TRANSACTIONSNASTPHL
ISSN 0115-8848 (print)
ISSN 2815-2042 (online)
https://transactions.nast.ph/

Vol. 46 (2024)
doi.org/10.57043/transnastphl.2024.0000

BIOGRAPHICAL ESSAY

MY TILAPIA ADVENTURE: FROM RESEARCH TO COMMERCIALIZATION

Rafael D. Guerrero III
National Academy of Science and Technology Philippines

ABSTRACT

This article highlights the pioneering work of Dr. Rafael D. Guerrero III in advancing tilapia aquaculture from research to commercialization. Beginning in 1971 at Auburn University, Guerrero developed hormonal sex-reversal techniques for tilapia to address overpopulation and enhance productivity. His studies demonstrated the efficacy of synthetic male hormones, achieving 97–100% male progeny. Upon returning to the Philippines, Guerrero expanded his work on various tilapia species and developed scalable methods for fry production. In 1982, he co-founded Aquatic Biosystems, introducing innovative feed products and training programs for commercial tilapia farming. His contributions positioned the Philippines as a global leader in farmed tilapia by the late 1980s. Despite challenges such as limited resources and climate change, tilapia farming in the Philippines remains robust, supported by Guerrero's enduring legacy of technological innovation.

Keywords: tilapia, hormonal sex-reversal, aquaculture

Correspondence:
Rafael D. Guerrero III
rafaeldg7@gmail.com

Citation
Guerrero RD III. 2024. My tilapia adventure: From research to commercialization. Transactions NAST PHL 46 (2024). doi.org/10.57043/transnastphl.2024.0000

About the Author: *Dr. Rafael D. Guerrero III is a member of the Agricultural Sciences Division of the National Academy of Science and Technology, Philippines. He is recognized for his scientific and technological contributions to the development of sex reversal and hatchery techniques that led to the commercial production of high-yielding market-size tilapia in the Philippines and other countries. He is the former director of the Philippine Council for Aquatic and Marine Research and Development (now part of PCAAARD, Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development) of the Department of Science and Technology).*

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

Abbreviations: BFAR, Bureau of Fisheries and Aquatic Resources; CLSU, Central Luzon State University; DFAA-AU, Department of Fisheries and Allied Aquacultures – Auburn University; DHT, 1-dehydrotestosterone; ET, 17α-ethynyltestosterone; MT, α-methyltestosterone; FAC, Freshwater Aquaculture Center; LLDA, Laguna Lake Development Authority; UPV, University of the Philippines Visayas; USAID, United States Agency for International Development;

My Introduction to Tilapia

Tilapia is the common name of a group of tropical fishes belonging to the Family Cichlidae that originates from Africa and the Middle East. It is not nativeto the Philippines but has become an important source of animal protein in the Filipino diet and for millions of other people throughout the world.

My adventure with tilapia began in 1972 in the United States at Auburn University in Auburn, Alabama where I undertook graduate studies sponsored by the Philippine Government and United States Agency for International Development. I was then an assistant professor of inland fisheries at the Central Luzon State University (CLSU) in Muñoz, Nueva Ecija.

I was one of the four "scholars" (two from CLSU and two from the University of the Philippines Visayas (UPV) who were sent to the US for advanced training on aquaculture. We were to man the Freshwater Aquaculture Center (FAC) at CLSU and the Brackishwater Aquaculture Center at UPV upon our return for the Inland Fisheries Project supported by the National Science and Development Board (the forerunner of the Department of Science and Technology).

I had no formal background on fisheries or aquaculture with my BS in Zoology and MS in Applied Zoology then. It was the trust and confidence in me of then CLSU president Dr. Amado C. Campos whom I had worked with earlier at Central Mindanao University in Musuan, Bukidnon, where he was also previously President, that got me the USAID scholarship slot.

