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Path Coefficient Analysis on Major Silk Quality Characteristics of the Silkworm, *Bombyx mori* L.

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By means of correlation analysis and path coefficient analysis, 18 characteristics of 325 conserved silkworm races were studied for the selecting efficiency on main silk quality characteristics. The result showed that selecting lines with heavier cocoon weight are beneficial to raise the weight of bave. Choosing strains with higher cocoon shell percentage, longer filament length and better reelability percentage is good for increasing non-broken filament length. Selecting lines with medium daily weight of bave produced in the fifth instar, medium cocoon shell percentage and simultaneously selecting heavier cocoon shell weight are favorable to promote reelability percentage. Choosing strains with heavier cocoon weight, higher cocoon shell percentage, heavier daily weight of bave produced in the fifth instar and heavier weight of bave but shorter filament length may hopefully breed out a race with thick filament size. And selecting strains with heavier weight of bave and fine filament size are beneficial to increase filament length. Selecting lines with higher cocoon shell percentage and heavier weight of bave are favorable to raise raw silk percentage of cocoon. There are no significant direct or indirect correlation coefficient between viability and major characteristics of silk quality. It is, therefore, feasible to breed a silkworm race with excellent vitality and good silk quality as well.

Key words: Silk quality characteristics, Selecting efficiency, Silkworm, *Bombyx mori* L.

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Introduction

Most characteristics of cocoon and silk quality are quantitative ones controlled by micro-effective multiple genes (Sericultural Research Institute, 1981) and easy to be affected by environmental conditions. Correlations among these characteristics are often existed. So, it is beneficial to raise the effect of selection and speed up the process and level of breeding to find out the positive correlation among profitable characteristics. Larva to pupa ratio, single cocoon weight, cocoon shell weight and cocoon shell percentage are the main factors affecting the harvest of cocoon (Yan and He, 1988). While the main factors affecting the non-broken filament length are filament length, reelability percentage and cocoon shell ratio. And cocoon shell weight and egg quantity produced are highly related to the weight of pupa (Yang and Zhong, 1987). In this paper, we studied the correlations of the major silk quality characteristics with the other ones, and analyzed the direct and indirect effects of each characteristic to the major silk quality ones with the method of path coefficient analysis based on 18 characteristics of 325 races. Up to now no experiment has been done on such a large number of silkworm races for study the correlation among silk quality characteristics. Thus, our results provide the reference to breed better silkworm races.

Materials and Methods

Resource of data

The data used in the article are from the investigation on 18 characteristics of 325 conserved silkworm races including Chinese monovoltine and bivoltine, Japanese monovoltine and bivoltine, European monovoltine, trimoltine and Chinese polyvoltine ones (Sericultural Research Institute, 1987; Zhang, 2000).

Methods of analysis

For the sake of easy analysis, 18 characteristics of 325 silkworm races are classified into 5 groups, *i.e.*: (1) duration of development including the 5th instar and all instar; (2) viability including larva to pupa ratio, larva to cocoon ratio, dead silkworm cocoon percentage; (3) cocoon quality including cocoon weight, cocoon shell weight and cocoon shell percentage; (4) silk economical characteristics including weight of bave, daily weight of bave produced in the 5th instar, filament length, filament size, reelability percentage, non-broken filament length and row silk percentage; and (5) silk cleanness including neatness, lousiness, rate of degumming loss. The correlation coefficient among these characteristics and their path coefficient analysis were carried out as described previously (Yang and Zhong, 1987; Yan and He, 1988). Before analysis the data were exchanged into arc-sine ($\sin^{-1}\sqrt{x}$).

Results and Discussion

Path coefficient analysis aimed at the weight of bave

The weight of bave is the most important characteristic of silkworm race. The correlation coefficient analysis (Table 1) showed that the weight of bave is closely related to cocoon shell weight, filament length, daily weight of bave produced in the 5th instar, cocoon shell percentage and row silk percentage. Their correlation coefficients are 0.937, 0.861, 0.922, 0.785 and 0.873, respectively. While path coefficient analysis showed cocoon shell weight and cocoon shell percentage, row silk percentage have higher direct path coefficient, 0.748, –0.494 and 0.427, separately, with weight of bave. Of which, cocoon shell weight has the most strong direct effect on weight of bave, showing the same tendency as its correlation coefficient. This means that cocoon shell weight is the decisive factor. But the direct effect of cocoon shell percentage on weight of bave, largely through the positive effect of cocoon shell weight on path chain, is contrary to that in correlation coefficient. Therefore, selecting lines with average cocoon shell percentage and as well as heavier cocoon shell weight are favorable to promote weight of bave. On the other hand, other characteristics are less important to weight of bave both in correlation coefficient and path coefficient.

