RACIAL DIFFERENCE IN THE EFFICIENCY OF FOOD UTILIZATION OF SILKWORM, *BOMBYX MORI* L.

Sardar M. Rafique[1] and Ghulam Ali Bajwa[2]

Abstract

Coefficients of food utilization namely, ingestibility, efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD) and approximate digestibility (AD), *vis-à-vis* larval body weight gain (LBWG) were calculated for seven silkworm strains (J-99, J-101, 205-MKD, 206-MKD, 206-PO, 207-PO, 208-PO) during Spring (26±1°C, 75±5% RH) and Autumn (30±2, 80±1% RH) rearing seasons. The results revealed a significant difference among the silkworm strains for ingestibility, ECI, ECD, AD and LBWG. During spring season maximum and minimum ingestibility, ECI, ECD and AD were 69.08% (J-101, 5th instar), 34.93% (205-MKD, 5th instar), 54.4% (205-MKD, 5th instar), 56.48% (J-101, 4th instar) and 39.63% (207-PO, 4th instar), 18.86% (205-MKD, 4th instar), 23.85% (205-MKD, 4th instar), 43.86% (207-PO, 5th instar), respectively. Ingestibility, ECI and ECD increased with the development of larvae but AD decreased. Overall maximum and minimum larval body weight gain was recorded in 206-MKD and 207-PO, respectively. During autumn season the highest and lowest ingestibility, ECI, ECD and AD were 62.09% (206-MKD, 5th instar), 20.86% (208-PO, 5th instar), 31.24% (208-PO, 5th instar), 60.75% (207-PO, 4th instar) and 40.54% (207-PO, 5th instar), 16.95% (208-PO, 4th instar), 19.26% (208-PO, 4th instar), 40.26 (207-PO, 5th instar), respectively. A slight increase in ECI and ECD was observed with the age of larva however, AD showed negative relationship with age. Overall maximum (2014.13 g larva^{-1}) and minimum (1547.75 g larva^{-1}) larval body weight gain was displayed by 206-MKD and 207-PO, respectively. During penultimate larval stage there was non-significant difference between spring and autumn season. On the other hand at high temperature (autumn season) ingestibility, ECI, ECD and LBWG were reduced drastically during final instar. It is therefore, recommended that for efficient utilization of food silkworm should not be reared above 26±1°C and 75±5% RH.

Key words: Silkworm *Bombyx mori*, Strains, Food consumption and utilization, ingestibility, ECI, ECD, AD, rearing season. Larval body weight.

Introduction

Studies on the consumption and utilization of food in insects facilitate the understanding of their adaptability to the environment. Efficient utilization of mulberry leaves by silkworm is vital for profitable sericulture enterprise. Because 60 percent of the total cost of production of silk is incurred on mulberry leaves (Rangaswami *et al.*, 1976). Moreover, nutritional background significantly

[1] Director General, Pakistan Forest Institute
[2] Senior Research Officer, Pakistan Forest Institute

influences the status of larval growth, silk quantity and quality, pupae, adult, silk seed production, cocoon shell ratio, etc.

The food consumption and utilization, however is subjected to various biotic and abiotic factors. For example, it was found that food consumption was decreased with an increase in the period of food deprivation (Nath *et al.*, 1990), with the age of foliage (Blake and Wagner, 1986), parasitism of larvae by uzi fly (Srikanth *et al.*, 1988), infection of BmNPV (Gururaj *et al.*,2001). On the other hand consumption, assimilation, conversion and metabolism increased with an increase in feeding duration (Mathavan *et al.*,1987) with nutritional quality of the food (Senthamizhselvan and Muthukrishnan, 1989). Similarly food consumption, weight gain and weight of frass produced increased with the age of *Erinnyis elle ello* (Filho and Vendramim, 1989). However, very little information is available on the racial variation in the consumption and utilization of food.

Present study was undertaken to workout coefficients of food utilization of different silkworm strains during 4^{th} and 5^{th} instars. As 97% of the food consumption of the whole larval duration takes place during these two stages (Nath *et al.*, 1990) and 80% just in 5^{th} instar (Hemavathi and Bharathi, 2003).

