# Yellowtail, *Seriola quinqueradiata*

10

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## Introduction

Yellowtail (*Seriola quinqueradiata*) is one of the economically important finfish for aquaculture in Japan. Commercial production of yellowtail began in the 1950s, and production has expanded rapidly since the 1960s. The total production of yellowtail in Japan was about 140,000 tons in 1997, representing about 70% of the total production of aquaculture marine finfish in Japan. Fish are normally cultured in floating net cages in coastal zones. Since artificial seed production has not been used for yellowtail, fingerlings of yellowtail, known as *mojyako* in Japanese, are caught in the wild while they are schooling along coastal currents with drifting objects (e.g. algae). Those fingerlings (< 10 g) are caught in spring and sold to growers when the fish has grown to 50–100 g in body weight. The duration of the growth period depends on the desired market size of the fish. Most yellowtail growers target a market size of about 2–5 kg, while some growers even raise the fish to a weight of 7–8 kg. A typical growth pattern and target size for the market are shown in Fig. 10.1.

Commercial yellowtail culture is done in sea cages made of nylon netting or metal. The size and number of cages vary. A relatively small-scale production site may have five cages of 10 m × 10 m × 8 m in size, while a relatively larger-scale production site often has more than 20 cages of 18 m × 22 m × 8 m or 12 m × 12 m × 12 m in size (H. Matsumoto, Kochi, 2000, personal communication). The optimum water temperature for yellowtail to grow is 20–29°C. Food consumption of yellowtail is drastically reduced at water temperatures below 17°C, particularly when a dry diet is fed. Optimum water salinity for yellowtail is 29.8 to 36.3 p.p.t. (with a chloride concentration of 16.5–20.1%) (Inoue, 1983). A dissolved oxygen (DO) level of more than 5.7 mg $l^{-1}$ is desirable for good growth. Growth reduction and abnormal behaviour have been reported when the DO level becomes lower than 4.3–5.7 and 2.9–4.3 mg $l^{-1}$, respectively. The stocking density of yellowtail depends on cage-site conditions, such as temperature, DO, mesh size and water exchange rate in the cage. The

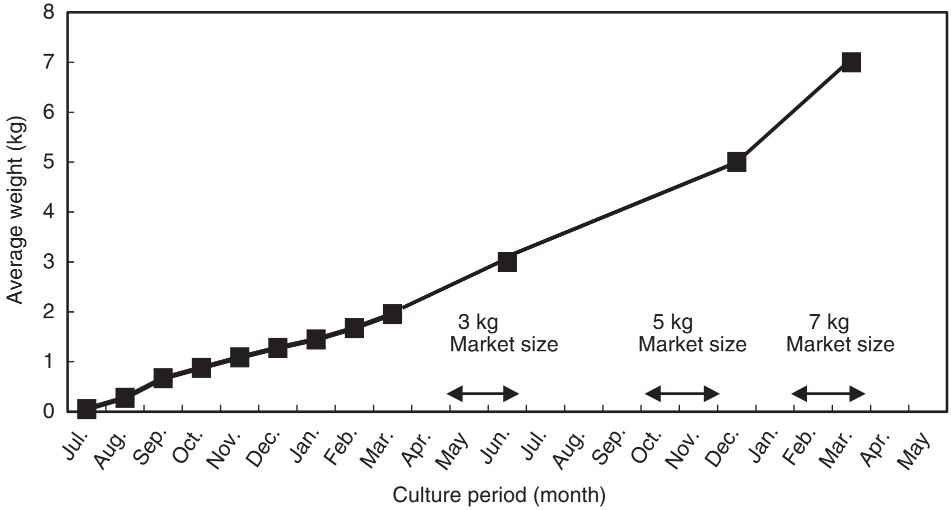


**Fig. 10.1.** Typical growth curve of farmed yellowtail.

recommended densities for various growth stages are 6.9, 5.6, 8.0 and 7.0 kg $m^{-3}$ for individual fish body weight of 0.05, 0.2, 0.8 and 3.5 kg, respectively. However, in practical situations, the fish are often kept at densities of more than twice these densities.