Path coefficient analysis aimed at non-broken filament length

Non-broken filament length is one of the most important characteristics of silk quality. From the map of path coefficient analysis (Fig. 1), we knew that it can be affected not only by factors of direct effects such as filament length and reelability percentage, but also factors of indirect effects like weight of bave, cocoon shell percentage, cocoon weight and cocoon shell weight. So it is not enough to reflect the true relationships between all factors and non-broken filament length to analyses from correlation coefficient only. Taking the advantages of path coefficient analyses, we can know the degree of correlations between all factors and non-broken filament length and then master the selecting yardstick to promote selecting efficiency.

The pheneotypic correlation and path coefficient between non-broken filament length and other 17 characteristics of 325 races are listed in Table 1. Simple correlation coefficient analysis showed that most characteristics have a high significant correlation with non-broken filament length except for filament size and viability. Of which filament length, cocoon shell weight, cocoon shell percentage, weight of bave, daily weight of bave produced in the 5th instar and row silk percentage are bigger, 0.744, 0.556, 0.515, 0.685, 0.672 and 0.676, respectively. While path coefficient analysis tells us that the main factors affecting non-broken filament length are cocoon shell weight, filament length, daily weight of bave produced in the 5th instar, cocoon shell percentage, reelability percentage and row silk percentage. Their path coefficients are -0.841, 0.741, 0.668, 0.618, 0.671 and –0.501, separately, with the same tendency as correlation coefficient except for cocoon shell weight and row silk percentage. And their direct path coefficients are haply consistent to the degree of their correlations. The direct path coefficients of cocoon shell weight and row silk rate to non-broken filament length are negative, expressing thought the indirect action of filament length, daily weight of bave produced in the 5th instar and cocoon shell percentage. The direct action of reelability percentage is partially covered by the action of filament length, daily weight of bave produced in the 5th instar and cocoon shell percentage resulting in weak correlation coefficient between reelability percentage and non-broken filament length. The above analysis suggests that filament length has the closest correlation with non-broken filament length, daily weight of bave produced in the 5th instar and cocoon shell percentage also should not be neglected. Therefore, selecting strains with heavier cocoon shell weight, longer filament length and better reelability percentage are propitious to increase non-broken filament length. Duration of development, viability and silk cleanness characteristics only have weak action on non-broken filament length.

Path coefficient analysis aimed at reelability percentage

Reelability percentage is a characteristic of lower heritability and it is easy to be affected by environmental fac-

Table 1. Correlation coefficients of 18 major economic characteristics, path poefficients of non-broken filament length of 325 silkworm races