Materials and Methods

Seven exotic bivoltine silkworm strains, viz. J-99, J-101, 205-MKD, 206-MKD, 206-PO, 207-PO and 208-PO were utilized for the present study. 100 disease free larvae for each strain were selected at random during 3^{rd} moult from the stock culture and weighed. They were fed weighed mulberry leaves (*Morus alba* var. PFI-I) five times a day, i.e. 6000, 1000, 1400, 1800, 2200 hrs up to spinning stage in woody trays (30 x 20 x 2.5 cm). The larval body weight, food ingested, left over food and feces were weighed daily at 1000 hrs. During spring seasons (March-April) temperature was 26 $\pm$ 1°C and relative humidity 75$\pm$5%. The trial was carried out in randomized complete block design with four replications. Same experiment was repeated in autumn season (September-October). During autumn season temperature was 30$\pm$2°C with 80$\pm$1% rH. For studying the food consumption and utilization gravimetric method was adapted (McFarlance, 1985). The formulae used for calculation of different coefficients were:

i. Ingestibility (%): $$\frac{\text{Amount of ingested leaf}}{\text{Total leaf supplied}} \times 100$$

ii. Efficiency of conversion of ingested food(ECI): $\frac{\text{Weight gained by larva}}{\text{Weight of food ingested}} \times 100$

iii. Efficiency of conversion of digested food (ECD):

$$\frac{\text{Weight gained by larva}}{\text{Weight of food ingested} - \text{Weight of feces}} \times 100$$

iv. Approximate digestibility (AD):

$$\frac{\text{Weight of food ingested} - \text{Weight of feces}}{\text{Weight of food ingested}} \times 100$$

Mean data of various parameters were statistically analyzed applying two-way analysis of variance (ANOVA) and difference among individual silkworm strains was effectuated by least significant difference (LSD) test.

Results

Data on food ingestibility (I), efficiency of conversion of ingested (ECI) and digested food (ECD), approximate digestibility (AD), *vis-à-vis* larval body weight gain (LBWG) in 4th, 5th instars and overall are presented in table 1. Overall differences in LBWG, Ingestibility, ECI, ECD and AD were highly significant during 4th and 5th instars as well as spring and autumn rearing seasons with exception of non-significance of AD in spring during 4th instar. The variation among individual silkworm strains for different indices of food consumption and utilization and LBWG revealed complex presentation. Season-wise outcome of the study is as follow:

Spring Rearing

During 4th instar maximum (402 mg larva^{-1}) LBWG was recorded in 206-PO, however this was statistically non-significant with 206-MKD, J-101 and 208-PO. Overall LBWG was highest in 206-MKD (3122.55 mg larva^{-1}) and statistically bracketed with J-99 and 205-MKD. On the other hand minimum LBWG during 4th and 5th stadia was in 205-MKD. (306.55 mg larva^{-1}) and 207-PO (1954.78 mg larva^{-1}), respectively. 206-MKD gained 6.8 times body weight during 5th instar while 207-PO 6.3 times. Ingestibility showed almost a linear relationship with body weight. Maximum ingestibility (61.08%) and minimum (39.63%) was registered in 206-PO and 207-PO, respectively during 4th instar while during 5th instar these entities were in J-101 and 207-PO. Food ingestibility was escalated with the larval development in all silkworm strains. During 4th instar 207-PO was

the most efficient strain to convert ingested (26.19%) and digested (38.01%) mulberry leaves into body weight while 205-MKD the least efficient for these indices (18.86%, 23.85%). ECI was increased from 12.91 percent (207-PO) to 85.21 percent (205-MKD) during 5th instar. Similarly, ECD was also increased from 21.6 to 128.09 percent. Contrarily, approximate digestibility lessene in final instar compared to that of penultimate one. Overall (4th and 5th instar combined) ingestibility, ECI, AD and ECD approximated to that of 5th instar. The least (2264.6 mg larva^{-1}) and most (3122.55 mg larva^{-1}) overall LBWG was achieved by 207-PO and 206-MKD, respectively. Japanese silkworm strains were relatively more efficient in food conversion and consequently gained more body weight.

