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Low-Cost Artificial Diets for Polyphagous Silkworms

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Abstract

This paper describes the development of low-cost artificial diets for the silkworm using a linear programming method as well as the breeding of polyphagous silkworm races with a high adaptability to the diets. On the basis of the results of nutritional studies, low-cost artificial diets for the silkworm have been developed by applying a linear programming method to the formulation of the composition of artificial diets. In parallel with the development of low-cost artificial diets, studies on the feeding response of the silkworms to the diets and its inheritance have been carried out and polyphagous silkworm races with a high adaptability to the diets have been bred. Development of a new type of silkworm rearing system based on these methods is deemed important.

Discipline: Sericulture
Additional key words: *Bombyx mori*, feed ingredient, linear programming method

Introduction

Artificial diets were applied for the first time in sericulture in Japan in 1977 for the rearing of young larvae of the silkworm in cooperative rearing houses. The practical application of artificial diets in sericulture which has enabled to save a great deal of labor for the rearing and to rear young healthy larvae has rapidly expanded. At present, about 50% of the silkworms in their young instars are reared on artificial diets rather than on mulberry leaves (Fig. 1). Although the use of artificial diets for the rearing of silkworms from the 1st to 3rd instars is important for the reasons described above, this practice is limited to the rearing of silkworms from the 1st to 2nd instars.

It is generally recognized that the high cost of artificial diets is a major constraint on the dissemination of silkworm rearing on artificial diets from the 1st to 3rd instars in the cooperative rearing houses. The cost of artificial diets accounts for about 35% and 50% of the total expenses for silkworm rearing from the 1st to 2nd instars and from the 1st to 3rd instars in the cooperative rearing houses, respectively. Consequently, it is essential to lower the cost of artificial diets in order to extend the period of silkworm rearing on artificial diets, so that farmers can adopt a more stable management system for sericulture. In the present paper the progress of the development of low-cost artificial diets as well as breeding of polyphagous silkworms with a high adaptability to the diets will be reviewed briefly.

Characteristics of artificial diets for the silkworm

Generally, commercial artificial diets for the

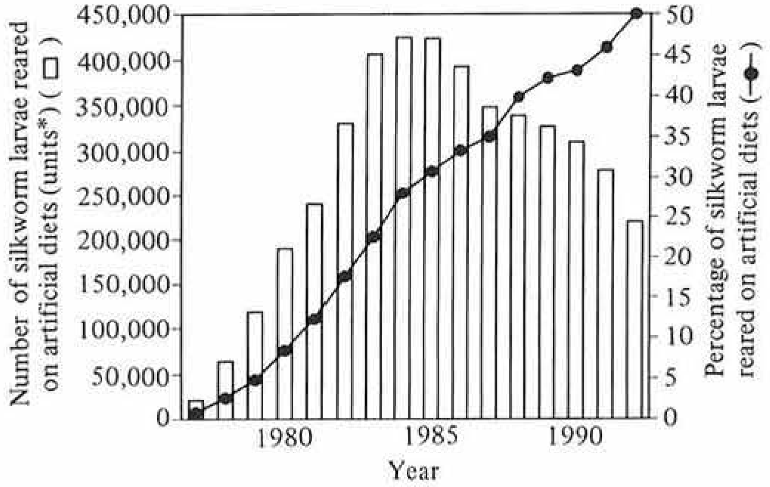

Fig. 1. Changes with time in silkworm rearing on artificial diets in the cooperative rearing houses
*One unit contains 20 thousand larvae.