I attended basic aquaculture courses in the winter term of Auburn University's school year 1971–1972 offered by the Department of Fisheries and Allied Aquacultures (now the School of Fisheries, Aquaculture and Aquatic Sciences). The late Dr. Homer Swingle, then Chairman of the department and professor of aquaculture deeply inspired me.

A Special Problem course became my first encounter with tilapia. I had to "overwinter" the juveniles of blue tilapia (*Oreochromis aureus*) that were kept indoors in tanks with warm water until they were stocked outside when water temperature was safe for them. It was quite an endurance for me to drive a pick-up truck of the department (after obtaining my Alabama driver's license, of course) daily for one and a half months to feed the fish, clean the tanks and apply a prophylactic against disease; and particularly because it was my first winter experience.

On weekends, my family and I went fishing for the blue tilapia and channel catfish (*Ictalurus punctatus*) for recreation and food in the fish-out ponds of the department. The blue tilapia that we caught and brought back for eating weighed almost 500 g each — a "colossus" compared to the "dwarf" and black-colored Mozambique tilapia (*Oreochromis mossambicus*) in our country then that had become invasive in our milkfish ponds.

On Solving the Overpopulation Problem of Tilapia

The tilapia is an early-maturing and frequently breeding fish that has the tendency to overpopulate in ponds resulting in stunted growth and low yields of large-sized fish. This major drawback had stymied the commercial farming of the species worldwide.

In preparing for my Ph.D. dissertation, I reviewed the literature and found that the methods of manual sexing and hybridization had been applied to control the population of tilapia for pond culture. The former method was done by separating the sexes by hand through visual examination of the mature fish which was tedious and subject to human error. The latter method involved the crossbreeding of two different species of tilapia (e.g., male *Oreochromis hornorum* and female *Oreochromis niloticus*) for the production of all-male hybrids which required the maintenance of pure lines

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

Figure 1. With Dr. Tom Lovell at the DFAA-AU in 1973 (Photo by Auburn-Opelika News)

of the fishes. In tilapia, the culture of all-male fish is preferred over all-female fish because the male grows faster and bigger than the female. Moreover, all-male fish cannot breed and multiply.

The experimental work of Clemens and Inslee (1968) on the use 17α-methyltestosterone (MT), a synthetic male hormone, at 30 mg/kg feed for the first 69 days of the life of *O. mossambicus* produced all-male broods. I decided to follow up on this approach for the production of all-male blue tilapia (*O. aureus*) fry because it appeared to be more effective and easier to apply than the two other methods mentioned. Incidentally, MT is an anabolic hormone that is not destroyed in the digestive system when given orally. It is widely used in human medicine and is not reported to be carcinogenic.

For my dissertation research, I used the blue tilapia (*O. aureus*) as my test fish and evaluated the effects of three synthetic male hormones, 1-dehydrotestosterone (DHT), 17α-ethynyltestosterone (ET) and 17 α-methyltestosterone (MT), fed at various levels (15, 30 and 60 mg/kg feed) for 18 and 21 days in indoor tanks on the sex reversal of sexually undifferentiated fry. The results showed that treatments with ET and MT at all levels produced significantly higher males compared with the control (no treatment). One hundred percent males were produced with ET at 60 mg/kg feed (Guerrero 1975).

While at Auburn, my major dissertation adviser Dr. William L. Shelton and I developed the aceto-carmine squash technique for sexing juvenile tilapia (1–2 months of age). The simple method was done by examining under the microscope a portion of the preserved and stained gonad of the fish for the presence of ovocyctes (female) or spermatogonia (male). The technique (Guerrero and Shelton 1974) allows the sexing of immature fish and is now widely applied by researchers worldwide.

The Basis of Tilapia Sex Reversal

Based on the theory of fish sex differentiation of Yamamoto (1969), prior to the sex differentiation stage when tilapia fry is 11 mm long or less, it is possible to redirect the direction of phenotypic sex (gonad) development in the fish from the normal female gonad (ovary) to male gonad (testis) by administering through the feed a male hormone like ET or MT at the right dosage (30 and 60 mg/kg diet) and length of time (18–21 days). Thus, the term sex reversal refers to the change in the phenotype (gonad) of the fish treated to the phenotype of the opposite sex depending on the hormone applied during the sex differentiation stage. In the sex reversal of genetic females into phenotypic males, there is therefore no change in the genotype of the fish.

