tryptophan in absence and presence of the acceptor respectively.

In methanolic solution (Figure 4 *a*), the presence of the dansyl group decreases the emission intensity of tryptophan by 39% for a peptide concentration of 3.75 μM with a concomitant increase in emission at the dansyl wavelengths. The distance corresponding to this efficiency of energy transfer is 24.8 Å which is less than the 33 Å predicted for a 22-residue α-helical peptide. If aggregated, interchromophore distances are likely to be equal to or less than 20 Å in helical, antiparallel aggregates. The dansyl emission at 530 nm indicates that the dansyl group is not shielded[13], which in turn is indicative that the peptide is not aggregated. We therefore interpret this data as arising from largely monomeric and helical peptides with an average end to end distance of 24.8 Å.

The energy transfer efficiency in HEPES buffer (Figure 4 *b*) at peptide concentration 3.75 μM is much higher (74%) indicative of an average interchromophore spacing of 19 Å. The dansyl emission at 500 nm clearly indicates that the peptide is aggregated[15]. The CD spectrum of the peptide under these conditions shows that the peptide is β-structured. We therefore conclude that the peptide forms stacked anti-parallel β-sheet structures in water. Energy transfer in liposomes is also high, close to 75% indicative of association of the peptide in the membrane phase (data not shown).

The conformation of AcPCH3 is dependent on its environment. Such solvent dependent as well as other types of conformational switching have been reported elsewhere[16–18]. In case of AcPCH3, addition of largely helical peptide from a methanolic stock to a liposome suspension results in largely helical peptide. This is likely to be due to insertion into the liposomal bilayer as the peptide in the suspending buffer is expected to take up β-structures (Figure 3) under these circumstances. The peptide is largely helical in the membranes (Figure 3) suggesting that channels made by AcPCH3 are made up of transmembrane helices.

In summary, the peptide AcPCH3 is α-helical in methanol and in membranes, and takes up β-structures when diluted into water from a methanolic stock. It mediates ion transport through liposomal membranes when a significant fraction of the peptide is helical. This sequence may provide a useful model for studying conformational switching in peptides.

1. Henderson, R., Baldwin, J. M., Ceska, T. A., Zemlin, F., Beckmann, E. and Downing, K. H., *J. Mol. Biol.*, 1990, **213**, 899–929.
2. Karle, I. L., Flippen-Anderson, J. L., Agarwalla, S. and Balaram, P., *Proc. Natl. Acad. Sci. USA*, 1991, **88**, 5307–5311.
3. Mackinnon, R., *Nature*, 1991, **350**, 232–235.
4. Heginbotham, L. and MacKinnon, R., *Neuron*, 1992, **8**, 483–491.
5. Tempel, B. L., Papazian, D. M., Schwarz, T. L., Jan, Y. N. and Jan, L. Y., *Science*, 1987, **236**, 770–775.
6. Kamb, A., Iverson, L. E. and Tanouye, M. A., *Cell*, 1987, **50**, 405–413.
7. Baumann, A., Krah-Jentgens, I., Mueller, R. *et al.*, *EMBO J.*, 1987, **6**, 3419–3429.
8. Atherton, E. and Sheppard, R. C., *Solid Phase Peptide Synthesis: A Practical Approach*, IRL Press, Oxford, 1989.
9. Nagaraj, R., Mathew, M. K. and Balaram, P., *FEBS Lett.*, 1980, **121**, 365–368.
10. Woody, R. W., *The Peptides: Analysis, Synthesis, Biology*, Academic Press, New York, 1985, pp. 15–114.
11. Chakrabartty, A., Kortemme, T., Padmanabhan, S. and Baldwin, R. L., *Biochemistry*, 1993, **32**, 5560–5565.
12. Vuilleumier, S., Sancho, J., Loewenthal, R. and Fersht, A. R., *Biochemistry*, 1993, **32**, 10303–10313.
13. Lakowicz, J. R., *Topics in Fluorescence Spectroscopy: Principles*, Plenum, New York, 1992.
14. Conrad, R. H. and Brand, L., *Biochemistry*, 1968, **7**, 777–787.
15. Nagaraj, R. and Balaram, P., *Biochem. Biophys. Res. Commun.*, 1979, **89**, 1041–1049.
16. Cerpa, R., Cohen, F. E. and Kuntz, I. D., *Folding Design*, 1996, **1**, 91–101.
17. Mutter, M. and Hersperger, R., *Angew. Chem. Int. Ed. Engl.*, 1990, **29**, 185–187.
18. Mutter, M., Gassmann, R., Butkus, U. and Altmann, K. H., *Angew. Chem. Int. Ed. Engl.*, 1991, **30**, 1514–1516.
19. Barenholz, Y., Gibbes, D., Litman, B. J., Goll, J., Thompson, T. E. and Carlson, F. D., *Biochemistry*, 1977, **16**, 2806–2810.