Table 1. Composition of an artificial diet of the silkworm and cost ratio of feed ingredients[8)]

Feed ingredients	Amount added (%)	Cost ratio (%)
Mulberry leaf powder	30.0	36.4
Defatted soybean meal	28.0	5.1
Cellulose powder	15.0	6.4
Corn starch	6.1	0.9
Citrate	3.7	1.8
Salt mixture	4.0	4.9
Sucrose	4.0	1.5
Agar	7.0	26.3
Ascorbic acid	0.5	1.3
Vitamin B mixture	0.4	7.4
Phytosterol	0.3	2.2
Soybean oil refined	1.3	0.5
Antiseptics	1.0	5.3
Total	101.3	100.0

silkworm used in the cooperative rearing houses contain 20 to 25% of mulberry leaf powder, on a dry weight basis, to achieve synchronous growth. About 5% of agar is added as gelling agent in the diets to keep the water content at a constant level of 70–75%, since the silkworms cannot take water unlike livestock. Mulberry leaf powder and agar are relatively expensive and account for nearly 60% of the cost of whole ingredients in the diets (Table 1)[8)]. Thus, the amount of expensive ingredients such as mulberry leaf powder or agar must be reduced or they must be excluded from the diets to lower the cost of the diets. It is also necessary to introduce into the silkworm diets some of the cheap ingredients used in feeds for livestock.

Breeding of polyphagous silkworm races

Utmost efforts are being made to improve the composition of artificial diets for the silkworm, due to their industrial importance. Along with the accumulation of qualitative and quantitative data on the nutritional requirements of the silkworms, an attempt was made to formulate the composition of artificial diets for the silkworm using a linear programming method in order to incorporate into the diet the nutrients necessary for the growth and development of the silkworms, in placing emphasis on the need to reduce the cost of the diet[2,3)]. At that time, however, the new low-cost diet was not put into practical use, since the silkworm races distributed commercially were repelled by the smell or taste of the feed ingredients in the diet, such as fish meal or yeast and, consequently, did not eat it easily. Thus, it was deemed necessary to breed silkworms that fed readily on diets containing fish meal or yeast, to use the new low-cost diet developed theoretically by the linear programming method.

To breed polyphagous silkworm races which can be reared on such a diet, studies were carried out on the feeding response of the silkworms to the diets, inheritance of the feeding response and method of selection of polyphagous silkworms[1,4–6]. The following results were obtained: (1) almost all the Japanese strains could grow on the diet, unlike most of the Chinese strains, (2) genetical control of feeding preference for the diet was mainly achieved by a major recessive gene located on the 3rd chromosome and by its modifier genes (Table 2), and (3) it became possible to breed polyphagous silkworm races by selecting newly hatched larvae with a high ability to feed on the diet.

Based on these findings, the breeding of new commercial silkworm races with a high adaptability to the diets has been initiated since 1988, and the hybrid designated as N 601 × C 601 (special name; Asagiri) was recognized and authorized in 1991 by the Japanese Government as a distinctive race with a high feeding adaptability to the low-cost diet and a capacity for silk production similar to that of the races generally used[7]. Then, two hybrids, Sin-Asagiri and Habataki were recognized and authorized as polyphagous races in 1992 and 1993, respectively.

Table 2. Inheritance of feeding response of the newly hatched larvae of the silkworm to the low cost artificial diet, LP-1 diet, designed using a linear programming method[6]

Crossing form	Rate of grown larvae after 48 hr
Sawa J	89.3
C 01	0.0
Sawa J × C 02	0.0
C 02 × Sawa J	0.0
(Sawa J × C 02) F2	7.7
(Sawa J × C 02) × Sawa J	32.0
(Sawa J × C 02) × C 02	0.0

Development of low-cost artificial diets for polyphagous silkworms using linear programming method

The studies on the development of low-cost diets proceeded in parallel with the breeding of polyphagous silkworms. To design the composition of artificial diets for the silkworm using a linear programming method, the following aspects must be clarified: (1) contents of various kinds of nutrients in feed ingredients, (2) amounts of various kinds of nutrients which must be incorporated into the diet, (3) limiting factors and optimum contents of feed ingredients which affect the feeding behavior as well as larval growth and physical properties of the diet, and (4) price of feed ingredients. More than 50 kinds of feed ingredients and contents of about 40 kinds of nutrients in individual feed ingredients were analyzed by computer. For (2), a great deal of information has been accumulated on the minimal optimal levels of nutrients required for securing the growth and survival of the silkworms, and the dose requirements are closely correlated with the content of the respective nutrients in mulberry leaves. For determining the limiting factors for each feed ingredient, feeding response to the artificial diets which contained feed ingredients for livestock, such as fish meal, yeast, pupal powder, rape bran, gluten meal and alfalfa, and subsequent larval growth were investigated (Table 3)[3,9]. The polyphagous strains showed a high feeding adaptability to the diets and a high survival rate on these diets, which both increased when a very small amount of

