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[Short Communication]

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Preliminary Report on Breeding of Coarse Size Variety $CU_1 \times CU_2$ of *Bombyx mori* L

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A number of Chinese, Japanese and European silkworm strains with coarse size filament were used for breeding the coarse size variety. Through cross breeding combined with pedigree selection within thirteen generations, a pair of coarse size silkworm variety, named $CU_1 \times CU_2$, was obtained after five years. Laboratory trials showed that the filament size of its F_1 hybrid was over 4.3 D, and the other economic characters were also good.

Key words: Silkworm, Variety, Coarse size, Breeding

Introduction

Silk is famed as the queen of fiber. Silk fabrics are in peoples good graces from ancient time to the present, leading to the fast development of sericultural industry. As the needs of silk goods in the world market become diversified, there has been increasing demand on special mixture fabrics and new woving products, both of which need to use coarse size filament. Up to now, the coarse size silkworm varieties are few (Xu *et al.*, 2000). For this reason, based on the available silkworm germplasms, we employed hybridization and directional pedigree selection methods in our breeding program that aimed to obtain the coarse size variety. As a result, a pair of coarse size varieties, "$CU_1 \times CU_2$", was obtained.

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Materials and Methods

Parentage selection

CU_1 was a variety derived from a three-way hybrid. To prepare it, firstly female moths of a variety named 57BC4 with good comprehensive character were crossed with male moths of another variety named W_{22} with high cocoon shell weight. Their F_1 generation was then crossed with LUYU, a variety with high cocoon shell weight of Chinese strain. As a fixed variety of the three-way hybrid of $(57BC4 \times W_{22}) \times LUYU$, CU_1 is a Chinese strain variety and is bivoltine and 4 molting. Its larval stage lasts 27–28 days. The average number of eggs per moth is over 680, its cocoon shell rate is 21–22%, the filament length of one cocoon is 1,000–1,200 meters and the filament size is 3.8–4.0 D.

CU_2 had W_{15}, an European strain with high single cocoon weight and cocoon shell weight, as female parent, and N208, a strain bred in Anhui Sericultural Research Institute with the highest single cocoon weight and cocoon shell weight, as male parent. As a fixed variety of the above hybridization, CU_2 is a Japanese strain variety with partial European strain characters and is bivoltine and 4 molting. The average number of eggs per moth is over 650, its cocoon shell rate is about 20%, the filament length of one cocoon is 1,000–1,500 meters and the filament size is 3.7–4.0 D.

Control of raising environment and selection techniques

Silkworm breeding for special uses must provide adequate raising environment according to the development of silkworms. This has been proved successful in the past breeding activities. In order to enhance the directional selection (Chen and Yao, 1995; He *et al.*, 1998), young larvae were raised under 26–27, 85–90% RH. Grown larvae were raised under 23–25, 65–80% RH. During each instar, fresh and appropriately matured leaves were fed to the larvae so as to add proteins into the larval bodies and speed up their development. Rearing trays were changed regularly and special care was taken while maintaining the breeding lines. In addition, the raising environment should also be controlled consistently to reduce influence of the environment on selection accuracy.

Keeping in mind that the breeding target is to obtain a coarse size variety with acceptable comprehensive characters, we attached great emphasis on investigating the influence of environmental factors on cocoon filament size and cocoon quality. To ensure that breeding target was realized, we examined individual cocoons for their weight, filament size and other characters. Those with favorable data were kept as the parents for reproducing offspring.

Results

The course of breeding

The F_1 generation was raised in spring of 1995 through mixed batch collection of newly hatched larvae. Because of heterosis, the F_1 generation showed strong physique, big body size, high cocoon weight. Lots of female cocoons had single cocoon weight of over 4 g. During larval stage, late molting and weak larvae were eliminated. In seed cocoon preparation period, firstly chose 100 female and male cocoons respectively, than did individual weighing to those with big and hard shells. Individuals with high cocoon weight, cocoon shell weight and cocoon shell rate were used in mixed egg production. During egg production period, each batch was composed of 40 healthy female and male pupae, respectively, among which the early emerged moths and caudal moths were eliminated.