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Predatory efficiency of larvivorous fish, *Gambusia affinis* on the mosquito larvae of *Aedes aegypti* and *Anopheles stephensi*

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The fish *Gambusia affinis* is the best predator on the larvae of *Aedes aegypti* and *Anopheles stephensi*. Predatory efficiency was found maximum on III instar larvae. 2–3 cm group of the female fish performed the best predation. An increase in the larval density accelerated the predatory efficiency in all length groups of the fish. Deprivation of food had an initial stimulation on the predatory efficiency of 2–3 cm group fish.

MOSQUITOES constitute the most important single family of insects from the standpoint of human health. They

constitute a far greater threat to man because mosquitoes are the major vectors of a number of pathogens among which malarial parasite deserves attention[1].

There was no aspect of life in the country which was not affected either directly or indirectly by malaria. The magnitude of the problem was great. The economic loss due to the man days lost at one time (1935) was estimated to be nearly Rs 10,000 million/year (ref. 2).

The control of malaria requires more potent insecticides. At the same time massive quantities of insecticides used for the control of malaria year after year started to attract public criticism[3].

Pesticides are potential sources of environmental pollution. The continued use of some long-lived insecticides would lead to world-wide environmental contamination that would be a serious hazard to all animal life, including humans. Thus, a new look at the entire approach to insect control was needed. In order to develop an alternative strategy, the biological control of mosquito was evolved[3].

Larvivorous value of certain fish and their role in mosquito control and anti-malaria programmes are very important[4]. Job[5] reported a list of larvivorous fish of India and the observations on the relative utility of these fish. Reddy and Pandian[6], Menon and Rajagopalan[7] also worked out the larvivorous value of some indigenous fish. De Bach[8] reported a number of factors that influence its success or failure.

Biological control is concerned with the environmental factors affecting the regulation and stabilization of population of insects[9]. Now it is recognized as a potent tool for check on insect population without any harmful effect on the human system[10].

Sharma[3] reported that fish are highly successful in the control of mosquito breeding at low cost and without any adverse impact on environment such as are faced with the application of insecticides, but require further studies on application in the control of mosquito.

A perusal of the literature indicates that little is known of the predatory efficiency of *Gambusia affinis* which is an efficient larvivorous fish. This mosquito fish was therefore selected for the present investigation.

The materials employed in the present study were mosquito fish of the species *Gambusia affinis* (Family: Poecilioidae). Fish were collected from the hatchery maintained by Vellore Municipality Commissioner's office. Fish were reared in 60.75 m capacity hatchery in illuminated conditions[11]. They were sorted into four length groups based on their standard length. The four groups are < 1 cm, 1–2 cm, 2–3 cm and 3–4 cm. Each group was reared in a separate tank.

In insectary, mosquitoes were propagated by Barraud cage device. Adult male and female mosquitoes were introduced in the ratio of about 10 : 2. To maintain this mosquito colony, the adult females were given blood meals at intervals of about 2–3 days by rabbit, and males were fed with 5–10% sugar solution[12].

Fish of each group were introduced into different glass troughs containing separately, I, II, III and IV instars of larvae of *Aedes aegypti* and *Anopheles stephensi*. The number of larvae consumed during 24 h by each was taken into account to determine its predatory efficiency. The impact of length groups of fish on predatory efficiency was determined. The influence of larval density on predation was also resoluted by using III instar larvae in different length groups of fish (III instar showed greater affinity over other larval instars).

The efficient female fish of 2–3 cm length group was taken for the food deprivation study (for 24 h) and its effect on predation was also recorded.

Female *Gambusia affinis* preferred III instar larvae over that of the other instars of *Aedes aegypti* and *Anopheles stephensi*.

The average of III instar larvae of *Aedes aegypti* predated upon, amounted to 70.5/day whereas I, II and IV instars were reduced to 50, 63.5 and 54.5/day respectively. The average predatory efficiency of the entire population of *Gambusia affinis* was calculated as 59.5/day. The greater predatory efficiency was noted for the 2–3 cm group over *Aedes aegypti* and it was 79.5/day. The efficiency of 1–2 cm and 3–4 cm group was 62/day and 46.5/day respectively. The least efficiency was noted in < 1 cm group, i.e. 50.5/day (Table 1).