Table 3. Feeding adaptability and survival of the newly hatched larvae of the silkworm reared on the artificial diet containing feed ingredients for livestock[9)]

Feed ingredients (5% added)	Commercial silkworms				Polyphagous silkworms			
	Asa・Hi × To・Kai		N 01 × C 01		N 601 × C 601		CSJ 01 × NSJ 01	
Fish meal	0[a)]	0[b)]	0	0	66	84	38	82
Yeast	0	4	8	10	92	98	90	94
Silkworm pupal powder	0	4	0	0	10	70	2	16
Rape bran	2	36	12	22	94	100	80	98
Gluten meal	2	28	28	42	86	100	80	94
Alfalfa	0	0	0	0	86	98	94	98

a): Rate of grown larvae after 24 hr, b): Rate of larvae surviving after 5 days.

Table 4. Composition of the low-cost diets, LPY-141 diet and LPY-501 diet, for the silkworm designed using a linear programming method[10,11)]

Feed ingredients	LPY-141 diet for			LPY-501 diet for		
	1st to 2nd instars	3rd instar	4th instar	1st to 2nd instars	3rd instar	4th instar
Mulberry leaf powder	4.000	4.000	-	4.000	4.000	-
Defatted soybean meal	31.983	35.566	36.782	35.000	38.000	38.000
Corn meal	30.000	30.000	30.000	40.702	46.506	46.608
Defatted rice bran	18.333	9.763	11.423	-	-	-
Rape bran	-	5.000	8.000	-	-	4.000
KCl	0.431	0.409	0.515	0.664	0.194	0.349
K_2HPO_4	-	0.108	-	1.085	1.483	1.317
$MgHPO_4 \cdot 3H_2O$	-	-	-	0.460	-	-
$MgSO_4$	-	-	-	0.318	0.909	0.844
$CaCO_3$	1.987	1.935	2.068	2.114	2.098	2.221
$FePO_4 \cdot 4H_2O$	0.084	0.085	0.086	0.094	0.069	0.096
Vitamin mix. for chick	0.172	0.173	0.177	0.174	0.128	0.182
Vitamin mix. for eel	-	-	-	0.016	0.200	-
Choline・Cl	0.020	-	-	0.043	0.035	0.009
Inositol	0.019	0.030	0.043	0.078	0.071	0.092
Ca-pantothenate	0.012	0.013	0.013	0.014	0.013	0.014
Niacin	-	-	-	0.008	0.006	0.007
Pyridoxine-HCl	0.001	0.002	0.002	0.002	0.002	0.002
Ascorbic acid	1.000	1.000	1.000	1.000	1.000	1.000
Citrate	4.000	4.000	3.000	3.000	3.000	3.000
Soybean oil refined	1.855	1.806	1.779	1.153	1.209	1.177
Phytosterol	0.194	0.200	0.204	0.165	0.167	0.172
Carragheenan	5.000	5.000	4.000	-	-	-
Antiseptics	0.910	0.910	0.910	0.910	0.910	0.910
Total	100.001	100.000	100.002	100.000	100.000	100.000

mulberry leaf powder was added to the diets, whereas the commercial races showed a very low feeding adaptability and almost all of the larvae were unable to survive on the diets.