## Nutrient Requirements

### *Protein and amino acids*

The protein requirement of fish is affected by several factors, such as growth rate, nutritional quality of the ingredients (protein digestibility and amino acid composition) and digestible energy content of the diet. Providing the optimum dietary energy levels for animals is important because a diet deficient in energy will result in the use of dietary protein for energy rather than for protein synthesis. On the other hand, excess energy in the diet may result in decreased nutrient intake by the animal or excessive fat deposition in the body. Therefore, a balanced energy-to-protein ratio (E/P) is important. Table 10.1 shows E/P values for yellowtail derived from reported optimum growth rates under various temperature and growth-stage conditions. These values indicate that a crude protein-to-gross energy ratio (CP/GE) of 20–26 g $kJ^{-1}$ ensures good growth, with a feed conversion ratio (FCR) of approximately 1.0 for yellowtail at a high temperature, while the value tends to be lower (about 20) in a cooler water temperature. Quantitative requirements of essential amino acid requirements for methionine, lysine, arginine and histidine are given in Table 10.2. These values were obtained by feeding graded levels of the respective crystalline amino acids in

**Table 10.1.** Estimated values of crude protein : gross energy (CP : GE) ratio based on the best growth from published results (modified from Talbot *et al.*, 1999b). Energy equivalents (kJ $g^{-1}$ of protein: 23.4, lipid: 39.8 and nitrogen-free extract: 17.2 were used (Cho *et al.*, 1982).

| Reference | Feed type | Water temp.* (°C) | Rearing period (days) | Start–end BW (g) | SGR† (% bw $day^{-1}$) | FCR† | PER§ | CP (% in diet) | CL (% in diet) | GE (mJ $kg^{-1}$) | CP : GE (g $mJ^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Start feeding before summer | | | | | | | | | | | |
| Takeuchi *et al.* (1992) | EP | 19–22 | 30 | 1.8–16.4 | 7.4 | 0.87 | 2.3 | 53.6 | 15.6 | 20.7 | 25.9 |
| Takeuchi *et al.* (1992) | EP | 20–24 | 35 | 3.7–35.9 | 6.5 | 1.03 | 1.9 | 55.2 | 10.3 | 18.6 | 29.7 |
| Masumoto *et al.* (1997) | SMP | 23–26 | 40 | 12–120 | 5.6 | 1.08 | 1.8 | 52.0 | 16.0 | 22.0 | 23.7 |
| Watanabe *et al.* (1998) | EP | 24 | 45 | 13.1–158 | 5.5 | 0.89 | 2.4 | 50.4 | 24.6 | 24.0 | 20.9 |
| Sakamoto *et al.* (1995) | EP | 25 | 36 | 40–179 | 4.2 | 1.00 | 2.2 | 54.0 | 20.4 | 23.1 | 23.5 |
| Viyakarn *et al.* (1992) | EP | 25 | 36 | 39–179 | | 1.00 | 2.0 | 54.0 | 22.0 | 23.5 | 23 |
| Start feeding in summer | | | | | | | | | | | |
| Shimeno *et al.* (1980) | SMP | 26–29 | 30 | 106–290 | 3.4 | 1.42 | 1.3 | 52.6 | 15.2 | 21.5 | 24.5 |
| Shimeno *et al.* (1985) | SMP | 26–29 | 30 | 88–214 | 3 | 1.36 | 1.3 | 57.1 | 16.2 | 21.6 | 26.4 |
| Takeda *et al.* (1975) | SMP | 25–29 | 28 | 65–201 | 4 | 1.19 | 1.3 | 71.0 | 8.0 | 20.0 | 25 |
| Start feeding after summer | | | | | | | | | | | |
| Watanabe *et al.* (1998) | EP | 27–22 | 64 | 130–341 | 1.5 | 1.41 | 1.5 | 50.4 | 24.6 | 24.0 | 20.9 |
| Sakamoto *et al.* (1995) | EP | 25–15 | 99 | 425–1240 | 1.4 | 1.60 | 2.2 | 50.7 | 26.0 | 24.3 | 21.1 |
| Viyakarn *et al.* (1992) | EP | 26–21 | 112 | 365–759 | 0.7 | 2.63 | 0.77 | 54.0 | 20.0 | 23.1 | 23.4 |
| Watanabe *et al.* (1992) | EP | 25–28–18 | 97 | 160–688 | 1.5 | 1.40 | 1.6 | 49.5 | 24.5 | 23.6 | 21 |
| Watanabe *et al.* (1992) | EP | 21–28–20 | 182 | 1190–3260 | 0.6 | 2.13 | 1.1 | 48.3 | 29.4 | 24.8 | 19.5 |