Autumn Rearing

Difference in efficiency of food consumption and utilization among the seven silkworm strains during 4th instar, 5th instar and over all was highly significant. This also led to variation in larval body weight gain by silkworm strains. 206-MKD gained maximum LBWG during 4th instar (431. 5 mg/larva), 5th instar (1582. 63 mg/larva) and overall (2014.13 mg/larva). In contrast 207-PO gained overall least body weight. Maximum food was ingested by J-99 (4th Instar), 206-MKD (5th instar) and J-101 & 206 PO (overall) which were significantly high while 207-PO overall was least ingesting strain. J-99, 205-MKD, 206-MKD, 206-PO and 207-PO were statistically non-significant among them for ECI during 4th instar. All these five strains converted above 20% ingested food into body matter. During 5th instar J-101 and 208-PO converted maximum ingested food and they did not differ statistically between themselves. A touch of decrease in ECI was found during 5th and overall as compared to 4th instar. Maximum AD was in 207-PO (4th instar), 208-PO (5th instar) and 207-PO (overall). Approximate digestibility was slightly decreased during 5th instar and in over all. The lowest AD (40.26%) was in 207-PO during 5th instar. As far as efficiency of conversion of digested food was concerned it followed almost the same pattern as ECI. Maximum (25.94%) ECD was recorded in 207-PO during 4th instar. Increase in ECD during 5th instar was 1.0-1.6 times over 4th instar. There was statistically non-significant difference in ECD among 207-PO, 206-PO, 205-MKD (4th instar); J-99, 205-MKD, 206-MKD, 206-PO (5th instar); J-99, J-101, 205-MKD, 206-MKD, 206-PO, 208-PO (overall).

Table 1. Food consumption and utilization indices of some silkworm strains in different developmental stages

Strains	Spring					Autumn				
	LBWG (mg/larva)	I (%)	ECI (%)	AD (%)	ECD (%)	LBWG (mg/larva)	I (%)	ECI (%)	AD	ECD (%)
					4th instar					
J-99	325.10 bc	54.52 c	19.87 bc	55.03ns	26.37b	429.0 ab	54.92a	20.13ab	59.43 ab	24.15 c
J-101	363.83ab	56.93bc	21.31bc	56.48	27.06b	393.0c	52.5b	19.40b	54.90bcd	23.17d
205-MKD	306.55c	54.05c	18.86c	51.58	23.85b	391.25c	48.24c	20.39a	56.83abc	25.03abc
206-MKD	399.53a	59.33ab	22.51b	52.25	28.40b	431.5a	47.59c	20.32ab	59.50a	24.82bc
206-PO	402.18a	61.08a	21.95bc	51.72	27.98b	416.0b	53.03ab	20.08ab	51.56d	25.46ab
207-PO	309.83c	39.63d	26.19a	50.41	38.01a	369.67d	44.15d	20.43a	60.75a	25.94a
208-PO	355.40abc	58.12ab	20.30bc	50.22	24.48b	357.33d	51.84b	16.95c	54.19cd	19.26c
CD	50.73	3.47	3.52		5.29	13.64	2.38	0.92	4.58	0.912
					5th Instar					
J-99	2571.98 ab	64.66 ab	34.22 a	48.2 b	51.17 abc	1355.13 c	47.82 cd	19.10 c	50.51 b	26.58 c
J-101	2383.0bc	69.08a	29.77b	49.42b	43.96d	1259.08d	44.5de	20.07ab	49.17b	29.0b
205-MKD	2511.35abc	62.11b	34.93a	48.12b	54.40a	1433.48b	50.73c	18.08d	44.988c	26.485c
206-MKD	2723.03a	68.2a	34.50a	51.05ab	54.13ab	1582.63a	62.09a	19.36bc	49.01b	27.46bc
206-PO	2181.23cd	65.84ab	28.60b	51.31ab	45.05d	1332.83c	56.32b	19.56bc	45.03c	26.58c
207-PO	1954.78d	56.99c	29.57b	43.86c	46.22cd	1178.08e	40.54f	17.073e	40.26d	23.17d
208-PO	2262.0bcd	64.69ab	29.39b	54.35a	48.54bcd	1481.63b	43.38ef	20.86a	54.83a	31.24a
CD	339.12	4.45	3.74	3.52	5.61	62.52	3.7	0.87	2.18	1.55
					Over all (4+5th instars)					
J-99	2897.08 ab	62.58 bc	31.65 ab	52.73 a	45.79 ab	1784.13 bc	48.79 b	19.33 a	56.59 ab	26.94 ab
J-101	2746.83b	66.54a	28.28c	54.21a	40.6d	1652.08d	52.28a	19.91a	55.97ab	27.23ab
205-MKD	2817.90ab	60.45c	31.96ab	49.81ab	47.76a	1822.30b	50.16ab	18.52b	57.15a	25.89b
206-MKD	3122.55 a	66.37a	32.26a	50.99a	48.50a	2014.13a	49.45ab	19.56a	58.62a	27.0ab
206-PO	2683.4 b	64.87ab	27.32c	50.56a	41.13cd	1748.83bc	52.07a	19.78a	52.31b	29.03a
207-PO	2264.6 c	53.43d	29.05bc	45.56b	44,87abc	1547.75e	41.12c	17.82c	60.67a	23.57c
208-PO	2617.4 b	63.39abc	28.29c	49.94ab	42.77bcd	1839.0b	50.67ab	19.96a	56.23ab	27.85ab
CD	352.73	3.78	3.08	4.44	4.26	59.55	3.23	0.69	4.71	2.13