In taking account of the limiting factors of the feed ingredients, nutritional requirements for larval growth and the content of nutrients of feed ingredients, the optimum formulation of the diets for the 1st to 2nd, 3rd, and 4th instar larvae of polyphagous silkworms, respectively, was designed by applying a linear programming method. One of these diets was designated as the LPY-141 diet (Table 4)[10]. The content of mulberry leaf powder was reduced or the ingredient was excluded altogether from the diets. Mulberry leaf powder was added only as a feeding stimulant, and the nutrients, such as amino acids, B vitamins and inorganic compounds, necessary for the growth of the silkworm were supplied from defatted soybean meal, corn meal and rape bran. The deficiencies in nutrients, such as B vitamins and inorganic compounds, were adjusted by adding to the diets respective substances or mixtures used for livestock. The larvae of the polyphagous races reared on the diets and transferred to mulberry leaves in the 5th instar produced a large amount of cocoons of good quality, whereas the larvae of the commercial hybrids were unable to survive normally on the diets (Table 5). It is assumed that the cost of the feed ingredients in the LPY-141 diet could be lowered by about one half of that of the commercial diet for the commercial hybrid race of the silkworm. Based on this information, commercial diets for the polyphagous silkworms were developed.

Subsequently, a diet, from which agar was excluded, was developed for polyphagous silkworms (Table 4)[11]. The diet designated as the LPY-501 diet consisted mainly of defatted soybean meal and corn meal. The cost of the LPY-501 diet was further lowered by removal of agar, as compared to that of the LPY-141 diet.

Development of artificial diets for simplifying the manufacturing process

The processes used for the manufacturing of the artificial diets of the silkworm consist of a series of steps including mixing the feed ingredients (namely, dried diet), mixing water with the dried diets and steaming them, packing the hot and soft diets in a vinyl bag and cooling them in water (namely, prepared diet), and transferring the prepared diets to the rearing areas. These diets are stored in a cold room until use. The price of the commercial diets is determined by adding the cost of the whole process and profits. Thus, these costs as well as the cost of feed ingredients must be reduced to decrease the price of artificial diets of the silkworm. Recently, two kinds of artificial diets have been developed to simplify the process for the manufacturing of the prepared diets from the dried diets. One is the 'Pellet diet' which is produced by using a twin-spindle extruder and can be fed to the silkworms by soaking with a suitable amount of water just before use. Another is the 'Yuneri diet' which can be fed to the silkworms by mixing with hot water at around 80°C without steaming.

Table 5. Cocoon quality and amount produced by the polyphagous silkworm race, N 601 × C 601, reared on low-cost diets[11]

	LPY-141 diet	LPY-501 diet
Rate of survivial of pupae (%)	95.8	95.3
Weight of cocoon (g)	1.87	1.82
Weight of cocoon layer (g)	0.43	0.42
Rate of cocoon layer (%)	22.2	23.1
Length of cocoon filament (m)	1,049	1,034
Weight of cocoon filament (g)	0.40	0.38
Size of filament (d)	3.50	3.36
Rate of reelability (%)	86	86
Rate of raw silk (%)	20.14	20.00

Larvae were reared on the LPY-141 and LPY-501 diets during the 1st to the end of the 4th instar, respectively, and the newly ecdysed 5th instar larvae were transferred to mulberry leaves.

Prospects

Through the breeding of polyphagous silkworm races and the development of low-cost artificial diets, it may become easier to extend the period of silkworm rearing on artificial diets until the end of the 3rd instar. Furthermore, if the period of silkworm rearing on artificial diets could be extended until the end of the 4th instar, farmers may rear only the 5th instar larvae on fresh mulberry leaves for a week which corresponds to the period from the beginning of the instar to cocoon-spinning. This system was designated as One-Week Silkworm Rearing System. If this system were to be applied, farmers would be able to raise silkworms approximately ten times each year, instead of usually three to four times at present, and to enlarge their sericultural operating scale without any investment in plant and equipment.

It was generally considered that artificial diets could not be used for silkworm rearing throughout the whole instars for silk production, due to the cost of the diets. However, with the breeding of polyphagous silkworms and the development of low-cost artificial diets this practice may become possible. Both theoretical and applied studies are currently in progress, including breeding of silkworms, improvement of artificial diets, development of rearing system and economical evaluation of the silkworm rearing system on artificial diets throughout the instars.

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