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16
Tilapias

Victor Suresh and Ram Bhujel

16.1 INTRODUCTION

Fish resembling tilapias were featured in paintings in the Egyptian tombs of 2500 BC. Some believe that it shows that tilapias were cultivated in ancient Egypt. It is also claimed that the fish caught by Jesus' disciples in the Sea of Galilee and fed to the multitudes were tilapias. Such claims may be disputed because of the lack of hard evidence, but there can be no disputing that tilapias are one of the most successfully cultured fish of modern times. Current global production of tilapias exceeds 2 million t/year (Fig. 16.1). China alone contributes nearly half of the global production (Table 16.1). Other leading countries include Egypt, Indonesia, the Philippines and Thailand. Most tilapias produced in these countries through aquaculture are used for local consumption, but there is also a substantial international trade in chilled and frozen tilapia products. The largest importer of tilapias is the USA, where consumption of tilapias has increased more than five times in the past decade (Fig. 16.2) and has exceeded that of trout since 1995. Central American countries, particularly Costa Rica and Honduras, produce relatively small volumes of tilapias, but most of it is exported as high-value, fresh-chilled fillets to the USA.

The remarkable success of tilapias as a farmed fish can be attributed to two main factors.

1. Their desirable qualities as a food fish: white flesh, neutral taste and firm texture. As a result, tilapias have gained acceptance in a wide variety of human cultures with differing tastes and food preferences.
2. They are an easily farmed fish: tilapias are easy to hold and breed in a captive environment. They tolerate crowding, relatively poor water quality and other stress factors, and are less susceptible to disease than many other cultured fish. They can be grown in a wide variety of aquaculture systems (Table 16.2). They eat algae and detritus naturally produced in culture systems as well as manufactured feeds containing ingredients derived from plants. They reach typical market size (500–800 g) in about 6–8 months under optimum water temperature conditions for growth, 28–30 °C.

Based on these characteristics, Pullin (1984) termed tilapias 'aquatic chicken': an animal that can be farmed as easily and economically, and with the same broad market appeal, as chickens.

The most important problem in producing tilapias to uniform and acceptable market size (>300 g) is their early and uncontrolled reproduction in culture systems, especially earthen ponds. Their early maturation and frequent reproduction directs a significant amount of energy towards reproductive development and activities, and thereby reduces the energy available for growth. Furthermore, uncontrolled recruitment of offspring in the culture system increases demand for food and other resources, resulting in stunted growth. Thus, several solutions to this problem have been developed by researchers and tilapia farmers. Most solutions rely on the production and stocking of all-male tilapias. Male tilapias grow faster than females (Fig. 16.3) and, therefore, all-male tilapia populations provide

Aquaculture: Farming Aquatic Animals and Plants, Second Edition. Edited by John S. Lucas, Paul C. Southgate.

Published 2012 by Blackwell Publishing Ltd.

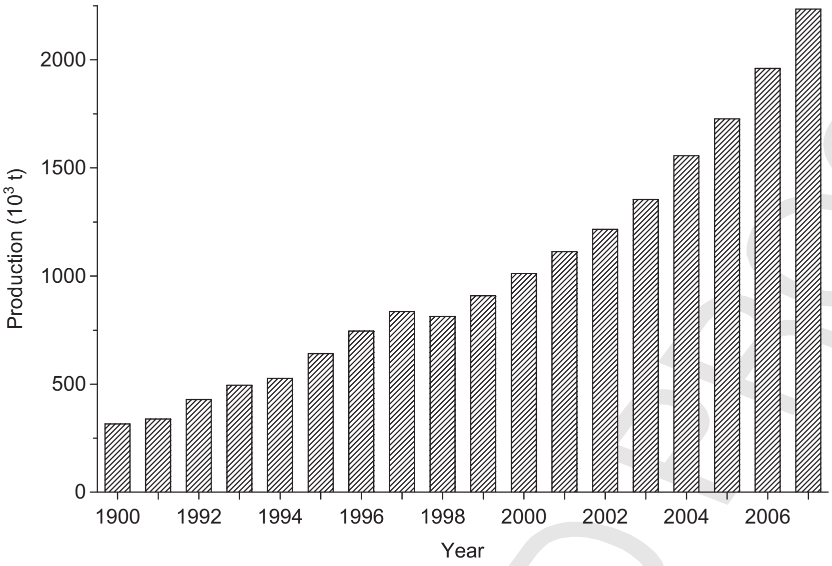

Fig. 16.1 Global production of tilapias in aquaculture, 1990–2007.

Table 16.1 Global tilapia production by countries in 2007 (Global Aquaculture Alliance 2008).

Country	Total volume (t)	Share (%)
China	1 165 000	45.6
Egypt	280 000	11.0
Indonesia	200 000	7.8
Philippines	190 000	7.4
Thailand	180 000	7.0
Mexico	106 250	4.2
Brazil	90 000	3.5
Vietnam	75 000	2.9
Taiwan	73 000	2.8
Others	196 908	7.7
	2 556 158	

an added growth factor, besides controlling unwanted recruitment.

Subsequent sections of this chapter provide a more detailed account of tilapia biology and culture. Tilapias are better understood than most aquaculture species because they have been a focus for researchers for over 50 years. In addition, a considerable amount of fundamental research has been done on tilapias. This is because of the ease with which they can be maintained in the laboratory and their short production cycle. Much of tilapia culture technology has resulted from understanding specific biological characteristics of tilapias. These are summarised in detail in several publications (Beveridge and McAndrew, 2000; El-Sayed, 2006; Lim and Webster, 2006).

16.2 FAMILY, SPECIES AND GENETIC VARIATION

16.2.1 Family

Tilapias belong to the family Cichlidae, a large family of tropical freshwater fish that have a bilaterally compressed body and exhibit parental care. Cichlid fish have a wide natural distribution throughout the tropics, but the tribe Tilapini, to which tilapias belong, occurred only in Africa and Palestine until translocations began. There are about 10 genera and over 100 species within Tilapini. The common term ‘tilapias’ refers to pure species as well as hybrids belonging to the genera *Tilapia*, *Sarotherodon* and *Oreochromis*, especially the larger species that are commercially exploited. These three genera are differentiated by the way they brood their eggs and larvae.

1. Tilapias of the genus *Tilapia* lay their eggs on a substrate, which may be a depression on the pond bottom or tree roots or submerged vegetation. Both parents care for the eggs until they hatch. Females fan and

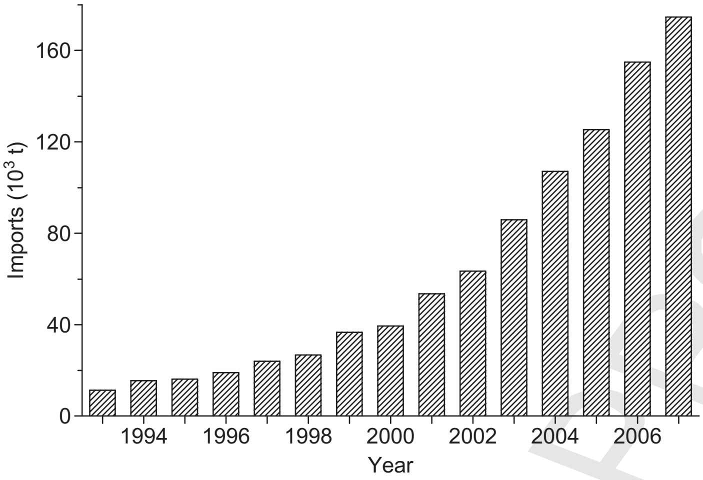

Fig. 16.2 Tilapia imports into the USA, 1993–2007, based on data provided by the National Marine Fisheries Service, USA.

clean the eggs with their fins while males guard the territory.

2. Tilapias of the genus *Oreochromis* lay their eggs in a pit or nest prepared by the males. After the eggs are laid, the female parent incubates the eggs in her mouth. Parental care continues for several days even after the eggs hatch and the fry are free-swimming.
3. Tilapias of the genus *Sarotherodon* are quite similar to *Oreochromis* in their reproductive behaviour, but both parents, or just the male parent, perform mouth brooding of their eggs and fry.

Most farmed species of tilapias belong to the genus *Oreochromis* and further details of reproduction in *Oreochromis* species are provided elsewhere in this chapter.

16.2.2 Species

Among the tilapias, members of the genus *Oreochromis*, such as *O. niloticus* and *O. aureus*, are favoured in aquaculture because of their performance under culture conditions (Table 16.3). Among the pure species, *O. niloticus* (common name, Nile tilapia) is favoured. The exceptional growth of this species in tropical freshwater conditions is the reason for its success. However, it has poor cold tolerance and does not perform well in high-saline waters. So, in subtropical waters, the more cold-tolerant *O. aureus* (common name, blue tilapia) is the species of choice. Species such as *O. spilurus*, which tolerate and grow at high salinity, are considered for farming in seawater, particularly in the Middle East, where freshwater resources are limited. *O. mossambicus* (common name, Mozambique tilapia) was the first tilapia species introduced into various parts of Asia and beyond. It has, however, lost favour owing to its excessive reproduction, which has created a bad reputation as a fish that stunts early in culture and rarely reaches its genetic potential for growth and ultimate size.