Path coefficients \ Correlation coefficient	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	Non-broken filament length (y)
Duration of 5th instar (x_1)	0.295	0.837	-0.271	-0.195	0.185	0.423	0.679	0.686	0.566	-0.407	0.042	0.245	0.609	0.011	0.272	0.155	0.575	0.343
Duration of all instar (x_2)	0.247	0.059	-0.327	-0.282	0.179	0.473	0.639	0.597	0.479	-0.384	0.007	0.310	0.563	0.197	0.302	0.137	0.487	0.299
Larva-pupa rate (x_3)	-0.080	-0.019	0.063	0.759	-0.728	-0.212	-0.142	-0.044	-0.051	0.187	0.027	-0.116	-0.088	-0.013	0.017	-0.081	0.010	0.050
Survival rate of larvae (x_4)	-0.058	-0.017	0.048	-0.037	-0.154	-0.207	-0.068	0.063	0.046	0.126	0.088	-0.128	-0.008	-0.033	0.076	-0.086	0.111	0.107
Dead worm cocoon per. (x_5)	0.055	0.010	-0.046	0.006	0.045	0.083	0.142	0.146	0.117	-0.172	0.066	0.045	0.119	-0.023	0.059	0.050	0.112	0.017
Cocoon weight (x_6)	0.125	0.028	-0.013	0.008	0.004	0.211	0.771	0.307	0.474	-0.238	-0.239	0.618	0.714	0.062	0.685	0.017	0.300	0.388
Cocoon shell weight (x_7)	0.200	0.037	-0.009	0.002	0.006	0.162	-0.841	0.833	0.806	0.449	-0.049	0.464	0.937	0.011	0.815	0.172	0.755	0.556
Cocoon shell per. (x_8)	0.203	0.035	-0.003	-0.002	0.007	0.065	-0.701	0.618	0.805	-0.475	0.153	0.173	0.785	-0.047	0.625	0.234	0.879	0.515
Cocoon filament length (x_9)	0.167	0.028	-0.003	-0.002	0.005	0.100	-0.678	0.497	0.741	-0.394	0.239	-0.017	0.861	-0.046	0.769	0.265	0.851	0.744
Reel-ability per. (x_{10})	-0.120	-0.023	0.012	-0.005	-0.008	-0.050	0.378	-0.293	-0.292	0.671	-0.038	-0.006	-0.325	-0.067	-0.204	-0.200	-0.285	0.254
Neatness (x_{11})	0.013	0.000	0.002	-0.003	0.003	-0.050	0.041	0.095	0.177	-0.025	-0.010	-0.397	-0.019	-0.061	-0.041	0.136	0.141	0.186
Filament size (x_{12})	0.072	0.018	-0.007	0.005	0.002	0.130	-0.390	0.107	-0.013	-0.004	0.004	-0.103	0.445	0.072	0.448	-0.205	0.203	0.045
Weight of bave (x_{13})	0.180	0.033	-0.006	0.000	0.005	0.151	-0.789	0.485	0.638	-0.218	0.000	-0.046	0.071	0.004	0.922	0.135	0.873	0.685
Exfoliation (x_{14})	0.003	0.001	-0.001	0.001	-0.001	0.013	-0.009	-0.029	-0.034	-0.045	0.001	-0.007	0.000	-0.026	-0.001	-0.000	-0.043	-0.112
Weight of bave at 5th instar (x_{15})	0.080	0.018	0.001	-0.003	0.003	0.144	-0.686	0.386	0.571	-0.137	0.000	-0.046	0.065	0.000	0.668	0.080	0.784	0.672
Re-gumming loss of cocoon shell (x_{16})	0.046	0.008	-0.005	0.003	0.002	0.004	-0.144	0.145	0.196	-0.134	-0.001	0.021	0.010	0.000	0.053	0.013	0.170	0.131
Raw silk per. of cocoon, (x_{17})	0.170	0.029	0.001	-0.004	0.005	0.063	-0.635	0.543	0.631	-0.191	-0.001	-0.021	0.061	0.001	0.524	0.002	-0.501	0.676

Note: In the table data underlined are direct path coefficients (P_i, i = 1, 2,…, 17), the upper part of the diagonal line is correlation coefficients ($r_{i,j}$, i = 1, 2,…, 17; j = 1, 2,…, 17) and the lower part is path coefficients ($p_{i,j}$). The last column on the right is correlation coefficients between non-broken filament length and other characteristics. The formula of path coefficients is $P_{i,j}=r_{i,j}\times P_i$, for example $x_9 \rightarrow x_6 \rightarrow$ non-broken filament length $P_{96} = r_{96} \times P_6 = 0.4740.211 = 0.09960.100$.

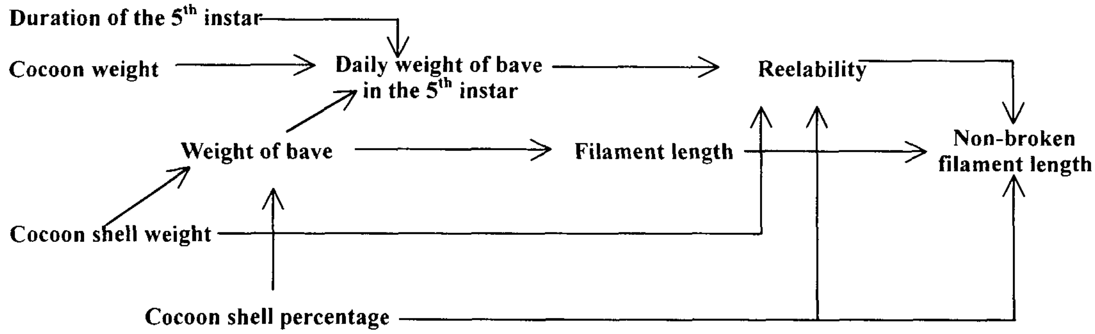

Fig. 1. Map of path coefficient network aimed at non-broken filament length.