LBWG: Larval body weight gain, I: Ingestibility, ECI : Efficiency of conversion of ingested food, ECD: Efficiency of conversion of digested food, AD: Approximate digestibility, * Significant at 95% level, ** Significant at 99% level, - Figures in a coloumn of a particular development stage sharing same alphabets are non-significant among themselves (P 0.05)

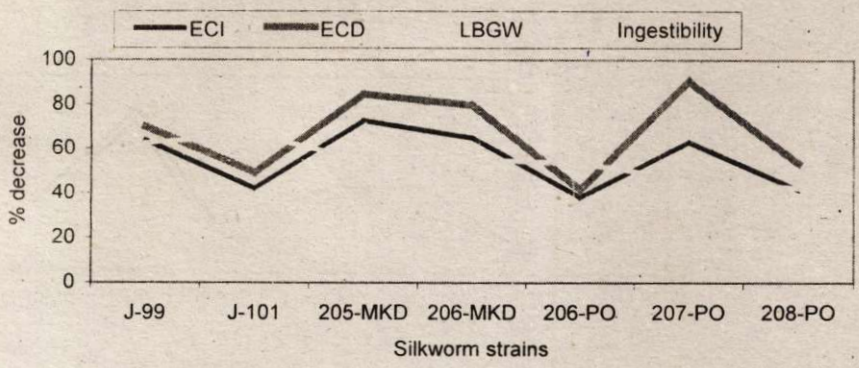
Two rearing seasons, i.e. Spring and autumn had profound impact on larval body weight gain in the seven silkworm strains. During 4th instar the difference in LBWG was 1.93 mg/larva (208-PO) to 103.9 mg/larva (J-99) in favour of Autumn Season. Whereas, during 5th instar LBWG in all strains was almost double in Spring rearing to that of autumn. However, food consumption and utilization indices like ingestibility, ECI, AD and ECD were higher in spring season than that of autumn. ECI was 38.12 (206-PO) to 72.57 (205-MKD) percent more in spring season. Similarly, ECD surged in spring season up to 84.47 (205-MKD) percent. However AD was high in autumn season than that of spring. Maximum (25.91%) and minimum (3.14%) increase of approximate digestibility was observed in 207-PO and J-101, respectively.

Discussion

The silkworm, *Bombyx mori* is an monophagous insect that feeds mainly on mulberry leaves. Efficiency with which food consumed and utilized has paramount importance in sericulture, because the food consumption has a direct relevance on the body weight of larva, cocoon, pupa eggs and shell ratio. To determine the overall efficiency with which insects utilize their food, calculation of one or more of the coefficients like efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD), approximate digestibility (AD) and food ingestibility (I) is involved. These coefficients of food utilization however, vary widely with the insect species. These coefficients also change with age both within and between instars (Mohanty and Mittra, 1992), sex (male & female) and with environmental factors such as temperature, humidity, degree of crowding, etc. (McFarlance, 1985). Present findings also reveal that ingestibility, ECI, ECD, AD and larval body weight gain (LBWG) vary considerably among the seven silkworm strains both within and between instars as well as two rearing seasons. High intake of food, ECI, and ECD shows a positive relationship with LBWG. For instance, in case of 206-MKD maximum ingestibility (66.37%), ECD (32.26%) and ECD (48.50%) culminate into maximum LBWG (3122.55mg larva^{-1}).