16.2.3 Strains

The wide geographic presence of species such as *O. niloticus* in Africa has meant that there has been significant genetic divergence, resulting in distinct subspecies and strains. Their subsequent transfers outside Africa have also provided opportunities for further development of distinct strains. For example, about 200 individuals of *O. niloticus* were sent from Cairo to Japan in 1962. Out of these, 120 individuals survived and formed the basis of the Japanese stock that exists today. About 50 individuals of this Japanese stock were presented to the King of Thailand in 1965 and were placed in a pond at Chitralada Royal Palace. This stock formed the basis of the Chitralada strain, which has performed exceptionally well under Thai farming conditions. Similarly, several other strains of *O. niloticus* exist in Asia and elsewhere. These strains are known by their origin in Africa (such as Ugandan strain or Ghanaian strain), the intermediate locations from which they were transferred (such as Israeli strain or Taiwanese

Table 16.2 Characteristics of tilapia culture systems.

	Extensive	Semi-intensive	Intensive	Super intensive
System type	Ditches, rice fields, backyard ponds, community ponds, reservoirs and tanks for irrigation	Ponds built specifically for fish farming	Small ponds, tanks, cages, raceways	Tanks, raceways
Stocking density (number of animals per per square metre or cubic metre)	<1	2–3	>5	>20
Source of seed (fingerlings) for stocking	Wild fish, by-product of culture	Own or commercial hatcheries	Own or commercial hatcheries	Own or commercial hatcheries
Reproductive control	None	All-male stock may be used	All-male stock	All-male stock
Fertilisation	None except incidental, run-off fertilisation	Manure and inorganic fertilisers applied	None	None
Feeds	None except occasional farm by-products and household wastes	Farm by-products such as rice bran, oilseed cakes or supplementary compound feeds	Complete, compounded feeds	Complete, compounded feeds
Aeration/water exchange	None	Limited, occasional water exchange	Used frequently	High
Culture duration	Seasonal	6–9 months	4–6 months	4–6 months
Yield (mt/ha/year)	<1	1–5	5–20	>20
Market	Producers' own consumption and local, rural markets	Local and national, export markets	Urban, high-value, export markets	Urban, high-value, export markets

Fig. 16.3 Sexual dimorphism in growth: male (top) and female (bottom) of the same age. (Photograph by Dr C. Kwei Lin.)

strain) or the destination in which they were further domesticated (such as the Philippines strain or Chitralada strain). Eknath *et al.* (1993) conducted strain evaluations in the Philippines, comparing growth performance of farmed Asian strains of *O. niloticus* and wild *O. niloticus* from across the natural range of the species in Africa. They showed that wild strains, in general, grew better than domesticated strains and that wild strains from East Africa (Egypt and Kenya) were better than those from West Africa (Ghana and Senegal). Among the domesticated strains, the Chitralada strain, further domesticated in the Philippines, fared best. The worst performance was shown by the most common strain in the Philippines, originally imported from Israel.

Table 16.3 Characteristics of *Oreochromis* species suitable for aquaculture.

Species	Growth	Critical environmental tolerance factors	Suitability
O. niloticus	Fastest growing species in many countries. Maximum size 2 kg	Lower lethal temperature = 12 °C; does not tolerate high salinity	Highly suitable for farming in tropical, freshwater and brackish water systems
O. aureus	Fast growing species. Maximum size 2 kg	Tolerates cold temperatures relatively better than most species (lower lethal temperature = 8 °C)	Best candidate for farming in subtropical freshwater and brackish water systems
O. mossambicus	Fast growth and large maximum size (~1.5 kg) observed in wild, but stunting common in culture	Lower lethal temperature = 10 °C. Grows well and reproduces under salinities as high as 35‰	Suitability as a pure species is questionable. A good candidate for hybridisation if salinity tolerance is desired in the offspring generation
O. spilurus	Grows fast when young but slows down in adulthood. Maximum size ~1 kg	Low tolerance of cold temperatures like most other *Oreochromis* species, but performs extremely well at high salinities	A good candidate for mariculure

16.2.4 Hybrids

There are several naturally occurring tilapia hybrids arising from two or more species sharing a geographic location. Some of these natural hybrids are good candidates for aquaculture. Intentional hybridisation for aquaculture purposes started with the accidental discovery that crossing female *O. mossambicus* with male *Oreochromis urolepis hornorum* resulted in all-male offspring (Hickling, 1960). Subsequent research showed that several other crosses also produce all-male or predominantly male offspring (Table 16.4). This was attributed to the differences in sex determination mechanisms between different tilapia species (section 7.3.3). Hybrids from female Nile tilapia and male blue tilapia are widely used in China (Lai and Yang Yi, 2004). The cross yields high male percentages (85–90%), and results in fast growth, large size, and tolerance of cold temperature and a wide range of salinities.

Table 16.4 Tilapia crosses that result in all-male or predominantly male offspring.

Female	Male	Males in offspring generation (%)
O. mossambicus	*O. urolepis hornorum*	100 in pure strains
O. niloticus	*O. urolepis hornorum*	100 in pure strains
O. niloticus	*O. nyasalapia macrochir*	100 in selected strains
O. niloticus	*O. variabilis*	100 in pure strains
O. niloticus	*O. aureus*	100 in selected strains and 70–80 in mass spawning
O. spilurus niger	*O. nyasalapia macrochir*	100 in pure strains
T. zilli	*O. andersonii*	100 in pure strains

16.2.5 Red tilapias

One of the significant advances in tilapia farming was the development of 'red tilapias' in the 1980s. Most tilapias, particularly *O. mossambicus*, which was then a widely cultivated species in Asia, have a dark grey-black skin colour. Their peritoneal cavity is also black in colour. This coloration was deemed unattractive in several markets, resulting in poor acceptance of the fish. Mutants that possessed red skin were observed in *O. mossambicus*, first in Taiwan, and later in the USA and Israel (Lovshin, 2000). These mutants were developed into red *O. mossambicus* strains, which evoked strong commercial interest in the culture of tilapias. Red tilapias not only lacked the stigma associated with the coloration of the wild-type tilapias, but also resembled premium marine species such as sea bream and red snapper. They had the potential to achieve wider consumer acceptance and higher prices in many markets. Because pure *O. mossambicus* red strains had poor growth characteristics, they were hybridised with faster-growing tilapias, such as *O. niloticus*, *O. aureus* or their hybrids. As a result, a large number of red tilapia strains are available for fish culturists. There are differences between the strains in the following:

- growth rate;
- tolerance of low temperature;
- tolerance of high salinity;
- other perfomance characterisitics.

Because many red tilapia strains were derived from *O. mossambicus*, they perform well in saline environments but may have low tolerance of cold temperatures.

16.2.6 Genetically improved tilapias

Despite the impressive growth rates of some strains of tilapias, such as the Chitralada strain of *O. niloticus*, the genetic base of tilapias in many countries used to be rather poor. Genetic improvement by means of selection or crossbreeding or both has been applied in developing strains of tilapias targeting a specific trait (mainly growth rate). A well-documented effort in tilapia genetic improvement is the development of the genetically improved farmed tilapias (GIFT) line of tilapias in Asia by the World Fish Center (Ponzoni, 2008). The line was developed by crossing eight strains of *O. niloticus* followed by combined family and mass selection for body weight. Field trials demonstrated that the first generation GIFT line yielded 18–58% larger fish compared with local strains of *O. niloticus*.

GIFT tilapia lines have been transferred to many countries in Asia and subjected to further genetic improvement through selective breeding. For example, the ninth generation of GIFT strain referred to as GIFT-strain Super Tilapia, or GenoMar Supreme Tilapia™, was introduced into China in 2001 (Lai and Yang Yi, 2004). A commercial venture called GenoMar Supreme Hatchery to undertake further development of the strain and distribution of fingerlings to the farmers has been established in the Hainan province in China.

At least two lines of true-breeding transgenic tilapias have been established (Mair, 2001). One is an *O. urolepis hornorum*-based hybrid that expresses a transgenic tilapia growth hormone gene and grows 55% faster than its non-transgenic counterpart. This was developed in Cuba and has been approved for use in commercial production in that country. The other line is an *O. niloticus* that is transgenic for a salmon growth hormone and grows three to four times faster than its non-transgenic counterpart. This line was developed in the UK and is yet to be approved for commercial use.

16.3 ECOLOGY AND DISTRIBUTION

16.3.1 General

Africa, excluding Madagascar but including parts of the Middle East, is the original home of all tilapias. In general, *Oreochromis* species are endemic to the central and eastern parts of Africa, whereas *Tilapia* and *Sarotherodon* species are more common in the western parts. However, species such as *Tilapia zillii*, *Sarotherodon galilaeus* and *O. niloticus* have a much larger native range. Another well-known species, *O. aureus*, is native to the Nile delta and the Middle East.

Tilapias live in a wide variety of natural ecosystems:

- slow-moving parts of rivers;
- floodplain pools;
- swamps;
- lakes;
- coastal lagoons.

They are considered to have evolved as riverine fish that eventually colonised lakes. They are strictly warmwater species. They stop growing at temperatures below 16 °C and do not survive below 10 °C. They survive and grow in brackish waters, and many species can tolerate and grow in seawater. Adult tilapias primarily eat plant materials (phytoplankton, benthic algae, macrophytes, etc.) and detritus derived from plant materials. They are also highly opportunistic feeders that are capable of changing their choice of food items or their feeding habits.

16.3.2 Translocations

The ability of tilapias to adapt to a wide variety of environmental conditions has led to the successful translocation of many tilapias within and outside Africa. The first translocation outside Africa occurred in the early 1930s, when *O. mossambicus* was introduced into Java (part of present-day Indonesia). From there it was introduced into much of tropical Asia and eventually into the Americas. Most of the introductions were purposeful, mainly for controlling aquatic weeds and insect pests, farming, or enhancing fisheries. But several accidental and undesirable introductions have also occurred. For example, *O. mossambicus* was introduced into Australia (Queensland) in the 1970s as an aquarium fish, which then escaped into natural waters and became established as a feral population. Currently, it is regarded as a pest species that threatens the natural ecosystem it occupies. Other tilapias that have been deliberately introduced for farming purpose have also established their natural populations over a wide geographic range. They include *O. niloticus*, *O. aureus*, *O. urolepis hornorum*, *Tilapia rendalli* and *T. zillii*.