* Order of values indicate direction of water temperature change during the experiment.
† PER = ((Ln end wt – Ln start wt)/days duration of experiment) × 100.
‡ g feed fed/g wt gain.
§ g wt gain/g protein fed.
EP, extruded type pellets; SMP, single moist pellets made from mash, oil and water; PER, protein efficiency ratio; CL, crude lipid; SGR, specific growth rate.

a test diet containing a mixture of intact protein sources such as fish-meal and soy protein. The amino acid profile of the test diet was similar to that of fish muscle. Signs of gross deficiency were observed in fish fed a diet with the lowest level of methionine (0.57% of the diet$^{-1}$). These fish exhibited bilateral cataracts within 20 days after the start of the feeding study. To meet the amino acid requirement, it is important to know the protein and amino acid availability from protein ingredients for yellowtail. The values of protein digestibility and amino acid availability are presented in Tables 10.3 and 10.4.

## Energy

It is generally believed that fish, like other animals, control their feed intake in order to meet their energy intakes in tune with their growth rates (Kaushik and Médale, 1994). Thus, energy requirement is an essential factor in the formulation and feeding of feed for efficient fish production. Masumoto *et al.* (1997) determined the energy requirement of juvenile yellowtail (23–26°C, initial body weight (BW) 12 g and final BW 120 g) for maintenance and maximum gain. The estimated maintenance energy level based on body composition analysis for fasting fish was 134 kJ kg$^{-1}$ BW day$^{-1}$, and the level for zero growth was estimated from the results of feeding experiments to be 214 kJ kg$^{-1}$ BW day$^{-1}$. The energy

**Table 10.2.** Quantitative amino acid requirements of yellowtail. Requirement values are expressed as per cent of diet. In parentheses, the numerators are requirements as per cent of dietary protein and the denominators are per cent of crude protein in the diet.

| Amino acid | Requirement | Reference |
|---|---|---|
| Arginine | 1.43–1.63 (3.40–3.88/42) | Ruchimat *et al*. (1998) |
| Histidine | 0.65–0.85 (1.49–1.95/43) | Ruchimat (1998) |
| Lysine | 1.78 (4.13/43) | Ruchimat *et al*. (1997b) |
| Methionine | 1.11 (2.56/43) | Ruchimat *et al*. (1997a) |

**Table 10.3.** Apparent crude protein (CP) and gross energy (GE) digestibility (%) for feedstuffs commonly used in yellowtail diets* (T. Masumoto, unpublished).

| | Apparent digestibility (%) of | |
|---|---|---|
| | CP | GE |
| Fish-meal (moist pellets) | 89 | ND |
| Fish-meal (extruded pellets) | 84 | 83 |
| Maize-gluten meal | 37 | 33 |
| Meat bone-meal | 80 | 82 |
| Meat meal | 97 | 99 |
| Poultry feather meal | 68 | 70 |
| Soybean meal | 93 | 62 |

* Measured for more than 20 fish.
ND, not determined.

requirement for maximum growth based on the relationship between growth rate and energy intake was estimated to be 772 kJ $kg^{-1}$ BW $day^{-1}$. These values are higher than those for carp, *Cyprinus carpio*, or rainbow trout, *Oncorhynchus mykiss*. For example, the maintenance energy requirement is 40–60 kJ $kg^{-1}$ BW $day^{-1}$ for carp (Ohta and Watanabe, 1996b) and about 90 kJ $kg^{-1}$ BW $day^{-1}$ for rainbow trout (Akiyama and Nose, 1980; Ohta and Watanabe, 1996a). The energy requirement for maximal growth of rainbow trout is 335–377 kJ $kg^{-1}$ BW $day^{-1}$ (Ohta and Watanabe, 1996a).