In generations F_2-F_3, the gene separation in these two generations is not stable genetically. Difference between the individuals is significant. At this time it is good to implement individual selection. We selected the coarse size individuals directly and indirectly, and intensive directional selection was carried out all over the whole seeding period. Moths with the good aspect of egg laying and uniform hatching were used to reproduce offspring. In generations F_4-F_6, single batch rearing was used. Because the coarse size belongs to measurable quantitative inherited traits, which are controlled by multiple genes and the effective genes are greatly affected by environmental factors, we adopted "mating within the same batches" method to allow expression of the effective genes to facilitate the selection.

In generation F_7, crossing between different batches were adopted in order to stabilize the favorable traits, integrate breeding environment, enlarge seeding batches, set up sub-lines, select the good batches from good lines, select high percentage of good eggs and good hatching batches. When collecting newly hatched larvae, superseded bad batches. During seed cocoon preparation, detailed survey was conducted to items including reeling filament size and other comprehensive traits. Two best batches were selected for each race. Then did individual cocoon weighing. Cocoons with shell weight over the average level were retained for reproducing offspring.

During the whole course of breeding, on the basis of paying attention to balanced development of all economic characters, emphasis was laid on obtaining the coarse size while giving consideration to the silk quality. In the later rearing course, strength of the larvae was specially concerned. Raising data of the breeding lines are shown in Tables 1 and 2.

Combination and raising data of F_1 hybrid

The common combining ability was tested for six generations since 1997 using the incomplete diallel crossing method. CU_2 had the best result among all the Japanese strains tested. Special combining ability test showed that $CU_1 \times CU_2$ had the thickest filament size (4.3 D) among a number of hybrid combinations tested. In addition, its other economic characters met the objectives of breeding plan and were above the standards set for general commercial varieties. Its cocoon filament length was 1,100−1,200 meters, unwinding ratio over 75% and filament size above 4.3 D.

The hybrids were bivoltine and 4 molting. Egg color of $CU_1 \times CU_2$ was celadon. Average egg number of $CU_1 \times CU_2$ was around 1,650 per gram. Egg color of $CU_2 \times CU_1$ was gray purple or purplish brown. Average egg number of $CU_2 \times CU_1$ ranged from 1,600 to 1,700 per gram. The individuals were uniform in hatching, molting and maturing and had long larval period (27−30 d in spring rearing season and 26−28 d in autumn rearing season). The fifth instar took about 9−11 d. Larval body was stout and was with normal marking. Body color of the 5^{th} instar larvae changed from greenish white to greenish gray. Cocoon shape was big and regular. Cocoon color was white. Cocoons were heavy. Shell ratio of male cocoons was over 30%. Moths were big and the mating ability was good. Average number of eggs per moth was over 650. Because the larvae had big body size, they were reared and mounted sparsely.

Several rules should be followed when the hybrids were reared.

(1) Proper incubation. The temperature should be kept at 24−26°C, RH = 85−90%. After blastokinesis period, the temperature should be raised to 25.5°C, and the eggs should be protected in darkness after head bluing to make

Table 1. CU_2 main achievement in per years rearing course

Year	Rearing season	Genera-tion	Rearing type	Duration of the fifth (d : h)	Duration of all instars (d:h)	Larva-pupa rate (%)	Rate of dead worm cocoon (%)	Cocoon weight (g)	Cocoon shell weight (g)	Radio of cocoon shell (%)	Cocoon filament length (m)	Unwinding ratio (%)	Non-broken length of a bave (m)	Size (D)
1995	Spring	F1	○	8 : 12	27 : 06	93.33	3.1	1.89	0.392	20.74	936	70.21	674	3.67
	Autumn	F2	○	8 : 00	26 : 06	92.98	3.6	1.72	0.381	22.15				
1996	Spring	F3	○	9 : 00	27 : 06	94.98	2.4	1.92	0.403	20.99	998	69.13	690	3.71
	Summer	F4	□	7 : 06	23 : 06	88.14	8.0	1.76	0.38	21.59				
	Autumn	F5	□	8 : 00	25 : 00	80.36	10.9	1.96	0.409	20.87				
1997	Spring	F6	□	9 : 12	27 : 12	86.29	8.2	2.11	0.418	19.8	1004	62.32	625	3.76
	Summer	F7	□	7 : 06	25 : 06	85.84	9.8	1.89	0.411	21.72				
	Autumn	F8	□	6 : 18	25 : 06	85.21	8.5	1.94	0.393	20.25				
1998	Spring	F9	□	9 : 12	28 : 21	86.34	6.1	2.573	0.516	23.45	1055	63.29	668	4.0
	Autumn	F10	□	8 : 00	24 : 06	61.60	33.9	2.015	0.430	20.35				
1999	Spring	F11	□	8 : 18	26 : 12	91.56	5.8	2.592	0.507	19.54	1145	75.79	868	3.73
	Autumn	F12	□	7 : 12	26 : 06	85.77	9.0	2.443	0.489	20.00				
2000	Spring	F13	□	9 : 00	27 : 06	97.32	2.1	2.587	0.519	20.08	1144	69.33	793	3.84