16.4 SEX DETERMINATION AND REPRODUCTION

16.4.1 Sex determination

Sex determination in tilapias is highly complex, with gender being determined by genetic, environmental and hormonal factors. Genetic determination is primarily through sex chromosomes and two different mechanisms for sex determination through sex chromosomes have been proposed.

1. Species such as *O. mossambicus* and *O. niloticus* possess a system similar to humans in which females are homogametic (XX) and males are heterogametic (XY).
2. Species such as *O. aureus* and *O. urolepis hornorum* possess a system in which females are heterogametic (WZ) and males are homogametic (ZZ). A cross of the species with different systems results in all-male or predominantly male progenies, as shown in Table 16.5.

Apparently, the male-determining gene (Z) in the WZ system dominates the female-determining gene (X) in the XY system, whereas the male-determining gene (Y) in the latter dominates the female-determining gene (W) in the former.

A number of studies have shown that sex chromosomes are not alone in determining sex in tilapias.

1. Genes in autosomes (general chromosomes) are suspected of playing a role in determining sex in *O. niloticus* and *O. aureus*. This may explain the inconsistent results obtained in the production of all-male *O. niloticus* × *O. aureus* progeny.
2. Some observations have been made with respect to the effect of temperature on tilapia sex determination. Exposure of *O. niloticus* fry to high temperature (34–35 °C) results in significant sex reversal in both directions, whereas that of *O. aureus* results in masculinisation. Another case is *O. niloticus* × *O. aureus*, a commercially produced hybrid in Israel. Because of its cold tolerance and, therefore, culture at relatively low temperatures, significant declines in the proportion of males have been observed in successive generations (Wohlfarth, 1994). The speculation that temperature dictates the sex of tilapia, however, remains controversial.
3. Steroid hormones have perhaps the most significant effect on sex determination in tilapias as well as in many other fish. Apparently there is an age (10–15 days after hatching) in the development of these species during which the sex is determined by the level of androgenic and oestrogenic hormones circulating in the body. Exogenous administration of a specific hormone or its analogue during this labile period will therefore result in the production of monosex stocks (section 7.6).

Table 16.5 Sex determination systems in tilapias that result in all-male or predominantly male progenies.

O. mossambicus, female (XX) × *O. urolepis hornorum*, male (ZZ)
↓
XZ (all-male hybrid)
O. urolepis hornorum, female (WZ) × *O. mossambicus*, male (XY)
↓
WX (25% female hybrids)
WY, XZ, YZ (75% male hybrids)

16.4.2 Reproductive biology

All tilapia species mature early (4–6 months) and reproduce year-round under suitable environmental conditions. Tilapias are perhaps the only major group of fish in aquaculture that breed in captivity without any special inducement or modification to their environment (Little and Hulata, 2000). The most common tilapia species, *O. niloticus*, reaches sexual maturity at a size of 30–40 g. When

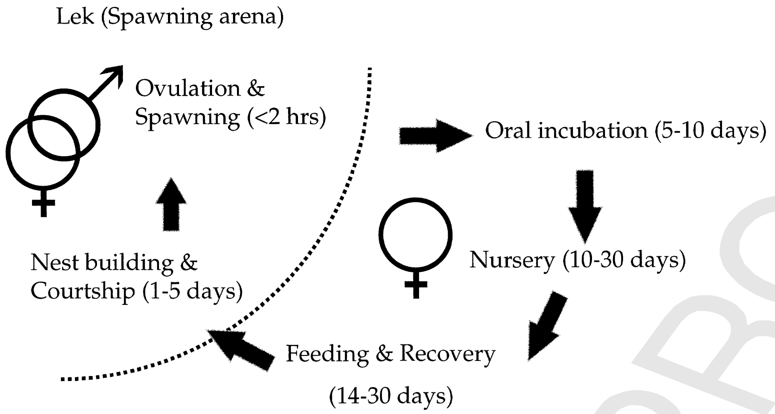

Fig. 16.4 Reproductive cycle of *Oreochromis* species.

mature, tilapias can spawn year-round if the water temperature stays between 24° and 35 °C. Typical breeding behaviour of *Oreochromis* species is shown in Fig. 16.4.

When a mature *Oreochromis* female is ready to spawn, she visits the breeding arena or 'lek'. The breeding arena consists of several males that form well-defended, individual nests. After brief courtship, the female lays her eggs while the male simultaneously fertilises the eggs. The female then picks up the fertilised eggs in her mouth for brooding and leaves the arena. Intensive parental care continues until the fry are large enough to be on their own. The female stands guard over the free-swimming fry. If the fry are threatened, they return to their mother's mouth until the threat passes. Mouth brooding lasts for 3 weeks, during which time the females eat little. Finally, the hatched fry are released in shallow waters. The female then resumes active feeding, which allows maturation of her ovaries. After a further 2–4 weeks, she is ready to spawn again.

Female tilapias lay their eggs in multiple batches. Typically, a female lays 8–12 batches/year under favourable temperature conditions. In the case of *Oreochromis* species, each batch contains about 2000 eggs. The eggs are large (3–5 mm) and contain sufficient yolk to supply nutrients to newly hatched fry for up to 5 days.

To boost broodstock productivity, the time between two successive spawnings may be considerably shortened by removing the fertilised eggs from a female's mouth. Once the clutch of eggs is removed, the female assumes that the eggs are lost and quickly returns to reproductive mode. This is similar to removing eggs from a chicken to encourage it to lay more eggs. The eggs removed from the females are incubated and hatched in upwelling jars or trays with clean flowing water (Fig. 16.5a,b) under controlled conditions that ensure high survival of eggs and fry making mass production of uniform seed possible.

16.5 CONTROL OF REPRODUCTION

As outlined in section 16.1, early maturation and prolific spawning of tilapias in grow-out systems present two major problems for tilapia farmers:

1. Energy resources are directed to the processes of sexual maturation and reproduction and become unavailable for somatic growth.
2. Continuous recruitment of young tilapias into the grow-out systems means increasing competition for resources such as space and food (Fig. 16.6).

In the past, several methods have been developed to control tilapia reproduction and recruitment. The most successful methods involve production of all male stocks because males grow faster than females in almost all tilapia species (Fig. 16.3).

16.5.1 Monosex tilapia production

16.5.1.1 Hand-sexing

Tilapias display distinct sexual dimorphism as they become juveniles. The males and females are differentiated by means of their genital morphology (Fig. 16.7).

- Males have a single longer and pointed opening which serves as an urogenital pore.

Fig. 16.5 Clutch removal: removing fertilised eggs from a female *O. niloticus* mouth in a hapa-based hatchery. (Photograph by Dr C. Kwei Lin.)

Fig. 16.6 Presence of male and female tilapias in culture systems results in reproduction before market size. (Photograph by Dr C. Kwei Lin.)

- Females have two round openings, one for urinary excretion and another for expulsion of eggs in the urogenital papillae.

This differentiation becomes more obvious when the fish are 10 g and larger. The typical practice is to sex tilapia individually before stocking for grow-out and select only the males for stocking. As this practice is very labour-intensive and wastes nearly 50% of the seed stock (females) it is rarely practised these days.

16.5.1.2 Hybridisation

The use of hybridisation to produce all-male populations was considered in section 16.4.1.

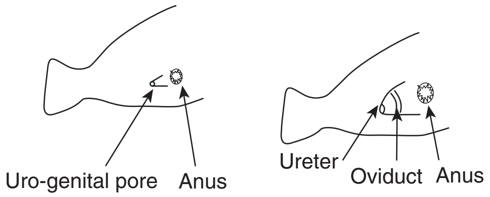

Fig. 16.7 Male (left) and female (right) tilapia genital papillae.

16.5.1.3 Hormonal sex reversal

General techniques for hormonal sex reversal in fish were outlined in section 7.5. Most commercial all-male tilapia stocks are produced by treating tilapia fry with synthetic androgens, particularly 17α-methyltestosterone (Phelps and Popma, 2000). The most commonly used protocol is to incorporate 17α-methyltestosterone into the fry diet at 40–60 ppm and feed it to the fry from the first feeding stage for 21–30 days. Seed stock with 99–100% males can be obtained if the protocol is strictly adhered to. A single hatchery can produce up to 20 million sex-reversed fry per month. Synthetic androgens such as fluoxymesterone and trenbolone acetate are also highly effective in producing all-male tilapia stocks. Instead of adding to the diet, the hormones could also be applied as a dip. Use of ultrasound at the time of of androgen dip application has shown improvements in masculinisation success, but this method produces highly variable results and is still under development. Use of hormones in sex reversal evokes environmental and food safety concerns because of the potential for hormones to enter water bodies and the human food chain. On this basis, genetic manipulation methods that do not require hormone use for masculinisation have been tried.

Tilapias can be feminised using oestrogens. Non-steroidal oestrogens such as ethynyloestradiol and diethylstilboestrol are commonly used in feminising tilapias. The purpose of feminisation is to use feminised genetic males in breeding programmes to produce all-male stock (section 7.7.3).