The energy requirements for maximal growth at various water temperatures and growth stages can be estimated by recalculating growth performance results from available published reports (Table 10.5). Expressed in terms of per unit of weight gain, the requirement would be about 2000, 3000 and 4000–5000 kJ 100 $g^{-1}$ for fish weighing < 200, 200–300 and > 500 g, respectively. Younger fish require less energy per unit weight gain than do older fish. Expressed in terms of daily requirement, the values are about 700–1000, 800–1000 and 300–500 kJ $kg^{-1}$ BW $day^{-1}$, respectively. These data suggest that the energy requirement is more affected by water temperature than by the growth stage of fish. The energy requirement of fish should be met by the digestible energy content in the diet. Therefore, measurements of the digestible energy of each

**Table 10.4.** Apparent amino acid and protein digestibility (%) of some dietary ingredients (Masumoto *et al*., 1996). Values are mean (± SD) of two replications.

| Amino acids | Brown fish-meal | Casein | Meat meal | Soybean-protein conc. | Maize-gluten meal | Full-fat soybean meal |
|---|---|---|---|---|---|---|
| Alanine | 89.7 ± 1.3 | 94.5 ± 1.1 | 86.0 ± 0.3 | 84.9 ± 2.1 | 47.3 ± 9.8 | 77.3 ± 5.4 |
| Arginine | 92.5 ± 2.1 | 96.0 ± 0.6 | 82.2 ± 1.5 | 89.9 ± 3.9 | 47.6 ± 9.4 | 85.4 ± 5.8 |
| Aspartic acid | 89.3 ± 3.3 | 95.5 ± 0.8 | 79.2 ± 1.1 | 90.3 ± 1.1 | 44.1 ± 9.3 | 82.0 ± 6.6 |
| Cysteine | 90.3 ± 2.5 | 96.2 ± 0.6 | 43.8 ± 8.5* | 87.2 ± 9.9 | 47.1 ± 10.5 | 85.0 ± 10.5 |
| Glutamic acid | 91.9 ± 3.0 | 98.2 ± 0.2 | 81.6 ± 1.0 | 92.0 ± 2.1 | 48.8 ± 9.6 | 86.4 ± 5.6 |
| Glycine | 92.0 ± 1.5 | 91.6 ± 1.0* | 89.8 ± 0.4* | 81.8 ± 4.6 | 42.4 ± 8.2 | 74.8 ± 7.6 |
| Histidine | 93.0 ± 2.9 | 98.3 ± 0.3 | 86.0 ± 0.4 | 92.5 ± 0.1 | 50.8 ± 8.8 | 53.0 ± 19.7* |
| Isoleucine | 90.2 ± 3.3 | 97.3 ± 0.4 | 75.9 ± 0.9 | 87.9 ± 0.9 | 45.0 ± 9.7 | 79.3 ± 6.3 |
| Leucine | 90.7 ± 3.1 | 97.7 ± 0.5 | 77.5 ± 1.2 | 86.9 ± 1.8 | 46.5 ± 10.4 | 78.0 ± 7.1 |
| Lysine | 93.1 ± 2.9 | 98.0 ± 0.4 | 85.0 ± 0.6 | 91.2 ± 1.4 | 47.6 ± 8.6 | 83.4 ± 6.2 |
| Methionine | 92.2 ± 3.2 | 98.1 ± 0.4 | 83.8 ± 0.5 | 86.8 ± 1.0 | 50.2 ± 9.8 | 76.0 ± 7.3 |
| Phenylalanine | 88.8 ± 3.1 | 97.4 ± 0.6 | 78.4 ± 1.0 | 88.9 ± 0.2 | 47.1 ± 10.4 | 79.4 ± 7.3 |
| Proline | 69.9 ± 7.0* | 98.8 ± 0.2 | 87.0 ± 0.5 | 88.9 ± 2.4 | 51.1 ± 9.9 | 82.6 ± 7.3 |
| Serine | 89.6 ± 2.6 | 96.8 ± 0.3 | 73.8 ± 1.7 | 86.1 ± 4.3 | 46.0 ± 10.0 | 79.0 ± 7.4 |
| Threonine | 88.9 ± 2.8 | 95.3 ± 0.4 | 73.8 ± 1.9 | 83.0 ± 2.6 | 43.4 ± 8.0 | 74.8 ± 5.8 |
| Tyrosine | 90.1 ± 3.4 | 98.3 ± 0.3 | 76.3 ± 1.4 | 89.1 ± 3.7 | 50.6 ± 9.5 | 82.0 ± 7.3 |
| Valine | 85.7 ± 2.7 | 95.2 ± 0.1 | 72.3 ± 1.4* | 79.7 ± 0.6 | 40.0 ± 6.5 | 69.1 ± 5.1 |
| Average | 89.3 | 96.7 | 78.4 | 87.5 | 46.8 | 78.1 |
| APD | 88.7 ± 0.0 | 95.4 ± 0.6 | 80.3 ± 0.0 | 87.3 ± 2.3 | 49.7 ± 9.1 | 83.2 ± 2.4 |

