentage); DCP (double cocooning percentage); C/L (number of cocoons per liter); CP (cocooning percentage); PR (pupation ratio); Cw (cocoon weight); CSW(cocoon shell weight); CSR (cocoon shell ratio); SP (silk productivity); crop/N (cocoon crop by number) and crop/w (cocoon crop by weight),.

Check parent superior over all hybrids for FD and LD characters. Only one hybrid of hy_1 acquired positive hybrid vigour for nine characters of mortality percentage, double cocooning percentage, cocooning percentage, weight of (cocoon, shell, and pupa), productivity of silk, crop by number also crop by weight. Hybrids of hy_3, hy_{18}, and hy_{19} recorded positive hybrid vigour for the same six characters of cocoon weight, cocoon shell weight, pupa weight, shell ratio, productivity of silk, and crops by weight. Also, the hy_3 has positive hybrid vigour for mortality percentage, and double cocooning percentage while hy_{18} has positive hybrid vigour in double cocooning percentage. Hy_{19} recorded positive hybrid vigour in number of cocoon/liters. hy_6, hy_9, and hy_{17} hybrids earned positive hybrid vigour for seven characters, the three hybrids contribute in six characters together there were cocoon weight, cocoon shell weight, pupa weight, cocoon shell ratio, silk productivity, and crop by weight in addition hy_6, and hy_9 registered positive hybrid vigour for double cocooning percentage also hy_{17} has positive hybrid vigour in mortality percentage.

There is no hybrid superior over the check parent for all traits together. These data are aligned with Malik *et al*. (2002)[31] evaluated 18 bivoltine genotypes and two newly authorized races (SKAU-R-1 & SKAU-R-6). Five genotypes *viz*. SKAU-R-8, SKAU-R-23, SKAU-R-25, SKAU-R-13 and SKAU-R-7 recorded best values than check parent (SKAU-R-6). Ghazy (2007)[32] used five check parents to evaluate 37 silkworm single local hybrids. The resulting data revealed that, there were some promising hybrids, hybrid of Kx I earned the best heterosis value over the check hybrid Bulgaria 1, and six single local hybrids represented hybrid vigour for all tested characters except double cocoon percentage. Only hybrid KXD earned hybrid vigour over the check hybrid Bulgaria-2 for all trait's exception pupa weight. Most single hybrids gained hybrid vigour over the check hybrid Bulgaria-2 of the 5th & whole larvae period, and pupation rate. Eleven single local hybrids appeared hybrid vigour over the check hybrid Turkey of all traits. Singh and SureshKumar (2012)[33] derived and evaluated 27 silkworm hybrids, and they proved that no single hybrid expressed consistent hybrid vigour in all tested characters. And, Ghazy (2012) [34] evaluated fourteen hybrids resulted from fifteen races of Egypt breeding program by using formulae of heterosis over check parent, Positive hybrid vigour were acquired of Giza C, Giza N, Giza O, Giza V, Giza W, Qanater 1 and Qanater 2 hybrids for most economic traits under study, the seven previous hybrids are superior and can be used in commercial scale. (Fouad, 2020b) [8] used five local silkworm hybrids hyA, hyB, hyX, hyD, and hyF, according to heterosis over check parent value G_1 and G_2 of different economic characters. The resulting data showed that local hybrid hyA exhibited Positive hybrid vigour over the check parent value of G_1 and G_2 of almost tested traits. In addition, (Shinde, 2024) [35] studied 6 bivoltine and 5 multivoltine races of the silkworm *Bombyx mori* L. to use mid-parent heterosis and better parents heterosis equations to ascertain the heterosis manifested in single cross hybrids with regard to significant economic features. Significant positive heterosis over mid-parent was appeared in thirty hybrids for tested economic characters. Also, Nagaraju and Goldsmith (2002) [36] noted that, there is a positive correlation between genetic distance and mid-parental heterosis. So, the data showed that parental homozygosity has a discrete effect on the expressing heterosis. Identify the inbred lines that produced extremely heterotic hybrids. Given that the silkworm breeding program maintains a large number of inbred lines, the hybrid vigor most suited for producing heterotic hybrids should be identified using the available parents.