In spring season overall ECI, ECD and AD fluctuate between 27.32-32.26%, 40.6-48.50% and 45.56-54.21%, respectively. Whereas, in autumn season overall ECI, ECD and AD move from 17.82 to 19.96%, 23.57 to 29.03% and 52.31 to 60.67%, respectively. These parameters are in conformity with McFarlance (1985), Ito & Kobayashi (1978) and Horie & Watanabe (1983). However, these values are slightly higher than Gururaj *et al.* (2001). This discrepancy may be due to changed silkworm strains, quality of food and other rearing conditions.

Fig.1 Overall decrease (%) in Ingestibility, ECI, ECD & LBWG during autumn season



Temperature depicts an inverse proportion with food ingestibility, ECI, ECD and LBWG. Reduction in food intake (17.02-25.49%), ECI (38.12-72.57%), ECD (41.68-90.37) and LBWG (42.33-66.26%) at 30 ± 2^{0}C (autumn season) substantiate this negative relationship (Fig. 1). Khawaja and Haq (1991) have also reported this seasonal inflict on larval body weight and coefficient of food utilization. Similarly, Reynolds and Nottingham (1985) have also reported reduction in food intake with increase in temperature.

In contrast, AD relates positively with high temperature (Fig.2). This reveals an important feature of food utilization, i.e. approximate digestibility in not a contributory of ECD. Food digestion in insects depends upon many digestive enzymes. These enzymes play a major role in the body of insects by converting complex food materials into micro molecules necessary to provide energy and metabolites for growth, development and other vital functions. However, enzymatic activities are subjected, among other factors, to temperature. High temperature has expedited enzymes interaction, while end metabolic products may have utilized for other vital functions like respiration, metamorphic actions, etc. rather than body weight.

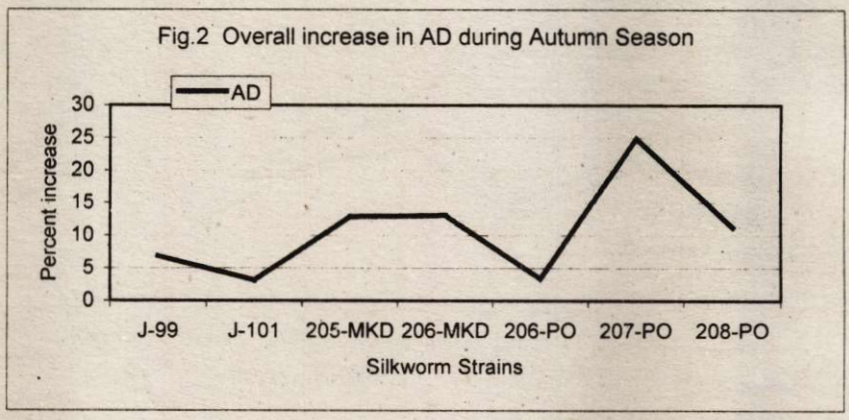


Fig.2 Overall increase in AD during Autumn Season

In addition, silkworm has developed a mechanism whereby low ECI and ECD are compensated by high AD. For example, in autumn season ECI and ECD are low but AD is high on the other hand, in spring season ECI and ECD are high and AD low. Furthermore, outcomes of the study indicate that ECI and ECD are two important coefficients, which show efficiency of food utilization in terms of body weight. Strains with high ECI and ECD are more efficient converter of food and vice versa.