16.5.1.4 Genetic manipulation

Genetic manipulation of tilapias to produce either monosex or sterile stocks has nearly a 25-year history. The method has been tried as an alternative to hormonal sex-reveral. Triploidy, gynogenesis and androgenesis are commonly used techniques that have been applied in the commercial production of tilapias. These techniques and their benefits and uses are described in detail in section 7.7.3. Chromosome manipulation techniques are not appropriate for routine production of sterile or monosex stocks because it is difficult to induce 100% triploidy, gynogenesis or androgenesis on a commercial scale. Furthermore, growth and survival of triploid, gynogenic and androgenic fish are generally inferior to those of normal diploids during early life stages.

16.5.1.5 Production of genetically male (YY) tilapias

Production of genetically male tilapias eliminates the need for using hormones to mass produce tilapia seed. The method, however, requires the use of hormonal sex reversal at the initial stages of broodstock development. It is a laborious and time-consuming method because of the extensive progeny testing involved. However, once a broodstock population is founded, it can be used in any hatchery system by replacing normal males with YY super-males. Hatcheries should then exercise sound broodstock management practices to prevent genetic contamination of the YY stock. Commercial stocks of genetically male tilapias are now available, including the pioneering stock produced by Fishgen Co. Ltd together with University of Wales, Swansea. All-male tilapia are sold commercially as ‘genetically male tilapia’ (GMT$^{\circledR}$) to distinguish them from sex- reversed male tilapia This stock has been shown to outperform equivalent mixed-sex tilapias and in some cases hormonally sex-reversed, all-male tilapias (Beardmore *et al.*, 2001). However, results are variable from country to country.

16.5.2 Recruitment control

Many resource-poor farmers choose culturing mixed-sex populations of tilapias because of lack of access to reliable technology to produce 100% monosex populations. They may also prefer to raise mixed sex tilapias to produce their own seed stock for future stocking.

To prevent overpopulation during culture, predators that eat newly recruited tilapia fry and fingerlings may be used. Several predator species have been tested:

- seabass (*Lates calcarifer*);
- walking catfish (*Clarias* spp.);
- snakehead fish (*Channa* spp.);
- Nile perch (*Lates niloticus*);
- mahseer (*Tor* spp.);
- some South American cichlid species.

To be used reliably, this method requires optimisation of predator–prey ratios, timing of predator release, population and size of the predator at release. It has not, however, achieved much success and has not been practised by commercial tilapia farmers.

16.6 SEED PRODUCTION

16.6.1 Harvesting from mixed-sex stock

Systems to produce seed stock for tilapia culture vary from location to location based on the following:

- local demand for seed;
- geographic conditions;
- environmental conditions;
- economic factors.

The simplest form is to use fingerlings that result as the by-product of tilapia grow-out in ponds or tanks. Any system that uses both sexes of a tilapia species in grow-out will inevitably produce tilapia seed as a result of natural reproduction (Fig. 16.6). Although reliable technologies are available to control reproduction through the production of all-male stock, many small farmers still use mixed-sex stocks in tilapia grow-out. For them, the fingerlings produced in their ponds are inexpensive stocking material for further grow-out. This system, however, has many drawbacks, mainly inefficiency and unreliable supply of uniform-size seed. Hormonal sex reversal, the most common technique used in the production of all-male tilapias, has very low success rate with the fry collected from the ponds.

The result of this inefficient system is the development of dedicated seed production systems. These systems may use open ponds, tanks or net cages (hapas) in ponds or large water bodies (Table 16.6).

16.6.2 Pond systems

Earthen ponds are widely used in the production of tilapia fry or fingerlings (Fig. 16.8). The ponds are typically small (0.01–0.1 ha) and well managed by means of fertilisation, water control, etc. Brood fish are stocked at low densities (0.5–1 tilapias/m^2) with a male : female ratio of 1 : 2 or 3, and they are fed. Fry and fingerlings are netted out on a periodic basis (daily, weekly or bi-weekly). This type of system may yield fry at a rate of 0.1–3/m^2/day. The following factors influence fry yield in pond systems (Little and Hulata, 2000).

1. Pond size. The smaller the pond, the better it can be managed and harvested, and therefore this increases its productivity. Ponds with an area less than 1000 m^2 are preferable.
2. Harvest interval. More frequent harvests result in removal of the larger seed, thereby reducing cannibalism on younger fry.
3. Stocking density. Lower stocking density typically improves broodstock efficiency and produces larger seed.

Table 16.6 Comparison of various representative hatchery systems to produce tilapia fry.

	Pond	Tank	Hapa
Species	*O. niloticus*	Florida red tilapias	*O. niloticus*
Location	Philippines	Bahamas	Philippines
System size (m^2)	300–500	34	1
Stocking density (number per square metre)	1	7	2
Size (g)	Male and female 50–100	Male and female 143	Female 86, male 50–200
Sex ratio (F : M)	3 : 1	3 : 1	1 : 1
Harvest strategy	Harvest of fry, twice per day	Clutch removal every 15–16 days and artificial incubation	Clutch removal every 4 days and artificial incubation
Fry output (number per square metre per day)	0.7	91.7	20
Female productivity (fry per kilogram per female per month)	82.9	3021	6990
Source	Guerrero (1986)	Watanabe *et al.* (1992)	Mair *et al.* (1993)

Fig. 16.8 Collection of tilapia fry from ponds using a scoop net.

However frequently and efficiently fry are harvested from breeding ponds, it is practically impossible to remove all fry from a pond. The pond is soon overpopulated with recruits from early spawns. This results in increased competition for food and space, which diminishes seed output. To overcome this problem, the breeding ponds have to be periodically drained to remove all fish. An alternative to this practice is to seine the pond and remove all broodstock, which are then transferred to another pond. The fry left in the pond are further nursed to a size suitable for stocking. Another alternative, practised in Israel, is to construct breeding ponds with two compartments: a spawning compartment and a fry-collecting compartment that is built at a lower level relative to the spawning compartment (Little and Hulata, 2000). The two compartments are separated by a sluice gate that retains the broodstock and allows collection of fry with minimal handling.

16.6.3 Tank systems

Concrete, plastic or fibreglass tanks may be used in tilapia seed production. A higher degree of control over the broodstock and seed, as well as the spawning environment, is a major advantage in the use of tanks as seed production systems (section 16.5.1). Practices such as clutch removal and broodstock reconditioning, which improve hatchery efficiency, can be implemented in tank-based systems with relative ease. Tank systems are typically used when water or land resources are limited. This is because of their high seed output per unit of water and land area. The main disadvantage of tank systems is the high cost of initial investment to construct them.

16.6.4 Hapa systems

Hapa-based hatchery systems provide some of the advantages of tank-based systems at a lower cost. A hapa is a cage made of netting that can be suspended in ponds or large water bodies such as lakes and reservoirs (Fig. 16.9). Brood fish are stocked inside the hapa. Eggs and larvae are regularly collected by clutch removal. The hapa can also be designed to have two nested compartments. The inner compartment has a mesh that retains the broodstock but allows the fry to swim to the outer compartment, which is composed of fine-mesh netting. The inner cage, with brood fish, is removed every 10–15 days and the fry collected in the outer cage are allowed to grow to a size suitable for stocking. The pioneering hapa-based system developed at the Asian Institute of Technology, Thailand (Fig. 16.9), has been described in Bhujel (2000). The system uses 40–120 m^2 hapas in which male and female tilapia are stocked at 1 : 1 or 2 ratio and 5 or 6 fish/m^2 density. Seed production in the hapas is over 100 fry/m^2/day. Several private hatcheries around the world in

Fig. 16.9 Net cages (hapa) used for tilapia fry production.

Bangladesh, Brazil, China, Thailand, the Philippines and Vietnam currently use this system. A major disadvantage of the hapa system is that the mesh openings of the hapas are easily fouled. This limits water exchange and supply of natural food organisms. So, hapas must be pulled out of the water periodically (every 15 days is recommended) and washed or sun-dried. This is a labour-intensive practice, but it provides opportunities to rest and recondition the broodstock, thereby improving their productivity.

16.7 NUTRITION, FEEDS AND FEEDING

16.7.1 Diet and feeding habits

Although tilapias in general are opportunistic omnivores, there is considerable specialisation in diet in some species. Young tilapias are carnivorous and prefer zooplankton. As they become juveniles, their diets shift to plant material or detritus of plant origin or both food sources. Common foods of tilapias in nature are phytoplankton, benthic algae, macrophytes and periphyton (the community of microscopic and small organisms on the surfaces of benthic structures). *Oreochromis* species feed primarily on microscopic plant materials, whereas *Tilapia* species prefer large plants.

Tilapias use a wide variety of feeding methods:

- visual feeding;
- suction feeding;
- biting;
- grazing.

The primary method of feeding in adult tilapias, particularly in *Oreochromis* species, is continuous suction feeding, in which food particles are entrapped by filtration as water is routinely passed over the gills. The food particles are crushed by the pharyngeal bones and then passed into the alimentary tract. Tilapias possess a stomach that can reach extremely acidic conditions ($pH < 1$) in proportion to the stomach fullness. This acidic condition lyses plant cells and prepares food material for further digestion in the intestine. Tilapias have a very long, coiled intestine. Intestinal pH is 6.8–8.8 and conducive to the action of digestive enzymes such as trypsin, chymotrypsin and amylase. Anaerobic fermentation may also occur in the hindgut. Crude protein digestibility and assimilation efficiency of plant matter (filamentous and planktonic green algae, and blue-green algae) ranges from 50 to 80%.

16.7.2 Nutrient requirements

16.7.2.1 Protein

Like most fish species, tilapias require a high concentration of proteins in their diets when they are young. Various assessments (30–56%) of the protein requirements of young tilapias have been reported. What is clear is that the protein level required for fry is greater than for adults.