tors. Of which duration of the 5th instar, cocoon shell weight, filament length, cocoon shell percentage, weight of bave, non-broken filament length and row silk rate have higher correlation coefficients with reelability percentage, –0.407, –0.449, –0.394, –0.475, –0.325, 0.254 and –0.285, respectively. All these correlation coefficients are negative values except that of non-broken filament length. The results of path coefficient analysis showed their path coefficients are –0.443, 0.871, –0.956, –0.814, 0.069, 1.191 and 0.803, separately. Of which the duration of the 5th instar, filament length, cocoon shell percentage, non-broken filament length show higher direct action and the same tendency as in correlation coefficient analysis. While cocoon shell weight and row silk percentage showed the opposite effect as in correlation coefficient analysis. And weight of bave only has weak direct action but daily weight of bave at the 5th instar has restively higher direct action on reelability percentage. So selecting lines with mean cocoon shell percentage, daily weight of bave produced in the fifth instar and heavier cocoon shell weight are favorable to promote the reelability percentage.

Path coefficient analysis aimed at filament size

Filament size is an important economic index in breeding of silkworm races with special filament size. Correlation coefficient analysis showed that cocoon filament length, non-broken filament length, lousiness and dead silkworm cocoon percentage have no significant coefficients with filament size; while larva to pupa ratio, survival rate of larvae have significant coefficients; and the other characteristics showed extreme significant coefficients, of which cocoon weight, cocoon shell weight, weight of bave and daily weight of bave produced in the 5th in star have positive correlation coefficients with filament size: 0.618, 0.464, 0.445 and 0.448, respectively. Then path coefficient analysis showed cocoon weight, cocoon shell weight, filament length, weight of bave and cocoon shell percentage have stronger direct action on filament size, 0.759, –0.600, –1.335, 0.648 and 0.654. Filament length has negative and weak correlation coefficient (–0.017) weakened by its indirect action but strong direct action on filament size. This result is not consistent with the point of view that there are strong positive correlation coefficient among weight of bave, filament length and filament size (Shen, 1928). This is probably due to the difference of materials. But path coefficient analysis is more reliable than simple correlation coefficient analysis. So in breeding of the races with a thick filament size, strains with heavier cocoon weight, higher cocoon shell percentage, higher daily weight of bave produced in the 5th instar and heavier weight of bave should be selected for succession of generation.

The correlation coefficient and path coefficient among filament length, weight of bave, cocoon shell percentage, filament size and row silk percentage will not be given unnecessary details. According to the experiment and analysis, selecting strains with heavier weight of bave and fine filament size is beneficial to increase filament length; selecting strains with higher cocoon shell percentage and heavier weight of bave are in favor of row silk percentage. By analyzing the direct and indirect effects of one characteristic to others related, path coefficient analysis is more reliable and comprehensive compared with correlation coefficient analysis. So that it can lead us to select silkworm characteristics effectively.

Path network among the economic characteristics of silkworm is complicated, and weather one silkworm race is good or not is decided by evaluation of some characteristics. In breeding of silkworm races, therefore, more emphasis should be paid on the level of comprehensive characteristics even races for special purpose.

Path coefficient analysis showed cocoon shell weight and cocoon shell percentage are closely related to silk economical characteristics. For the purpose of breeding races with better comprehensive character we must master the intension of selection on them. But over done on selecting of high cocoon shell percentage will bring bad effect to weight of bave and reelability. Selecting strains with average cocoon shell percentage and cocoons with bigger shape are favorable to improve reelability percentage and increase the weight of bave.

Viability and silk cleanness characteristics almost have no correlation with silk economical characteristics including weight of bave, daily weight of bave produced in the 5th instar, filament length, filament size, reelability percentage, non-broken filament length and row silk ratio. So that, it is feasible to breed a silkworm race with excellent vitality, low lousiness and good silk quality.

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