The average of III instar larvae of *Anopheles stephensi*

Table 1. Predatory efficiency of female fish *Gambusia affinis* over larvae of *Aedes aegypti*. Values (% of larvae consumed) shown are mean of 4 replicates (period 24 h)

Length group of *Gambusia affinis*	Life stages of prey (*Aedes aegypti*) % consumed at density 150 nos.			
	I instar	II instar	III instar	IV instar
< 1 cm	44	52	60	46
1–2 cm	52	66	72	58
2–3 cm	64	86	98	70
3–4 cm	40	50	52	44

Table 2. Predatory efficiency of female fish *Gambusia affinis* against larvae of *Anopheles stephensi*. Values (% of larvae consumed) shown are mean of 4 replicates (period 24 h)

Length group of *Gambusia affinis*	Life stages of prey (*Anopheles stephensi*) % consumed at density 100 nos.			
	I instar	II instar	III instar	IV instar
< 1 cm	19	20	22	18
1–2 cm	21	32	39	28
2–3 cm	33	47	55	40
3–4 cm	24	41	43	37

Table 3. Predation as a function of larval density and predator size. Values (% of larvae consumed) shown are mean of 4 replicates of *Aedes aegypti* and *Anopheles stephensi*

Length group of *Gambusia affinis*	Species name of the prey	Density of III instar larvae			
		50 nos.	100 nos.	150 nos.	200 nos.
< 1 cm		44	57	61	75
1–2 cm	*Aedes*	56	63	73	89
2–3 cm	*aegypti*	77	82	98	99
3–4 cm		33	46	52	64
< 1 cm		17	22	31	46
1–2 cm	*Anopheles*	23	39	53	61
2–3 cm	*stephensi*	46	55	68	77
3–4 cm		40	43	59	63

Table 4. Effect of food deprivation on predation of 2–3 cm length group of female fish *Gambusia affinis* over III instar larvae of *Aedes aegypti*

Time intervals (h)	Larvae consumed (*n*)
1–3	15
3–5	17
5–7	20
7–9	22
9–11	30
11–13	18
13–15	11
15–17	10
17–19	6
19–21	2
21–24	–

predated upon, amounted to 39.75/day whereas I, II and IV instars were reduced to 24.25, 35 and 30.75/day respectively. The average predatory efficiency of the entire population was calculated as 32.43/day. 2–3 cm group also showed greater efficiency against *Anopheles stephensi* (43.75/day). The efficiency of 1–2 cm and 3–4 cm group was 30/day and 36.25/day respectively. The least efficiency was noted in < 1 cm group, i.e. 19.75/day (Table 2).

From this investigation it was inferred that 2–3 cm group female fish shows greater predatory efficiency, and this may be due to their metabolically active state.

The effect of larval density on predation was also studied with III instar larvae of *Aedes aegypti* and *Anopheles stephensi*. The highest predation (81.75 and 61.75/day) was noted when the larvae were stocked in 200 numbers steadily. This observation agrees with Job's[5] and Inasu's[4] findings that the increased larval density induces the predator to kill the prey indiscriminately (Table 3).

Deprivation of food for 24 h altered the predatory efficiency of the predator, female *Gambusia affinis* of 2–3 cm group. The efficiency raised from 15 larvae/2 h to an optimum 30 larvae/2 h; then it decreased to a value of 2 larvae/2 h (Table 4).

The present observation shows that female *Gambusia affinis* is the best larvivorous fish that can be selected for the biological control of mosquito. The highest predatory efficiency was noted in 2–3 cm length group of fish against *Aedes aegypti*. This group had the average consumption of 79.5/day. Its predatory efficiency was increased at the fastest rate when the larval density increased.

1. Moore, P. D., in *The Encyclopedia of Animal Ecology* (ed. Colindauxe, P. A.), Equinoxe (Oxford) Ltd, England, 1991, pp. 132–137.
2. Park, J. E. and Park, K., *Textbook of Preventive and Social Medicine*, Banarsidas Bhanot Publ., Jabalpur, 1987, pp. 182–190.
3. Sharma, V. P., *Workshop for Medical Specialists* (Ministry of Defence), Malaria Research Centre, Delhi, 1993, pp. 1–8.
4. Inasu, N. D., *J. Environ. Biol.*, 1996, **17**, 133–136.
5. Job, T. J., *Health Bull.*, 1953, **12**, 277.
6. Reddy, S. R. and Pandian, T. J., *Oecologia*, 1974, **16**, 253–256.
7. Menon, P. K. S. and Rajagopalan, P. K., *Indian J. Med. Res.*, 1977, **66**, 772–778.
8. De Bach, P., in *A Text Book of Entomology* (eds Ross, H., Ross, C. A., Ross, J. R. P.), John Wiley, New York, 1982, pp. 643–645.
9. Nayar, K. K., Ananthakrishnan, T. N. and David, *General and Applied Entomology*, Tata McGraw-Hill, New Delhi, 1976, pp. 438–455.
10. Uma Sharma and Grover, S. P., *An Introduction to Indian Fisheries*, Bishen Singh Mahendra Pal Singh, Dehra Dun, 1982, pp. 83–86.
11. Shanmugam, K., *Fishery Biology and Aquaculture*, Leo Pathipagam, Madras, 1992, pp. 86–104.
12. *Manual on Practical Entomology in Malaria*, World Health Organization, Part II, WHO, Geneva, 1975.

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