Field studies show that adult tilapias grow well when feeds containing 25–32% protein are used and that feeds containing higher protein levels do not add any substantial value in terms of growth. The recommended levels of protein in the diet range from 40 to 45% for fry to 25–30% for grow-out, with brood fish requiring a slightly higher level (25–35%) than fish intended for grow-out. There may be considerable differences in nutrient requirements and utilisation among different strains of tilapia, as Ng *et al.* (2008) demonstrated for crude protein in red tilapia hybrids and GIFT tilapia strain in Malaysia. The GIFT tilapia strain have a higher potential for growth, feed intake and feed efficiency, and are better able to utilise a diet containing higher protein than the red hybrids.

16.7.2.2 Energy

Although a feed that meets the protein requirements of tilapias is likely also to meet the energy requirements, balancing protein and energy is important in optimising feed cost relative to growth and other production parameters. The optimal protein–energy ratio in tilapias is 110–120 mg protein/kcal of energy when the fish are young. This decreases to about 100 mg/kcal of energy as they grow and reach adulthood.

Lipids and carbohydrates are cheaper sources of energy than protein. In general, warmwater omnivores such as tilapias utilise carbohydrates better than lipids. Lipid levels above 12% in feeds cause reduced growth in tilapias, probably because of reduced feed intake, whereas digestible carbohydrates as high as 40% are well utilised. Among carbohydrates, starch and dextrin are better utilised than glucose, whereas cellulose and other fibre components are not digestible. Inclusion of fibre above 5% causes depressed growth in tilapias.

16.7.2.3 Lipids and fatty acids

As noted, tilapias do not appear to use lipids effectively as an energy source. Suggested maximum lipid levels in the diet for tilapias range from 5 to 12%. Excess lipids also result in substantial carcass and visceral deposition of fats. Vegetable oils such as corn oil and soybean oil are superior sources of lipids compared with animal fats, including fish oil. It appears that tilapias require low levels (= 1% or less) of linoleic acid (18:2*n*–6) and linolenic acid (18:3*n*–3) in
2 their diet (section 8.9.7).

16.7.2.4 Minerals

In the typical hard water used in aquaculture, there is sufficient calcium to meet the calcium requirements of tilapias. In soft waters, dietary calcium is required. Similarly, a dietary supply of magnesium is important in waters that are low in this ion. Recommended dietary levels of minerals have been based on the requirements of other freshwater fish, especially channel catfish (section 17.6.1).

16.7.2.5 Vitamins

The need for vitamin supplementation in semi-intensive pond culture of tilapias is questionable, because natural foods are rich in many vitamins. However, complete feeds for tilapias in intensive systems, particularly indoor tank systems, require comprehensive vitamin supplementation of the kind that is used in complete feeds for other fish in
intensive culture (section 8.10). 2

16.7.3 Feeds and feeding

16.7.3.1 Feedstuffs

Tilapias are capable of utilising a wide variety of feedstuffs either as a single feed or as a part of compounded feed. Feedstuffs that are fed to tilapias in extensive grow-out systems include the following:

- rice bran and various other grain by-products;
- oil seed residues;
- aquatic and terrestrial plants;
- kitchen waste.

Numerous feedstuffs, including some of those above plus various animal by-products, tubers and fermentation by-products, are used in compounded feeds. Protein and energy digestibility for these feedstuffs ranges between 30 and 90%+ (Hanley, 2000) and, from this range, clearly some feed ingredients are to be preferred. Other factors that influence the choice of components used in feed formulations are as follows:

- cost;
- fibre content;
- amino-acid profile;
- palatability;
- toxins;
- digestive enzyme inhibitors.

Table 16.7 shows examples of some feed formulations for tilapias. Once considered essential, fish meal has declined in its importance in tilapia feeds. Today, tilapia feeds can be formulated without any fish meal and still perform optimally in most culture systems. This is a major advantage of tilapias for aquaculture.

Table 16.7 Model tilapia feed formulations based on ingredient availability and costs in the USA.

Ingredient	Semi-intensive ponds (26% protein)	Intensive ponds (32% protein)	Intensive tanks (36% protein)
Soybean meal	38.3	48.5	50.8
Wheat middlings	4	20	18
Fish meal	4	6	12
Corn	50.8	22.6	16.5
Dicalcium phosphate	1	1	0.8
Vegetable oil	1.5	1.5	1.5
Vitamin mix	0.2	0.2	0.2
Mineral mix	0.2	0.2	0.2

Modified from Lovell (1998).

16.7.3.2 *Feed forms and sizes*

Tilapias accept feeds as dry meal, moist meal and pellets. Although dry meal is suitable for feeding fry, neither dry nor moist meals are appropriate for feeding growers in intensive culture systems. A considerable portion of meal-type feeds is wasted. Complete feeds that incorporate high-quality ingredients must be pelleted or extruded to minimise waste. Such processing also enables easy handling, storage and distribution of the feed by the farmer.

Particle size is an important consideration in selecting feeds for tilapias, which prefer smaller feed particles than many other cultured fish species. Unlike other species that swallow whole feeds, tilapias tend to chew large particles. These are repeatedly taken into the mouth and ejected until they are reduced to an appropriate size. This results in leaching of the nutrients and feed wastage. Table 16.8 presents the appropriate particle forms and sizes recommended for feeding tilapias of different body sizes.

Table 16.8 Feed forms and particle sizes recommended for tilapias.

Body size (g)	Particle size diameter (mm)	Recommended form
<1	0.5–1	Meal
1–2	1–1.5	Crumbles
2–30	1–2	Crumbles
30–100	2.4	Pellets/extruded particles
100–250	3.2	Pellets/extruded particles
250 to market size	4.8	Pellets/extruded particles

Modified from Luquet (1991) with permission.

16.7.3.3 *Feed input*

The extent to which natural foods are available to tilapias influences the amount and quality of feed input. In ponds, the amount of natural foods available to individual fish depends on several factors such as soil fertility, type and amount of fertilisers added, and the number and weight of fish stocked. Tilapias stocked at small size (<10 g) and low density (1–2/m^2) typically grow very well on natural foods, and pond fertilisation may be sufficient to meet the nutrient requirements for growth. However, once the fish reach 40–80 g, satisfactory growth cannot occur on natural foods alone. Supplementary feeds are needed at this stage to attain good growth rates. As natural foods are high in protein, feeds rich in energy, such as rice bran, are ideal supplementary feeds. As the fish grow further to a larger size, for example >300 g, natural foods and supplementary feeds are not sufficient to sustain growth, so complete feeds are required for further growth. As stocking densities increase, growth plateaux occurs with smaller sizes of fish, so that complete feeds must be introduced earlier in the culture cycle. The potential of complete feeds to increase growth of tilapias in semi-intensive pond culture was demonstrated by Edwards *et al.* (2000) (Fig. 16.10). *O. niloticus* juveniles of ~25 g initial weight were stocked at 4/m^2 in 200-m^2 fertilised ponds for 4 months. The ponds were subjected to one of the following treatments:

- (F): fertilisation (4 kg N urea, +2 kg P triple superphosphate, Na$_3$PO$_4$);
- (F + E): fertilisation + energy (pelleted cassava starch + lipid);
- (F + E + P): fertilisation + energy + protein (fish meal and soybean meal);
- (F + E + P + P): fertilisation + energy + protein + phosphorus (as dicalcium phosphate);
- (F + E + P + P + V): fertilisation + energy + protein + phosphorus + vitamins.

Growth was significantly improved as each nutrient type was added into the feed, except for the vitamins. The

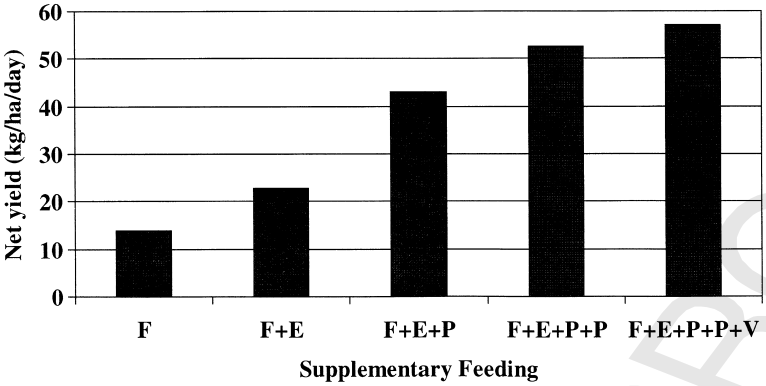

Fig. 16.10 Effect of supplementary nutrients on tilapia yield in semi-intensive ponds (see section 16.7.3 for more details). Modified from Edwards *et al.* (2000) with permission from Kluwer Academic Publishers.

addition of the energy source approximately doubled the net yield. Similarly, the addition of the protein meals approximately doubled the net yield. Addition of phosphate increased net yield by ~9 kg/ha/day. The increase in net yield with addition of vitamins, however, was not statistically significant, supporting the view that the natural feeds available to the animals in semi-intensive culture should provide sufficient vitamins.

16.7.3.4 Feeding allowance

There are two options for practical feeding of fish. One is to feed the fish to satiation and the other is to feed a restricted ration (section 15.5.2). Best growth is normally achieved by feeding to satiation. However, satiation levels are not necessarily the most economic feeding levels, because food conversion at satiation levels is often poor. Also, it is difficult to determine satiation levels in fish because food consumption occurs in the water medium. This may lead to overfeeding, which is wasteful and deleterious to water quality. As a result, restricted rations are recommended for feeding fish. The choice between satiation and restricted feeding should be based on the protein and energy density of the feed. Although restricted feeding of high-protein, high-energy diets is beneficial, low-protein, low-energy diets have to be fed at satiation levels to meet the nutritional requirements of the species.