* Significantly different ($P < 0.05$) from APD within the same column.
APD, apparent protein digestibility.

**Table 10.5.** Requirements of CP and GE values estimated from published best growth results.

| Reference | Water temp. (°C) | DFR (%) | FCR | Req. for 100 g BW gain* CP (g) | Req. for 100 g BW gain* GE (kJ) | Req. for 1 kg BW fish per day† CP (g) | Req. for 1 kg BW fish per day† GE (kJ) |
|---|---|---|---|---|---|---|---|
| Start feeding before summer | | | | | | | |
| Takeuchi *et al.* (1992) | 19.0–22.4 | 4.4 | 0.87 | 47 | 1801 | 24 | 911 |
| Takeuchi *et al.* (1992) | 20.2–24.1 | 4.5 | 1.03 | 57 | 1916 | 25 | 837 |
| Masumoto *et al.* (1997) | 23–26 | 4.3 | 1.08 | 56 | 2376 | 22 | 946 |
| Watanabe *et al.* (1998) | 24 | 3.3 | 0.89 | 45 | 2136 | 17 | 792 |
| Sakamoto *et al.* (1995) | 25 | 3.6 | 1.00 | 54 | 2310 | 19 | 832 |
| Viyakarn *et al.* (1992) | 25 | 3.5 | 1.00 | 54 | 2350 | 19 | 823 |
| Start feeding in summer | | | | | | | |
| Shimeno *et al.* (1980) | 26–29 | 4.6 | 1.42 | 75 | 3053 | 24 | 989 |
| Shimeno *et al.* (1985) | 26–29 | 4.1 | 1.36 | 78 | 2938 | 23 | 886 |
| Takeda *et al.* (1975) | 25–29 | 4.8 | 1.19 | 84 | 2380 | 34 | 960 |
| Start feeding after summer | | | | | | | |
| Watanabe *et al.* (1998) | 27.3–21.8 | 2.8 | 1.41 | 71 | 3384 | 14 | 672 |
| Sakamoto *et al.* (1995) | 25–15 | 2 | 1.6 | 81 | 3888 | 10 | 486 |
| Viyakarn *et al.* (1992) | 26–20.6 | 2.8 | 2.63 | 142 | 6075 | 15 | 647 |
| Watanabe *et al.* (1992) | 25–28–18 | 2.4 | 1.40 | 69 | 3304 | 12 | 566 |
| Watanabe *et al.* (1992) | 21–28–20 | 1.4 | 2.13 | 103 | 5282 | 7 | 347 |

* 100 g × FCR × CP (g) or GE (kJ) content values given in Table 10.1.
† 1000 g × DFR × CP (g) or GE (kJ)/1000 content values given in Table 10.1.
DFR, daily feeding rate.

ingredient are essential for establishing an adequate feeding rate for fish. Digestible energy values for common ingredients used in yellowtail culture are given in Table 10.3. The value for maize-gluten meal is much lower than that reported for other fish. The apparent digestibility for GE for the soybean meal is lower than that for CP, suggesting that there are undigestible carbohydrates for yellowtail in soybean meal.