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

Continuing Research on Tilapia Sex Reversal and Developing Hatchery Techniques

Upon graduating in 1974 at Auburn University with a Ph.D. in Fisheries Management, I returned to CLSU and was designated Assistant Director of the FAC. I continued my studies on tilapia sex reversal by applying the method on the Mozambique tilapia (*O. mossambicus*) and Nile tilapia (*O. niloticus*). Using MT at 30 mg/kg feed for three to four weeks, I obtained 93–98% males in the treated fry of the former species (Guerrero 1976). In the latter, 96–98% male fry resulted with treatment of MT at 15–50 mg/kg feed given for 42 days (Guerrero and Abella 1976).

After solving the overpopulation problem of tilapia, there was a need for effective and efficient techniques for the mass production of tilapia fry for sex reversal treatment. The most simple and low-cost method for mass production of tilapia fry I developed was the use of suspended net enclosures (hapas) in ponds which I initially used for the breeding of *O. niloticus* x *O. mossabicus*. With a 1.5 x 1 x 1 m net enclosure stocked with fed 12 breeders at a sex ratio of three females to one male, a monthly production of 1,647 hybrid fry was obtained (Guerrero 1977). I believe I was the first in record to report the method.

Following our methods for the treatment of tilapia fry for sex reversal, Rothbard et al. (1983) scaled up the production of sex-reversed tilapia hybrids in Israel with the production of 98–100% males using 60 mg/kg diet of ET for 28–29 days in shaded outdoor tanks. In the United States, Obi and Shelton (1983) used 30 mg/kg diet of MT for 21 days and produced 100% males of sex-reversed *O. hornorum*.

From Research to Consultancy and Marketing

I joined the Laguna Lake Fishpen Development Project of the Laguna Lake Development Authority (LLDA) funded by the Asian Development Bank as a hatchery consultant after resigning from CLSU in 1982. The project involved the culture of milkfish in fish pens and the Nile tilapia in cages in Laguna de Bay for small fish farmers. I conducted studies on the breeding of Nile tilapia in fixed net enclosures (Figures 3).

Figure 2. A floating net cage for culture of sex-reversed Nile tilapia at CLSU with Dr. R.O. Smitherman of DFAA-AU in 1978 (Photo by J.W. Avault)

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

In the study using net enclosures, we found no significant difference in the fry production of two net enclosure designs (single enclosure and double enclosure) but found significantly more fry production in the single enclosure of 7.5 fry/m2/day with the stocking of breeders at 4/m2, sex ratio of three females to one male and feeding with a commercial pellet feed (Guerrero and Garcia 1983).

Using shallow earthen ponds (0.5 m deep), supplementally-fed Nile tilapia breeders stocked at 4/m2 with a sex ratio of three females and one male had a fry production of 2–6/m2/day after 43 days. Fry reared in net enclosures at 1,000/m2 for 7 days with supplemental feeding had a survival of 79% (Guerrero 1986).

In 1982, my wife, Luzviminda, and I founded Aquatic Biosystems, a consultancy and marketing firm in Bay, Laguna (Figure 4). We produced the first commercial tilapia sex reversal feed (SRT-95) in the market that made the application of the sex reversal treatment cheaper and more convenient for hatchery operators. We also operated a commercial one-hectare pond hatchery for Nile tilapia that produced sex-reversed fingerlings and conducted hands-on trainings for local and foreign participants for the commercial production of sex-reversed tilapia.