As discussed in the previous section, natural availability of foods also determines feed allowance. Trials in Thailand showed that feeding at 50% of satiation rates in fertilised ponds gave similar growth and yield as full satiation feeding (Diana, 1997). Other factors that must be considered when determining feeding allowance include the following.

Table 16.9 Feeding allowance and frequency for tilapias at different body sizes (modified from Lovell, 1998).

Body size (g)	Daily feeding allowance (% of body weight)	Feeding frequency (number of meals per day)
<1	30–10	8–12
1–5	10–6	6
5–20	6–4	4
20–100	4–3	3–4
>100	3–2	2–3

1. Body size. As a fish increases in size, it is obvious that the absolute amount of feed it can consume increases. However, the amount of feed it can consume per unit of body weight decreases. Recommended feeding allowances for different body sizes are provided in Table 16.9.
2. Temperature and other water quality factors. Feeding allowances presented in Table 16.8 are for tilapias grown at optimum temperature conditions (26–32 °C). Feed consumption in tilapias decreases with decreasing temperature owing to declining metabolic rate and ceases at 16 °C. Appropriate reductions in feeding allowance will be required under such conditions

Table 16.10 Feeding allowance as modified by water temperature.

Temperature (°C)	Percentage of normal daily feeding allowance
>32	80
24–32	100
22–24	70
22–20	50
20–18	30
18–16	20
<16	No feeding

Table 16.11 Desirable water quality for tilapia culture.

Water quality parameter	Desirable level
Temperature	26–32 °C
Dissolved oxygen	>3 ppm
Total ammonia	<1 ppm
pH	6.5–8.5
Alkalinity	>20 ppm
Hardness	>50 ppm
Salinity	0–20‰

(Table 16.10). Reductions in feeding allowance are also required when temperature increases above optimum levels. At such conditions, dissolved oxygen (DO) levels decrease and the toxicity of ammonia increases in culture systems. So, feeding levels have to be lowered at high temperatures too.

Reduced feeding levels are recommended whenever water quality problems are anticipated or encountered. Adverse weather conditions such as high winds and heavy rainstorms cause changes in water quality in pond systems. Heavy algal blooms in pond systems, which may be caused by high feeding rates, can cause severe oxygen depletion. In such events, feeding is suspended until conditions improve.

High stocking densities mean high feed input to the culture system. This leads to DO depletion and high ammonia levels. Stress due to poor water quality leads to poor feed consumption and conversion. So culturists using high stocking densities must use devices such as aerators and mixers or water exchange to maintain water quality at or above acceptable levels (Table 16.11). Pond trials in Honduras showed that maintaining DO in excess of 10% saturation produces more rapid growth (Diana, 1997). In static ponds, feed application must not exceed 120–130 kg/ha/day.

16.7.3.5 Feeding frequency and time

Tilapias are known to eat continuously through the day in their natural habitat, so multiple feedings may be beneficial. Fry, which eat up to 16% of their body weight every day, need to be fed 8–12 times a day. This frequency is reduced as they grow (Table 16.9). At the grow-out stage, two or three meals per day are sufficient for optimal growth. Daytime is the best time to feed tilapias. In their natural habitat, they eat during the day, with little or no feeding activity at night.

16.7.3.6 Feeding method

Hand feeding, although labour intensive, is considered to be the best method to feed tilapias because it allows the farmer to observe the animals and their feeding response. It is essential that the feed is distributed evenly over the water surface to allow all the fish to feed. Tilapias are socially aggressive and tend to develop social hierarchies in which one individual dominates others and appropriates more feed. Uneven distribution of feed will result in dominant individuals occupying places that receive the most feed and eventually lead to large variation in fish size at harvest.

Automatic feeders and demand feeders are useful for feeding fish in cage culture, especially when access to cages is difficult or time-consuming. They are also useful in large farms that would require extensive manpower to feed the fish or when manpower is prohibitively expensive. Automatic feeders are becoming widely used in many parts of the world, including in pond culture of tilapia in China (Fig. 16.11). The various methods for feed distribution in aquaculture systems are outlined in section 15.5.2.

16.8 GROW-OUT SYSTEMS

16.8.1 Extensive systems

Extensive systems for tilapias include a broad range of culture units:

- backyard ponds;
- roadside ditches;
- irrigation tanks;
- reservoirs;
- rice fields;
- wastewater treatment ponds (Table 16.2).

Fig. 16.11 Automatic feeder used in tilapia farming in China.

These systems are located in the tropics, operated by poor rural farmers for subsistence. They use basic aquaculture technology. Stocking is irregular and may consist of small tilapias harvested from the wild. No intentional fertilisation or feeding is carried out and yields are <1 t/ha/year. Although such systems are quite underproductive compared with the yield potential of tilapias, they are important to the farmers because they provide inexpensive animal protein to the farmer's family and some supplemental cash income.

16.8.2 Semi-intensive pond systems

Semi-intensive pond systems represent a vast improvement over extensive systems of production. The ponds are intentionally built for aquaculture. Stocking is planned. Seed is produced on the farm or bought from a hatchery. Methods to control reproduction in grow-out are applied. As in other semi-intensive pond culture, fertilisation of ponds is performed. Feeds, prepared on-farm or at a feed mill, are used. Yields are typically 3 t/ha/year, but some well-managed systems may yield up to 10 t/ha/year. Most tilapia production in the world originates from semi-intensive pond systems.

Semi-intensive tilapia culture systems can be used effectively to satisfy the needs of subsistence farmers as well as the increasing desire of small-scale farmers to intensify production to generate cash income. Considerable research has been directed towards understanding the scientific basis of productivity in semi-intensive tilapia pond systems and has resulted in a vast improvement of our knowledge of optimising pond inputs such as fertilisers and feeds.

16.8.2.1 Fertilisation of ponds

The ideal levels of N and P in pond water to sustain production of phytoplankton are difficult to estimate. In general, a N : P ratio of 10 : 1 is recommended because this is the ratio between nitrogen and phosphorus in most phytoplankton. A N level of 1.3 ppm and a P level of 0.15 ppm are recommended by some. Others favour a higher level of N (15–30 N to 1 P) to discourage the growth of nitrogen-fixing blue-green algae, which are low in nutritive value to fish, and to encourage the growth of green algae and diatoms, which have a high nutritive value. Loading rates of 4 kg N/ha/day and 1 kg P/ha/day are optimum for semi-intensive tilapia ponds. N loading rates in excess of 4 kg/ha/day, however, may be counterproductive as ammonia may increase to toxic levels. Lin *et al.* (1997) recommend 1.4–2 kg P/ha/day for new ponds because P is easily precipitated into insoluble forms by cations and is strongly adsorbed by pond soils. The high level of P fertilisation is also applicable to ponds in acid sulphate soils because of the soil's sequestering action.

The recommended levels of N and P may be applied in the form of organic fertilisers, such as livestock manures or crop residues, or as inorganic fertilisers. Livestock manures have traditionally been used in Asian aquaculture as fertilisers. In addition to supplying N, P and C, they may contribute trace elements. Furthermore, they may also play a role in the detrital food chain. However, the levels of N, P and the N : P ratio of most livestock manures are below optimum. Excessive application of manures to compensate for their low nutrient density results in severe oxygen depletion in the water and accumulation of organic matter in the pond bottom, which ultimately reduces yields. So, it is recommended that ponds are fertilised with livestock manures at moderate rates together with inorganic fertilisers to compensate for the nutrient deficiency. One particular strategy that has proved effective is to apply chicken manure at a rate of 200–250 kg /ha/week (dry-matter basis) and to supplement it with urea and triple superphosphate (Na_3PO_4) at the rates of 28 kg N/ha/week and 7 kg P/ha/week respectively. At a stocking density of three tilapias/m^2, this fertilisation regime provided an extrapolated net yield of 8–11 t/ha/year.

16.8.2.2 Supplementary feeding

The rationale and principles of supplementary feeding have been covered in section 16.7.3. Supplementary feeding is important in semi-intensive pond culture of tilapias, and most nutrients required in complete feeds are also required in supplementary feeds (Edwards *et al.*, 2000). In practice, two options exist for supplementary feeding in semi-intensive pond culture of tilapias.

1. Provision of feeds that complement the natural productivity of the ponds. In this approach, the animals are provided with feeds throughout the grow-out period.
2. Start feeding once fish growth plateaux on natural foods alone. Beginning feeding at a moderate size may be more economical than at smaller sizes (Diana *et al.*, 1996).

16.8.3 Polyculture

Polyculture of tilapias with other fish species is practised in many countries. Traditional polyculture is based on the premise that various species stocked together utilise different trophic niches that exist in a pond and therefore produce more biomass than if they were stocked alone in monoculture (section 2.3.5). Tilapias have been grown with carps in the Asian polyculture systems (extensive and semi-intensive ponds) for many decades. Similarly, tilapias have been grown along with common carp in semi-intensive pond systems in Israel (section 5.5.1). A recent trend in South and Central America is to grow tilapias with shrimp in brackish water ponds, as shrimp monoculture has been affected by several viral disease problems (section 21.3.1).