## *Lipids and fatty acids*

Yellowtail require the n-3 rather than the n-6 series of fatty acids (Furukawa *et al.*, 1966; Tsukahara *et al.*, 1967). Moreover, unlike rainbow trout or other freshwater fish species, yellowtail are unable to use 18:3 (n-3) as an essential fatty acid (EFA) and require n-3 highly unsaturated fatty acids (HUFA) with 20 or more carbon atoms (Yone, 1978). A comparison of the effect of various fish-oil sources on the growth of yellowtail (40 g) showed that oil high in n-3 HUFA (squid liver oil, sardine oil and skip-jack oil) had better nutritional value than that of oil containing low levels of n-3 HUFA (pollack liver oil and herring oil) (Deshimaru *et al.*, 1982a). The optimum dietary lipid level for young yellowtail (45–80 g) was 9% when squid oil containing 27% n-3 HUFA was used and 15% when pollack liver oil containing 13% n-3 HUFA was used (Deshimaru *et al.*, 1982b). Based on these results, the n-3 HUFA requirement for yellowtail is estimated to be approximately 2% of the diet (Deshimaru *et al.*, 1982b). It appears that docosahexaenoic acid (DHA), 22:6n-3, is physiologically more important than eicosapentaenoic acid (EPA), 20:5n-3, at the larval stage of yellowtail. When yellowtail larvae were fed either EPA- or DHA-fortified rotifers, both groups of fish showed equally good survival. However, larvae fed EPA-enriched rotifer showed significantly poor results for activity tests compared with larvae fed DHA-enriched rotifer (Furuita *et al.*, 1996). They suggested that fortification with DHA is necessary for the live food for yellowtail because live foods, such as rotifers or *Artemia*, do not contain enough DHA to meet the EFA requirement of larval stage.

## Carbohydrates

The optimum carbohydrate level for yellowtail was investigated by feeding a fish-meal-based diet supplemented with gelatinized starch at levels of 0, 10, 20 or 40% (Shimeno *et al.*, 1979). The growth rate, feed efficiency and energy retention, as well as body fat and glycogen content, were higher in fish fed diets with 10% and 20% starch levels than in fish fed diets with 0% and 40% starch levels. The protein digestibility of fish fed a diet with a starch level of 40% was lower than that of fish fed a diet with 20% starch (56% vs. 78%). Furuichi *et al.* (1986) also reported that the growth rate of fish fed a diet with 20% $\alpha$-starch was similar to that of fish fed a diet with 10% starch, although the feed efficiency was significantly lower in the former group of fish. These results suggested that the optimum gelatinized starch level is less than 20%.

The effects of various carbohydrate sources on the growth rate of yellowtail were also tested. At the 15% inclusion level, the growth of fish fed starch was better than that of fish fed fructose (Shimeno *et al.*, 1979). Yellowtail cannot utilize dietary glucose well. In fact, the digestibility of glucose is higher than that of gelatinized starch, although the growth performance of fish fed glucose is inferior to that of fish fed starch at a 10% dietary level (Furuichi *et al.*, 1986). Carnivorous fish, such as yellowtail, cannot utilize as much dietary carbohydrate as omnivorous fish, such as common carp. This lower ability of carbohydrate utilization is related to the lower amylase activity, carbohydrate metabolism enzyme activity and insulin response. Among these factors, the lower response of insulin secretion seems to be the most responsible. The insulin secretion response is substantially lower and slower in yellowtail than in other fish, such as common carp or red sea bream (*Pagrus major*), as indicated in Fig. 10.2 (Furuichi and Yone, 1981, 1982a,b). It was reported that the plasma insulin level in yellowtail