○; mixing rearing and □; batch rearing.

Table 2. CU_1 main achievement in per years rearing course

Year	Rearing season	Genera-tion	Rearing type	Duration of the fifth (d : h)	Duration of all instars (d:h)	Larva-pupa rate (%)	Rate of dead worm cocoon (%)	Cocoon weight (g)	Cocoon shell weight (g)	Radio of cocoon shell (%)	Cocoon filament length (m)	Unwinding ratio (%)	Non-broken length of a bave (m)	Size (D)
1995	Spring	F1	○	9 : 11	26 : 06	88.41	10.6	2.48	0.592	23.79	1048	83.00	870	3.97
	Autumn	F2	○	8 : 06	25 : 03	87.15	7.6	2.32	0.510	21.99				
	Spring	F3	○	9 : 12	27 : 00	91.50	6.2	2.69	0.592	22.01	1054	78.00	871	4.11
1996	Summer	F4	□	7 : 06	23 : 06	90.49	6.7	2.02	0.432	21.39				
	Autumn	F5	□	8 : 12	27 : 00	91.01	5.5	1.97	0.436	22.13				
	Spring	F6	□	9 : 18	30 : 06	91.04	7.7	2.22	0.512	23.06	1032	73059	759	3.82
1997	Summer	F7	□	7 : 00	24 : 23	82.78	11.9	1.89	0.373	19.96				
	Autumn	F8	□	7 : 18	25 : 06	87.85	10.1	2.06	0.431	20.93				
1998	Spring	F9	□	10 : 00	27 : 06	88.10	7.8	2.73	0.640	23.43	1104	59.52	657	3.90
	Autumn	F10	□	9 : 00	25 : 06	77.16	15.6	2.04	0.436	21.37				
1999	Spring	F11	□	10 : 06	27 : 00	93.00	4.7	2.875	0.636	22.14	1099	79.37	873	3.96
	Autumn	F12	□	6 : 18	26 : 06	77.00	15.4	2.612	0.553	21.17				
2000	Spring	F13	□	9 : 18	27 : 06	95.23	3.0	2.869	0.623	21.72	1103	81.12	895	3.78

○; mixing rearing and □; batch rearing.

Table 3. CU_1 and CU_2 main achievement in per years rearing course

Year	Rearing season	Duration of the fifth (d:h)	Duration of all instars (d:h)	Larva-pupa rate (%)	Rate of Dead worm cocoon (%)	Cocoon weight (g)	Cocoon shell weight (g)	Cocoon shell rate (g)	Cocoon filament length (m)	Unwinding ratio (%)	Non-broken length of a bave (m)	Size (D)
1999	Direct Cross	9:18	27:6	89.65	2.2	3.183	0.647	21.52				
(Autumn)	Reverse Cross	8:18	26:18	91.56	3.5	3.185	0.702	22.05	1109	80.21	890	4.28
	Average	9:09	27:00	90.61	2.8	3.184	0.675	21.79				
2000	Direct Cross	9:12	27:00	95.16	2.0	2.936	0.623	21.22				
(Autumn)	Reverse Cross	9:12	27:00	97.83	1.2	2.707	0.573	21.16	1056	79.32	838	4.30
	Reverse Cross	9:12	27:00	96.49	1.6	28.22	0.598	21.19				