Conclusion

In nutshell, it is concluded that efficiency of food utilization varies with silkworm strains. J-101, 206-MKD, 206-PO and 208-PO ingested the highest mulberry leaves while 207-PO was the lowest food ingesting strains both in spring and autumn season. In spring season J-99, 205-MKD, 206-MKD converted food into body matter more efficiently than J-101, 206-PO and 208-PO. More or less same pattern of ECI and ECD was observed in autumn season. However, comparative efficiency of conversion of ingested and digested food was low in all silkworm strains in autumn season, i.e. at higher temperature ($32\pm2^{\circ}C$). Therefore, for economical utilization of food temperature and relative humidity should not be high than $26\pm1^{\circ}C$ and $75\pm5\%$, respectively during 4^{th} and 5^{th} instars. Moreover, AD has little contribution towards larval body weight.

References

Blake, E.A. and M.R. Wagner, 1986. Foliage age as a factor in food utilization by the Western spruce budworm, *Choristoneura occidentalis*. Great Basin Naturalist, 46(1): 169-172.

Filho, W.R. and J.D. Vendramim, 1989. Consumption and utilization of leaves of rubber tree clones (*Hevea brasiliensis*) by *Erinnyis ello ello* (L. 17581) (Lepidoptera-Sphingidae). Anais-da-Sociedade Entomol. 18(2): 295-311.

Gururaj, C.S., B.M. Sekharappa and S.K. Sarangi, 2001. Chronological variation in the food consumption and utilization in BmNPV infected silkworm, *Bombyx mori* L. Indian Jour. Seri., 40(2): 115-118.

Hemavathi, B. and D. Bharathi, 2003. Effect of thyroxine on food utilization by silkworm, *Bombyx mori* L. Indian Jour. Seri., 42(1): 16-20.

Horie, Y. and K. Watanabe, 1983. Daily utilization and consumption of dry matter in food by the silkworm, *Bombyx mori* (Lepidoptera: Bombycidae). Appl. Entomol. & Zool., 18(1): 70-80.

Ito, T. and M. Kobayashi, 1978. Rearing of the silkworm. In The Silkworm: an important laboratory tool, Y. Tazima [Ed.] kodansha Ltd., Tokyo. P.86.

Khawaja, K.A. and M.U. Haq, 1991. Comparative studies on the prospects of silkworm (*Bombyx mori* L.) rearing during autumn and spring season at Faisalabad. Pak. Entomol., 13(1-2): 46-49.

Mathavan, S., G. Santhi and N.B. Sethuraman, 1987. Effects of feeding regime on energy allocation to reproduction in the silkworm, *Bombyx mori*. Proc. Indian Acad. Sci. (Animal Sci.), 96(3): 333-340.

McFarlance, J.E., 1985. Nutrition and Digestion organs. In Fundamentals of Insect Physiology, Murray S. Blum [Ed.], Johan Wiley and Sons, New York, pp. 71-72.

Mohanty, A.K. and A. Mittra, 1992. Food utilization efficiency of tropical tsar silkworm *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) on *Terminalia tomentosa* Arn. Phytophaga-Madras (India), 4(2): 73-80.

Nath, T.N., S. Nath, M. Shamsuddin and G.S. Rao, 1990. Effect of food deprivation on dry matter utilization, shell and cocoon weight and fecundity of multivoltine silkworm, *Bombyx mori* L., race Nistari. Indian Jour. Seri., 29(2): 174-181.

Rangaswami, G., M.N. Narasimhanna, K. Kasiviswanathan, C.R. Sastry and M.S. Jolly, 1976. Sericulture Manual 1-Mulberry cultivation. FAO, Rome, Italy, pp.150.

Reynolds, S.E. and S.F. Nottingham, 1985. Effect of temperature on growth and efficiency of food utilization in fifth instar caterpillar of the tobacco hornworm, *Manduca sexta*. Jour. Insect Physiol., 31(2): 129-134.

Senthamizhselvan, M., and J. Muthukrishnan, 1989. Effect of feeding tender and senescent leaf by *Eupterote mollifera* and leaf and flower by *Spodoptera exigua* on food utilization. Proc. Indian Acad. Sci. (animal Sci.), 98 (2): 77-84.

Srikanth J., H. Basappa and S. Lingappa, 1988. Effect of Uzi-fly parasitization on food consumption and growth of the mulberry silkworm, *Bombyx mori* L. Insect Sci. & Applicat., 9(3): 373-376.