The suitability of a given species in polyculture depends on its compatibility with other species, and tilapias have been shown to be compatible with some carp species and other fish. However, in polyculture, tilapias and other fish species are stocked at low densities: 5000–10 000 fish/ha compared with 30 000–40 000 fish/ha as stocked in semi-intensive monoculture of tilapias. Limited studies and field experience suggest that tilapias are not appropriate species for polyculture at high densities. Tilapias are typically more aggressive in their feeding, and tolerate crowding and poor water quality conditions better than most tropical aquaculture species. When tilapias fetch attractive prices in the local or export markets, it is probably more profitable to grow them at high densities in monoculture than at low densities in polyculture. In many countries, such as Taiwan and Israel, tilapia farming began as polyculture, but has eventually developed into intensive monoculture. Tilapia polyculture is more desirable, however, when a farmer requires production of a variety of species for the market and where the other species used in polyculture also fetch an attractive price. In rural south-east Asia, tilapias are polycultured with Indian carps and silver barbs because the last two also fetch an attractive price in the local markets.

16.8.4 Integrated farming

Tilapias play an important role in integrated agriculture/livestock-aquaculture systems in Asia. Integration of tilapia farming with pig, chicken and duck production systems is practised mostly in China and south-east Asia. Typically, the housings for the livestock are constructed adjacent to or above the tilapia ponds (section 2.3.5 and Fig. 2.9). The pond, therefore, receives manure and uneaten feed from the livestock system on a regular basis. An extrapolated net fish yield of 10 t/ha/year was reported in a tilapia–duck integrated system in Thailand and much of the production was attributed to the inefficient feeding of ducks that resulted in feed wastage. In rural Nigeria, small farmers fertilise their tilapia ponds with excreta from their chicken farms. The ponds serve an important purpose in being the source of water for the farm crops and for poultry in the dry season (Njoku and Ejiogu, 1999). Ponds integrated at 1000 chickens/ha received an excreta load of 3600 kg/ha/month (dry-matter basis), which resulted in an extrapolated net yield of 18.25 t/ha of an African catfish species and 14.9 t/ha of *O. niloticus*. Integrated aquaculture practices are further discussed in sections 2.3.6 and 4.7.3.

16.8.5 Intensive pond systems

Semi-intensive pond systems in the tropics are typically stocked at a rate of two or three tilapias/m^2, and they yield an average of 3 t/ha per crop, as previously indicated (Table 16.2). In areas where land or water or both are limited, or climatic conditions restrict growing season to less than 1 year, it is desirable to achieve very high productivity by using high stocking densities. Experimental culture of tilapias in earthen ponds at stocking densities of 5–10/m^2 has demonstrated that intensive tilapia farming is feasible in earthen ponds. Such intensive pond systems, however, must be managed to maintain adequate water quality, otherwise significant retardation in growth and food conversion will occur. For management purposes, the ponds must be small (<0.5 ha) and designed to drain and fill effectively within a short period. Aerators are used to maintain desirable DO levels, especially during the critical late night and early morning hours (Fig. 3.6). Adequate circulation of the water must be provided to minimise accumulation of organic waste in the pond bottom. There may also be daily exchange of a part of the water to remove organic debris accumulating on the pond bottom. In Israel and Taiwan, where intensive pond systems were

Fig. 16.12 Red tilapias reared in cages in Colombia. (Photograph by Dr George Chamberlain.)

developed, the production systems are connected to a large reservoir that serves as a water treatment body (section 5.4). Wastes accumulating on the bottom of ponds are flushed to the reservoir periodically by means of water exchange. Tilapias and carps are stocked in the reservoir at low densities to harvest the algae and thereby reduce nutrient load in the water. Yields ranging from 10 to 30 t/ha per crop are possible in intensive pond systems.

16.8.6 Cages

Cages provide the opportunity to grow fish in manageable units in large bodies of water such as lakes, reservoirs and the open ocean, as well as running water bodies such as rivers and irrigation canals (Fig. 16.12). An additional advantage of using cages for tilapia grow-out is that it minimises unwanted recruitment as most eggs drop through the bottom of the cages (although the stock still engage in energy-wasting reproduction). There is commercial cage culture of tilapias in Colombia, Brazil, Indonesia, the Philippines, Vietnam and China. Reservoirs built for irrigation and hydroelectric power generation are used in many locations to grow tilapias in cages. The cages may be made of locally available bamboo, netting, etc., or constructed from commercial-grade materials such as PVC and steel. A wide range of cage sizes are used. Large cages (>1000 m^3) are used, but are hard to manage. Such cages are typically stocked at 20–25 tilapias/m^3 and yield about 1 kg fish/m^3 per month. For intensive production, smaller cages (>500 m^3) are preferred and stocking densities are usually more than 100 tilapias/m^3. The typical yield in such systems exceeds 2 kg fish/m^3 per month. Popma and Rodriquez (2000) reported that cages in two major reservoirs in Colombia produced ~2225 t tilapias/year. Productivity ranged from 67 kg/m^3/year to 116 kg/m^3/year.

16.8.7 Raceways, tanks and water recycle systems

Intensive culture of tilapias in raceways is practised when there is an abundant supply of gravity-fed running water. There are a handful of commercial projects in Central America that grow tilapias in raceways. The source of water includes rivers, irrigation canals and reservoirs for hydroelectricity generation. The raceways are typical of this culture system, being generally long and narrow, lined with concrete and having water exchange rates in the range of 300–2400% per day. High stocking density (>50 tilapias/m^3) and biomass (>20 kg/m^3) are used. Typical yields of more than 40 kg/m^3 per 6 months are possible in raceway systems.

Rectangular, square, octagonal or circular tanks, lined with concrete or plastic, are also used in intensive tilapia farming (Figs 16.13 and 16.14). Stocking densities and yields are as high as those in raceway systems, but the tank systems are commonly used in conjunction with a water recirculation system to minimise water use. The recirculation system may involve exchange with an extensive pond for waste removal as described in section 16.8.5.

Fig. 16.13 Net-partitioned raceways to raise tilapia fingerlings. (Photograph by Al Ballaa Est., Saudi Arabia.)

Fig. 16.14 Concrete tanks for growing tilapias intensively in Taiwan. (Photograph by Dr C. Kwei Lin.)

Alternatively, it may involve a sophisticated recirculating system with components for removal of solid waste, soluble nitrogenous compounds, addition of oxygen and disinfection of the water (section 2.4.4). These systems are generally used in temperate regions of the world, particularly the USA, for commercial production of tilapias. In many cases, the water for these systems is derived from either geothermal springs or power plant effluents. The systems are generally housed within a greenhouse or a similar enclosure to conserve heat (Fig. 16.15). The systems may also be coupled with hydroponic production of vegetables, such as lettuce or tomatoes, which takes advantage of the nutrient-rich effluents from the tilapia culture units.

Fig. 16.15 Careful water quality management in an intensive tilapia culture system in southern California, USA. (Photograph by Dr C. Kwei Lin.)

16.8.8 Growing tilapias in saline waters

The ability of tilapias to tolerate and grow in saltwater has resulted in the development of commercial tilapia grow-out systems that utilise brackish or seawater (Suresh and Lin, 1992). Although semi-intensive culture of tilapias in brackish water ponds is now widely practised in Egypt, Ecuador and the Middle East, there are only a handful of experimental projects involving intensive tilapia culture in seawater in the Caribbean islands and the Middle East. Tilapias cultured in these systems have achieved growth rates and yields that are similar to tilapia cultured in equivalent freshwater systems. For example, Florida red tilapias grown in 0.2 ha brackish water (20–27‰ salinity) ponds at three fish per square metre and fed a 25% protein diet reached an average weight of 452 g in 160 days and yielded a crop of 11.5 t/ha in 220 days (Watanabe *et al.*, 1997). In Ecuador, tilapia replaced or supplemented shrimp stocked in brackishwater ponds when shrimp monoculture was affected by various viral diseases. Tilapia production in shrimp ponds grew rapidly in the late 1990s so that Ecuador became the largest supplier of fresh tilapia fillets to the US market in 2000 (Velasco and Freire 2008). Average tilapia yield in brackishwater ponds is 7 t/ha achieved in 370–408 days.

16.9 DISEASE MANAGEMENT

Tilapias are far more tolerant of adverse water quality conditions and other stress factors, and are less prone to diseases than most other cultured fish. However, there has been a steady increase in the incidence and severity of diseases in intensive tilapia culture systems during the past few years. Common infectious and parasitic diseases of tilapias are presented in detail by Conroy and Conroy (2008).

16.9.1 Common diseases1125%

16.9.1.1 Bacterial diseases

Streptococcosis due to *Streptococcus* species, particularly *S. iniae* and *S. agalactiae*, has emereged as a serious threat to intensive farming of tilapias worldwide (Klesius *et al.* 2006). Infection results in septicemia and neurotropic disease and causes cumulative mortality ranging from 30 to 50%. Early clinical signs are anorexia, lethargy, loss of orientation and erratic swimming. Later, the fish exhibit exophthalmia, a deformed back, and hemorrhages in the periorbital, intraocular area and base of fins and perianal region. Adverse changes in water temperature are usually associated with the onset of disease. Parasitic infections predispose fish to streptococcal infections.

Motile Aeromonas septicaemia due to *Aeromonas hydrophila* and related species is another common disease of tilapias. Clinical signs include the following:

- frayed fins;
- haemorrhaged skin and fins;
- inflamed skin and fins;
- scale loss;
- ulcerations on the body, head and mouth;
- liver pale, with small red spots;
- dark-red spleen.

Aeromonas infections occur in freshwater. Poor water quality, cold temperature and skin injury may facilitate infections. The mortality is typically chronic with low daily losses.

Other bacterial infections include vibriosis (due to *Vibrio* species), edwardsiellosis (due to *Edwardsiella tarda*) and columnaris (due to *Flavobacterium columnare*). Recently, a rickettsia-like organism identified as *Francisella* species has also been associated with high tilapia mortalities in Central America (Soto *et al.* 2009). Non-specific clinical signs, such as erratic swimming, anorexia, anaemia, exophthalmia and high mortality, are displayed. Infected fish have an enlarged spleen and kidney that contain white nodules. The disease causes mortality of about 50%.