Data in Table. 5 obvious the arrangements of tested hybrids of total heterobeltiosis and the ratio of positive values. The data explain that there were thirteen hybrids that acquired the best positive total hybrid vigour form twenty hybrids. The highest best total hybrid vigour were hy_2, hy_4, hy_{11}, hy_1, hy_{12} and hy_5. These results are agree with (Ghazy and Fouad, 2021) [25] studied and evaluated nineteen local hybrids with modified heterobeltiosis formula (hybrid vigour over better parent value) were applied of thirteen economic traits. Arranging of selected hybrids for total heterobeltiosis and ratio of positive value bringed hybrid Eg_5 took the first order followed of Eg_{16} hybrid.

Table 5: Arrangements of selected hybrids of total heterobeltiosis and the ratio of positive values

Character hybrid	RPV%	Order Number	hybrid	Total Hybrid Vigour	Order Number
hy_1	64.286	1	hy1	137.306	4
hy_6	50	5	hy6	67.149	11
hy_{11}	42.857	9	hy11	164.485	3
hy_{17}	50	6	hy17	-150.965	18
hy_3	57.143	2	hy3	-165.902	19
hy_{20}	50	7	hy20	89.167	8
hy_{18}	57.143	3	hy18	-106.294	17
hy_{19}	57.143	4	hy19	-47.645	14
hy_{13}	42.857	10	hy13	-52.899	15
hy_{14}	35.714	15	hy14	14.074	13
hy_2	42.857	11	hy2	232.076	1
hy_{10}	42.857	12	hy10	-327.146	20
hy_8	35.714	16	hy 8	69.867	9
hy_9	50	8	hy9	69.213	10
hy_{16}	42.857	13	hy16	-130.262	16
hy_7	35.714	17	hy7	55.353	12
hy_4	42.857	14	hy4	229.097	2
hy_{15}	35.714	18	hy15	127.229	7
hy_5	35.714	19	hy5	130.409	6
hy_{12}	28.571	20	hy12	136.219	5

Where: RPV= ratio positive value, hy_1=HC_{16}XGizaT, hy_2=GizaT XGizaO, hy_3 =Giza O X HC_{16}, hy_4 = HC_{45} X CH_{19}, hy_5= CH_{19} X HC_{45}, hy_6 = CH_{16} X Giza D, hy_7= Giza D X Giza N, hy_8= HC_{40} X HC_{38}, hy_9= HC_{38} X HC_{40}, hy_{10}= CH_{17} X CH_{26}, hy_{11}= CH_{12} X CH_{17}, hy_{12}= CH_{26}X CH_{12}, hy_{13}= CH_{22}X CH_2, hy_{14}= CH_2X CH_{22}, hy_{15}= Giza C X HC_{43}, hy_{16}= HC_3X HC_{37}, hy_{17}= HC_{37}X HC_3, hy_{18}= CH_{32} X HC_4, hy_{19}= HC_{34} X HC_4, hy_{20}= HC_4 X HC_{34}.52

Conclusions

No single silkworm, *Bombyx mori* L. hybrid collected better results for all characters together. Hybrids of hy_3, hy_{18}, and hy_{19} recorded positive hybrid vigour for the same six characters of cocoon weight, cocoon shell weight, pupa weight, cocoon shell ratio, silk productivity, and crop by weight. Also, the hy_3 has positive hybrid vigour for mortality percentage, and double cocooning percentage while hy_{18} has positive hybrid vigour in double cocooning percentage. Hy_{19} recorded positive hybrid vigour in number of cocoons per liter. Hybrids of hy_6, hy_9, and hy_{17} earned positive hybrid vigour for seven characters, the three hybrids contribute in six characters together there were cocoon weight, cocoon shell weight, pupa weight, cocoon shell ratio, silk productivity, and crop by weight in addition hy_6, and hy_9 registered positive hybrid vigour for double cocooning percentage also hy_{17} has positive hybrid vigour in mortality percentage. There were six promising hybrids. It can be used at the commercial level or development races of breeding program.

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