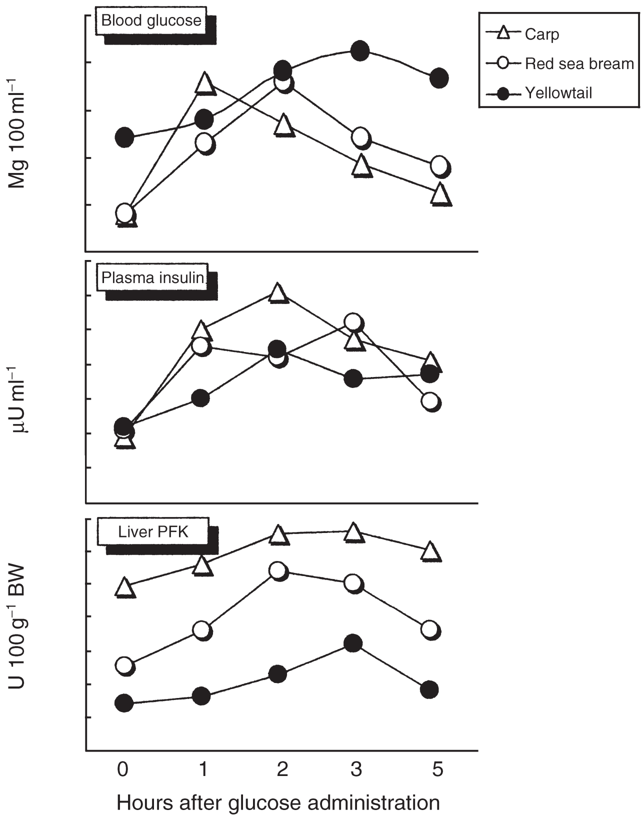


**Fig. 10.2.** Changes in blood glucose, plasma insulin levels and liver phosphofructokinase (PFK) activity of fish after orally administered glucose (Furuichi and Yone, 1981, 1982a,b).

reached a maximum at about 2 h and that the activity of carbohydrate metabolism enzyme activity became high at 2–3 h after administration of glucose. Therefore, most of the dietary carbohydrate, which is absorbed before the rise in enzyme activities, is excreted without being utilized. This suggests that poor utilization of carbohydrate by yellowtail is due to carbohydrate metabolism rather than lower absorption of carbohydrate.

## *Vitamins and minerals*

The quantitative requirements of the yellowtail have been determined by feeding purified casein-gelatin diets containing graded levels of vitamins. The requirement value can vary depending on the criteria used – e.g. maximum weight gain, feed conversion efficiency or tissue vitamin concentration. Table 10.6 shows vitamin requirement values based on maximum growth rate and liver concentration

**Table 10.6.** Vitamin requirements of yellowtail determined based on growth and maximum liver storage expressed as dietary concentration (mg $kg^{-1}$ dry diet) and daily requirement (mg $kg^{-1}$ BW $day^{-1}$) (Hosokawa, 1999).

| | Requirement | | | |
|---|---|---|---|---|
| | (mg $kg^{-1}$ dry diet) | | (mg $kg^{-1}$ BW $day^{-1}$) | |
| Vitamin | Growth | Storage | Growth | Storage |
| Thiamine hydrochloride | 1.2 | 11.2 | 0.4 | 3.6 |
| Riboflavin | 2.9 | 11.0 | 1.0 | 3.6 |
| Pyridoxine hydrochloride | 2.5 | 11.7 | 0.8 | 3.8 |
| Nicotinic acid | 12.0 | – | 3.9 | – |
| Pantothenic acid | 13.5 | 35.9 | 4.5 | 11.5 |
| Inositol | 190 | 423.0 | 53.0 | 116 |
| Biotin | 0.22 | 0.67 | 0.06 | 0.19 |
| Folic acid | 0.8 | 1.2 | 0.24 | 0.39 |
| Choline chloride | 2100.0 | 2920.0 | 615.0 | 856 |
| Cyanocobalamin | 0.053 | – | 0.017 | – |
| Ascorbic acid | 122.0 | – | 34.0 | 34.0 |
| Retinol (as acetate) | 5.68 | – | 5100 | – |
| α-Tocopherol | 119.0 | – | 35.0 | 35.0 |

(Hosokawa, 1999). Vitamin deficiency signs are similar to those reported for other fish species. However, the onset of deficiency is quicker than that in most other species, indicating the fast-growing nature of yellowtail fingerlings (Table 10.7).

The interaction between macronutrients and vitamins was studied. When the dietary protein level was increased from 59% to 79%, the pyridoxine requirement increased by 1.4-fold. On the other hand, the α-tocopherol requirement increased from 35 to 93 mg $kg^{-1}$ and 160 mg $kg^{-1}$ as the dietary lipid level increased from 8% to 15% and 25%, respectively (Hosokawa, 1999).

The effects of megadoses of vitamins E and C on immune responses in yellowtail fingerlings were studied. When the fish were fed diets containing two to five times or 16–50 times the required amount of dietary vitamin E or vitamin C, respectively, phagocytic activity and antibody titre in fish fed those diets increased compared with those in fish fed diets with the required levels of vitamin E or C. As a result, fish fed megadoses of these two vitamins increased their resistance to Pseudotuberculosis and streptococcicosis (Hosokawa, 1999).