Aquatic Biosystems was tapped as consultants of the Meralco Foundation in 1984 to set up its one-hectare commercial hatchery using concrete tanks in Jala-Jala, Rizal for the production of sex-reversed Nile tilapia fingerlings for grow-out in Laguna de Bay using fixed net cages (Figure 5). It was the biggest facility of its kind at that time in the country with the production of more than one million sex-reversed fingerlings per month.

In a study, breeders of Nile tilapia weighing 80–270 g were stocked at 3-week intervals in concrete tanks measuring 20 m x 5 m x 1.2 m each at a biomass density of 400 g/m2 with a female to male ratio of 2:1 ratio by weight for fry production. More than six million fry produced in the facility were stocked in outdoor nursery tanks at 500–1,000/m2 from May to November and treated for sex reversal using SRT-95 containing 30 ppm MT for 21 days. Mean survival of the fry was 78.1% after the treatment period.

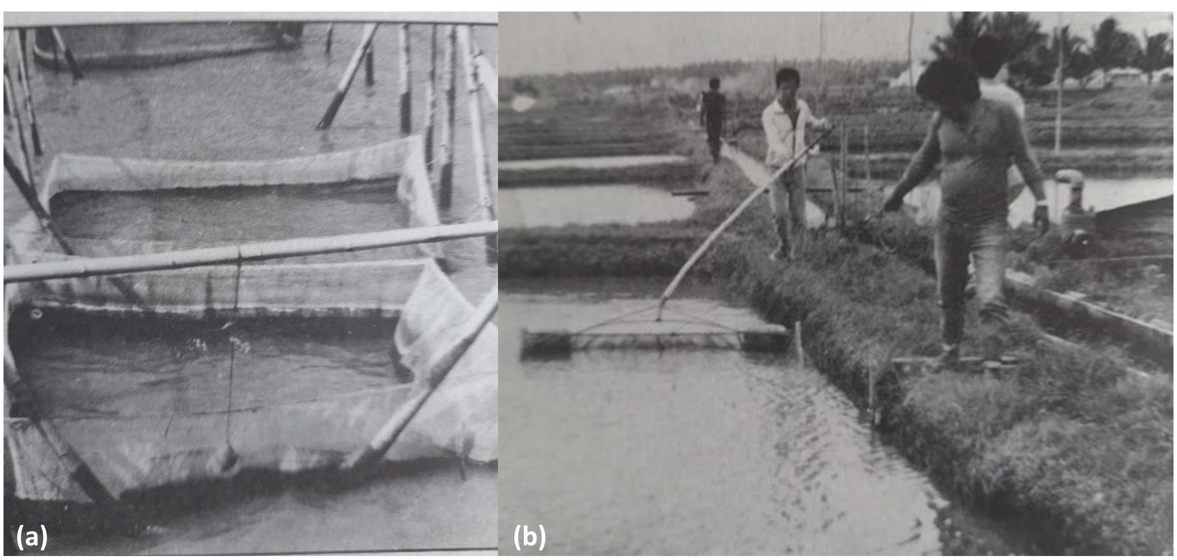

Figure 3. (a) Fixed net enclosures for breeding of Nile tilapia in Laguna de Bay of the LLDA. (b) Collection of Nile tilapia fry from an earthen pond of the LLDA project.

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

Figure 4. (a) Feeding of a commercial hormone feed (SRT-95) to Nile tilapia fry in a concrete tank. (b) Luzviminda Guerrero of Aquatic Biosystems with Nile tilapia breeders used for producing fry for sex reversal.