Clinical signs of most bacterial infections in tilapias are quite similar, so it is necessary to isolate, culture and identify the pathogen for diagnosis and treatment purposes.

16.9.1.2 Viral diseases

Lymphocystis and infectious pancreatic necrosis-like virus have been known to occur in tilapias, but neither poses a major disease threat. There are a few isolated reports of diseases due to identified or unidentified viral pathogens, but, so far, no viral disease has been widespread in the tilapia industry.

16.9.1.3 Fungal diseases

Secondary infections due to the water mould *Saprolegnia parasitica* are common in many fish species, including tilapias. Infections occur after injury and particularly when water temperature drops below the optimum. It is a common problem in hatcheries, affecting eggs and reducing hatch rates.

16.9.1.4 Parasite problems

The protozoan parasite *Ichthyophthirius multifiliis* (common name, ich), can cause severe mortalities in tilapias and other freshwater fish (section 17.7.4). This parasite is most lethal at water temperatures between 20 °C and 23 °C, so it is not a problem when tilapias are farmed in their normal warmwater temperatures. Other ciliated protozoans that affect tilapias are *Trichodina*, *Trichodinella*, *Chilodonella*, *Apiosoma*, *Ambiphrya* and *Epistylis* species. Common monogenetic trematodes such as *Dactylogyrus* and *Gyrodactylus* species, and parasitic crustaceans such as *Lernaea*, *Ergasilus* and *Argulus* species, have been observed in tilapias. Tilapias grown in seawater are highly susceptible to an ectoparasitic marine monogenean flatworm, *Neobenedenia melleni* (Watanabe *et al.*, 1997). Although most parasites do not cause mortality, they predispose the fish to other serious infections such as streptococcosis, because they damage the scale, skin, fins or gills.

16.9.2 Control of diseases

Table 16.12 shows some of the chemotherapeutic treatments for common infectious diseases in tilapias. Although prophylactic therapies are recommended as part of a disease prevention programme, treatment therapies with antibiotics have been limited in success. Relapse of diseases after antibiotic therapy is common.

Considerable success has been achieved in vaccinating tilapia against *Streptococcus* species. (Klesius *et al.* 2006). The vaccine is prepared by culturing the infectious organisms and killing them in formalin (section 16.9.2). Researchers have found that the most effective vaccine incorporates not just the killed cells, but also the culture medium in which the infectious organisms are grown. The vaccine is called an extracellular products (ECP) vaccine. Optimum body size for vaccinating tilapia is 1–5 g. An immersion bath in the vaccine is used for primary vaccination. A booster delivery of the vaccine is provided through feed for 21–30 days after the bath. Tilapia vaccinated in this manner are protected against infections for 9–12 months and typically have 85–95% lower mortality than unvaccinated tilapia.

Plumb (1999) recommended the following environmental and stress management practices to reduce the incidence of diseases in tilapia culture:

- maintain the highest possible water quality;
- maintain prudent stocking densities and standing crops;
- disinfect the water supply and equipment used in the culture facility;
- expedite removal of dead and moribund fish;
- handle tilapias gently during stocking, sampling, etc.;
- use prophylaxis during and after handling to aid wound healing.

Diseases are also better managed by understanding the requirements of the disease agent. Tilapia hatcheries use saltwater at 5–10‰ to control ciliate protozoan parasites. Marine flatworm may be controlled by the use of low-salinity water. Although this type of treatment is possible in a land-based system, it is impossible or very difficult for seacages, which must be towed into low-salinity water, if this is feasible. So, a novel method of using tropical cleaner fish such as the cleaning goby (*Gobisoma genie*)

Table 16.12 Chemotherapeutic treatments for common infectious diseases of cultured tilapias.

Drug/chemical	Concentration	Duration	Treatment purpose
Potassium permanganate	2–4 ppm	Indefinite immersion	Prophylaxis, external bacterial infections such as septicaemia and columnaris, and parasites
Formalin	20–25 ppb	Indefinite immersion	
Copper sulphate	0.5–3 ppm	Indefinite immersion	
Potassium permanganate	4–10 ppm	1-h immersion	
Formalin	167 ppb	1-h immersion	
Chloramine-T	10–20 ppm	1-h immersions for 3 days	External bacterial infections
Terramycin	50 mg/kg/day	In feed for 12–14 days; 21-day withdrawal period	Systemic bacterial infections such as vibriosis, edwardsiellosis and streptococcosis
Romet 30	50 mg/kg/day	In feed for 5 days; 42-day withdrawal period	
Erythromycin	50 mg/kg/day	In feed for 12 days	
Amoxycillin	50–80 mg/kg/day	In feed for 10 days	
Hydrogen peroxide	500 ppb	1-h immersion	Fungi

Modified from Plumb (1999) with permission from the World Aquaculture Society.

and the neon goby (*Gobisoma oceanops*) has been found effective in reducing the parasite load in such conditions.

16.10 HARVEST, PROCESSING AND MARKETING

Harvest size of tilapias varies from 150 g to over 600 g, depending upon the market requirements. Some markets, such as in the Philippines, prefer smaller size tilapias because the typical portion size is a whole fish per person. So, a family of four or five members prefers to buy four or five fish weighing a total of ~1 kg for a meal. Larger harvest sizes are required for filleting. Tilapias have relatively low dressing yields: only 50–55% of the fish is available as dressed carcass and 25–30% as fillets. So a tilapia weighing more than 500 g is required to produce a fillet weighing 100 g.

Seining is the most common method used to harvest tilapias from ponds. It is difficult, however, to harvest tilapias by seining alone because they tend to jump over the seine or escape underneath the seine. Partial or complete draining of the ponds is required for a complete harvest. Tilapias reared in more intensive systems are relatively easier to harvest because of the smaller size of the system and the high density of fish.

Tilapias reared in ponds often develop an off-flavour problem due to metabolites of bacteria and blue-green algae that thrive in nutrient-rich ponds. This problem is solved by stopping feeding and flushing water through ponds 3–7 days ahead of harvest. Alternatively, the fish could be harvested and stocked in tanks with a flow-through water supply.

Harvested tilapias may be sent directly to the market or to a processor for further processing and packing. When market conditions dictate that the tilapias are sold alive, extreme care must be exercised in harvesting and transporting the fish. Typically, the fish are transported in metal or plastic holding tanks with adequate aeration. Fish for further processing may also be transported alive or in ice. Tilapias are processed in several different ways depending upon market requirements. The whole fish may be cleaned and frozen whole or frozen as fillets. However, fresh-chilled products fetch higher prices than frozen products in most markets. For chilling, the fish may be gutted and de-headed before refrigerated packing, or converted into fillets. Fresh-chilled products have a shelf-life of 10–15 days after slaughter.

Market value of tilapias ranges widely. Although whole tilapias in a local market in a developing country may cost less than US$1/kg, the retail price of fresh whole tilapia in a developed country may exceed US$10/kg (Fig. 16.16). This enormous range of prices provides opportunities for producers as well as processors to maximise their returns by keeping their operations flexible, which in turn is beneficial from an economic perspective (section 12.5). Producers may serve the entire spectrum of the market or

Fig. 16.16 Seafood stand, with tilapia, at the Pike Market, Seattle, Washington State, USA. The sign says 'FRESH WHOLE TILAPIA'.

target a specific market niche and optimise their resources to meet the needs of the chosen niche.

Nutritive value of tilapia to humans is regarded as low by some nutritionists based on data that the fish has low levels of *n*–3 fatty acids and high levels of *n*–6 fatty acids, especially arachidonic acid (Weaver *et al.* 2008). This assessment is not widely accepted by other nutritionists who point out that the overall fat content of tilapia is low, and therefore its fatty acid levels cannot be compared with oily fish such as salmon (Harris 2008). Further, it is pointed out that the association between arachidonic acid intake and poor heart health has not been unequivocally established. Table 16.13 presents comparative nutritive values of tilapia, salmon and chicken breast meat to show that tilapia has lower *n*–3 fatty acids than salmon, but lower fat, higher *n*–3 fatty acids and lower *n*–6 fatty acids than chicken breast. Recently, it has been shown that tilapia reared in semi-intensive pond systems have higher levels of *n*–3 fatty acids than tilapia intensively reared in tanks (Karapanagiotidis *et al.*, 2006). Overall, tilapia presents a food option that is high in protein, and low in fat and cholesterol, even though it does not have a high level of *n*–3 fatty acids like oily fish such as salmon.

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Table 16.3 Selected nutrients provided by 100-g raw portions of tilapia, farmed Atlantic salmon, and chicken breast meat (source: Nutrient Data Laboratory of the United States Department of Agriculture).

Nutrient	Tilapia	Farmed Atlantic salmon	Chicken breast meat
Energy (kcal)	96	208	263
Protein (g)	20.08	20.42	14.7
Total lipid (g)	1.70	13.42	15.75
Total saturated fatty acids (g)	0.77	3.05	3.26
Total monounsaturated fatty acids (g)	0.65	3.77	6.48
Polyunsaturated fatty acids (g)			
1. Linoleic acid (*n*–6)	0.21	0.9	3.2
2. Linolenic acid (*n*–3)	0.043	0.167	0.14
3. Arachidonic acid (*n*–6)	0.003	0.06	0
4. Eicosapentaenoic acid (*n*–3)	0.007	0.862	0
5. Docosahexaenoic acid (*n*–3)	0.113	1.104	0
Cholesterol (mg)	50	55	41

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