Table 4. Hybrids achievement in rural areas

Year	Rearing season	Duration of the fifth (d:h)	Duration of all instars (d:h)	Larva-pupa rate (%)	Rate of Dead worm cocoon (%)	Cocoon weight (g)	Cocoon shell weight (g)	Cocoon shell rate (g)	Cocoon filament length (m)	Unwinding ratio (%)	Non-broken length of a bave (m)	Size (D)
ANHUI	Direct Cross	9:12	27:06	91.26	2.3	3.221	0.682	21.17				
	Reverse Cross	9:00	26:18	91.54	3.2	3.198	0.712	22.06	1115	82.31	918	4.32
	Average	9:06	27:00	91.40	2.8	3.205	0.697	21.72				
SHAN-	Direct Cross	10:06	28:12	92.98	1.8	3.342	0.764	22.86				
DONG	Reverse Cross	10:00	27:18	94.29	2.4	3.421	0.785	22.95	1204	78.23	942	4.35
	Average	10:03	28:03	93.64	2.1	3.382	0.775	22.35				
	Direct Cross	9:18	27:00	96.32	1.9	2.936	0.697	23.74				
JIANGSU	Reverse Cross	9:06	27:00	97.97	1.1	2.892	0.702	24.27	1086	80.23	871	4.30
	Average	9:12	27:00	96.49	1.5	2.911	0.700	24.01				

Table 5. Raw silk and fabric performance

Item	Coarse size silk	Ordinary silk (general scope)	Ratio of addition%	Remarks
Cocoon filament size (dtex)	5.02	3.45	31.27	
Size of raw silk (dtex)	25.10 (theoretical value) 27.32 (actual value)	22.68		
Broken tenacity of raw silk (gf)	95.7	60 – 80		
Relative broken tenacity of raw silk (cN/dtex)	3.434	2.958 – 3.123	9.06 – 13.86	Addition
Broken stretch rate (%)	23.165	18 – 21	9.34 – 22.30	Addition
Stretch elasticity rate (%)	46.76	42.12	9.92	Addition
Broken merit (kgf·mm/dtex)	0.298	0.257	13.76	Addition
Primary model test weight (cN/dtex)	73.757	44 86 (general 73)	1.03	Few addition

hatching uniform.
(2) Requirement of temperature and humidity in various instars. The first and second instars: 26 – 27°C, depression of wet bulb 0.5 – 1°C; the third instar: 25 – 26°C, depression of wet bulb 1 – 2°C, the fourth instar: 24 – 25°C, depression of wet bulb 2°C; the fifth instar: 23 – 24°C, depression of wet bulb 2 – 3°C.
(3) Silkworm bed should be rearranged and rearing trays should be changed on time to avoid mulberry leaves being unevenly distributed and eaten because the young silkworms are phototactic and tend to stay together. The leaves for first meal of each instar should be tender and fresh. Losing silkworm should be avoided during rearing.
(4) Disinfection should be conducted during the rearing period to protect silkworms against diseases. Ventilation should be enhanced, and low temperature with high humidity or high temperature with high humidity should be avoided.
(5) On the second day of the fourth instar, number of silkworms in each tray need to be fixed at 300. The hybrid silkworms have very good appetite. The leaf consumption ranges from 272 to 284 kg for 10,000 eggs. Silkworm beds should be rearranged well, especially in the fifth instar because the larvae grow very fast.
(6) Silkworms in the mounting period should not be too dense. The mounting environment should be kept dry and maintained at 23 – 24 to improve cocooning rate, reduce non-cocooning silkworms, and improve cocoon quality.

Performance of the hybrids in rural areas

In 2002 – 2003, the hybrids were reared in rural areas of Anhui, Jiangsu and Shandong Provinces. The results showed that the cocoon filament size was above 4.7 dtex (Table 4).

Characters of silk and fabrics

In 2001, silk and fabric performance were tested using the cocoons obtained from lab rearing. For each group, five cocoons were used to conduct the test. It showed that the coarse size variety had a filament size of 27.985 dtex, and the filament strength and elongation was better than the control ones (shown in Table 5).

Discussion

In China, sericulturists began to breed silkworm varieties with coarse size only a few years ago, but the progress was significant. Up to now, 2– 3 hybrids have been experimented in rural areas. The general feedback was that: under favorable rearing condition like in spring, they showed their special good characters, leading to high output of desired cocoons. However, under unfavorable rearing condition like in summer and autumn, their special traits are difficult to show. So how to breed a variety that can grow well in all rearing seasons and have high yield of coarse size filament cocoons has become the items for silkworm breeders. The coarse size hybrid we obtained showed better results than the existing coarse size varieties in harsh environment, making it a promising variety for future commercialization.

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