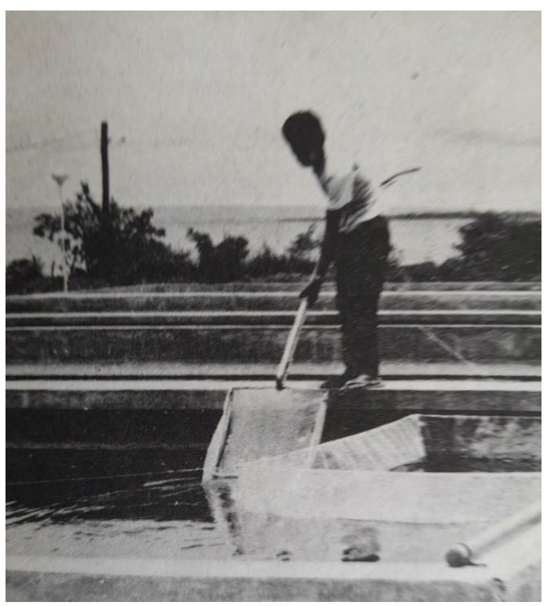

Figure 5. Nile tilapia fry collection from a concrete breeding tank of the Meralco Foundation.

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

After 73 days of culture in cages, three thousand of the treated fish were hand-sexed to determine the effectiveness of the sex-reversal treatment. The percentage of males obtained was 99%. The cost of producing a thousand of the sex-reversed fingerlings was estimated to be USD0.58. The results showed the feasibility of commercial production of sex-reversed Nile tilapia fingerlings in the country (Guerrero and Guerrero 1988).

Being a new approach for controlling the population of tilapia for culture, there were initial concerns by prospective adopters on the safety of the hormone-treated fish for human consumption and the environment. It was explained that with the low levels of the synthetic hormone used and for a short duration (3 weeks), there is no increase in the plasma testosterone levels of treated fish compared to those of untreated fish as reported by Rothbard et al (1983). As to the metabolites of MT that are excreted by treated fish into the environment, Homklin et al (2009) reported on the biodegradation of MT in the sediment of a pond used for sex-reversed tilapia and found the presence of MT-degrading bacteria.

The Philippines Becomes the Top Producer of Farmed Tilapia in the World

In 1986-1988, the Philippines became the world's largest producer of farmed tilapia with productions of 55,819–75,046 metric tons (Pullin 1996). Aside from the Philippines, the tilapia sex reversal technology is also commercially applied in Israel, Thailand, and many other countries in Asia and South America.

Where the Philippines is Now as a Tilapia Producer: Problems and Challenges

The Philippines is still one of the top 10 farmed tilapia producers in the world with a production of 251,826.85 metric tons in 2022 (BFAR 2023) and the future of our tilapia farming industry remains upbeat. With the country's growing population and the declining catch from marine fisheries, there is an increasing demand for more aquaculture products such as tilapia (Figure 6) which is the second most important farmed fish next to milkfish.

Our tilapia farming industry is, however, beset with problems and challenges such as the limited freshwater resources for further growth, the impacts of climate change and the pressing high cost of feeds.

For further expansion of farming areas, utilizing idle brackish water ponds throughout the country and harnessing suitable coastal waters in the various regions for salt-tolerant tilapia culture in ponds and cages are recommended (Figure 7). Appropriate measures to address the problems of flooding brought about by strong typhoon, heavy rains and high-water temperatures during the summer months need to be applied. The use of locally produced and available substitutes for feed ingredients such as imported soybean meal can help reduce the cost of feeds.

Grateful for this Adventure

I attribute the success of my tilapia adventure to the funding provided by the government to the CLSU-FAC, the support of other government and non-government institutions and to the many industry adopters of our technologies.

Acknowledgements

I am most grateful for the grace of our Lord and the help and encouragement extended to me by my colleagues at the FAC, LLDA, Meralco Foundation, and especially to my wife for making my "tilapia adventure" a very exciting and fulfilling one.

Editor's Note:

In recognition of his valuable contributions to tilapia science and technology development up to commercialization, Dr. RD Guerrero III received numerous awards: the Rizal Pro Patria Award, 1976, Department of Agriculture; one of the Ten Outstanding Young Men (TOYM) of the Philippines, 1978; and IBM Award for Science and Technology, 2008, DOST-IBM

Transactions NAST PHL Vol. 46: (2024)
doi.org/10.57043/transnastphl.2024.0000

Figure 6. A bountiful harvest of sex-reversed Nile tilapia

Figure 7. Expansion of tilapia farming in brackishwater ponds and cages in the country using salt-tolerant Nile tilapia and its hybrids is recommended.

Philippines. In 2004, Dr. Guerrero was awarded the Heine Memorial Award by the International Tilapia Foundation in recognition of his contribution to the advancement of science in 2004, during the 6th International Symposium on Tilapia in Aquaculture.

Disclosure of conflict of or competing interest:

No conflict of interest.

References Cited:

Clemens HP, Inslee T. 1968. The production of unisexual broods of *Tilapia mossambica* sex-reversed with methyltestosterone. Trans. Amer. Fish. Soc. 97(1): 18-21. https://doi.org/10.1577/1548-8659(1968)97[18:TPOUBB]2.0.CO;2

Department of Agriculture Bureau of Fisheries and Aquatic Resources. 2023. 2022 Philippine Fisheries Profile. Bureau of Fisheries and Aquatic Resources, Quezon City. 180 p.

Guerrero RD, Shelton WL. 1974. An aceto-carmine squash method for sexing juvenile fishes. Prog. Fish-Cult. 36:56. https://doi.org/10.1577/1548-8659(1974)36[56:AASMFS]2.0.CO;2

Guerrero RD III. 1975. Use of androgens for the production of all-male *Tilapia aurea* (Steindachner). Trans. Amer. Fish. Soc. 104:342-348. https://doi.org/10.1577/1548-8659(1975)104%3C342:UOAFTP%3E2.0.CO;2

Guerrero RD III. 1976. Culture of male *Tilapia mossambica* produced through artificial sex reversal. In: Advances in Aquaculture. FAO Technical Conference on Aquaculture, Kyoto, Japan. P. 166-167

Guerrero RD III, Abella TA. 1976. Induced sex-reversal of *Tilapia nilotica* with methyltestosterone. Fisheries Research Journal of the Philippines 1: 46-49.

Guerrero RD III. 1977. Production of tilapia fry in floating net enclosures. FAO Aquaculture Bulletin 8(3-4):4.

Guerrero RD III and Garcia AM. 1983. Studies on the fry production of *Sarotherodon niloticus* in a lake-based hatchery. In: Proceedings of the International Symposium on Tilapia in Aquaculture, Tel Aviv, Israel. P. 388-393

Guerrero RD III. 1986. Production of fry and fingerlings in earthen ponds at Pila, Laguna, Philippines. In: The First Asian Fisheries Forum, Asian Fisheries Society, Manila, Philippines. p. 49-52

Guerrero RD III and Guerrero LA. 1988. Feasibility of commercial production of sex-reversed Nile tilapia fingerlings in the Philippines, pp. 183-186. In: The Second International Symposium on Tilapia in Aquaculture. ICLARM Proceedings 15, p. 183-186

Homklin S, Wattanodorn J, Ong SK, Limpiyakorn T. 2009. Biodegradation of 17alpha-methyltestosterone and isolation of MT-degrading bacteria from sediment of Nile tilapia masculinizing pond. Water Sci Technol. 59(2):261-5. https://doi.org/10.2166/wst.2009.868

Obi A, Shelton WL. 1983. Androgen and estrogen sex reversal in *Tilapia hornorum*. In: Proceedings of the International Symposium on Tilapia, Tel Aviv, Israel. p. 165-173

Pullin RSV. 1996. World tilapia culture and its future prospects. In: The Third International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 41, p. 1-6

Rothbard S, Solnik E, Shabbath S, Amado R, Grabie I. 1983. The technology for mass production of hormonally sex-inversed all-male tilapia. In: Proceedings of the International Symposium on Tilapia, Tel Aviv, Israel. P. 425-434

Yamamoto T. 1969. Sex differentiation, pp. 117-175. In: W.S. Hoar and D.J. Randall (Eds.). Fish Physiology. Vol. III. Academic Press, New York. https://doi.org/10.1016/S1546-5098(08)60113-2