There have been only a few studies on the mineral requirements for yellowtail. Hosokawa *et al.* (1985) examined the effects on the growth of yellowtail of casein-based semipurified diets supplemented with various levels of mineral mixture (Halver, 1957). The best growth was obtained from the diet containing an 8% mineral level. Fish fed a diet without the mineral mixture showed an initial loss of appetite, followed by dark coloration, scoliosis, anaemia and death, but these signs were improved by feeding a recovery diet containing

**Table 10.7.** Vitamin deficiency and number of days to develop deficiency signs in yellowtail (Hosokawa, 1999). Common vitamin deficiency signs such as anorexia, reduced growth or increased mortality are not included.

| Vitamin | Deficiency signs | Days |
|---|---|---|
| Thiamine | Dark coloration, congestion in fins and opercula | 24 |
| Riboflavin | Congestion in fins and eyes, dark coloration, cloudy lens | 30 |
| Pyridoxine | Epileptiform fins, convulsions, ataxia | 14 |
| Nicotinic acid | Skin lesions, haemorrhage in body surface, loss of caudal fin | 20 |
| Pantothenic acid | Blue coloration, clubbed gills | 10 |
| Inositol | Dark coloration, ataxia, skin lesions | 20 |
| Biotin | Haemorrhage in fins, opercula and liver | 24 |
| Folic acid | Congestion in fins and opercula, dark coloration, macrocytic anaemia | 24 |
| Choline | Dark coloration, poor feed conversion | 3 |
| Cyanocobalamin | Congestion in fins and opercula, haemorrhagic liver | 25 |
| Ascorbic acid | Scoliosis, dark coloration, ataxia, haemorrhage in body surface, hypochromic anaemia | 20 |
| Vitamin A | Dark coloration, ataxia, haemorrhage in fins and eyes | 19 |
| Calciferol | None | – |
| α-Tocopherol | Dark coloration, ataxia, haemorrhage in fins and opercula | 28 |
| Menadione | None | – |

the mineral mixture (Makino, 1990). In omission tests, some of the deficiency signs described above were observed in fish fed diets devoid of iron and phosphorus, indicating the essentiality of these two minerals (Makino, 1990). The minimum levels of dietary iron and phosphorus were estimated to be about 60–160 mg $kg^{-1}$ and 6.7 g $kg^{-1}$ dry diet, respectively. These values are in agreement with the values reported for red sea bream and Atlantic salmon (*Salmo salar*). It has also been reported that iron-proteinate (a commercial compound binding iron to soybean hydrolysate) was superior to iron citrate or iron sulphate as the iron source (Kubota *et al.*, 1983; Kuwabara *et al.*, 1983).

When yellowtail were fed diets devoid of sodium (Na), potassium (K) and chloride (Cl), they exhibited no apparent deficiency signs. Thus, the yellowtail's requirements for these minerals may be met with absorption of these minerals from sea water by drinking. Fish fed diets devoid of calcium and magnesium showed slightly reduced growth rates and feed efficiency, which may be an indication of the essentiality of these minerals in the diet. The suitable mineral-mixture level was tested in a fish-meal-based diet and it was found to be 1% (Ikeda, 1976). However, the necessity of iron and phosphorus supplementation in a fish-meal-based diet has been reported.

### *Special diets*

It has been suggested that krill meal, especially the astaxanthin in the meal, is an effective component in the reproductive performance of red sea bream brood-stock. Verakunpiriya *et al.* (1997) added a supplement of synthetic astaxanthin instead of krill meal to a practical diet of dry pellets and examined the reproductive performance of yellowtail brood-stock. They found that the supplementation of astaxanthin in dry pellets was effective for brood-stock yellowtail and the optimum level appears to be 30 p.p.m., but egg quality was reduced at levels above 30 p.p.m.

## Feeding Practices

Yellowtail culture had been expanded due to massive catches of low-cost fish used as food, such as sand-lance and sardine. However, in recent years, the catch of these fish has decreased and their cost has therefore increased. This has forced many yellowtail producers to change from feeding fish to the use of a formulated diet. As shown in Fig. 10.3, formulated diet production has increased and the production of dry diet (mainly extruded pellets) is now almost the same as that of mash (mainly used for moist pellets). Feeding extruded pellets for the first year of

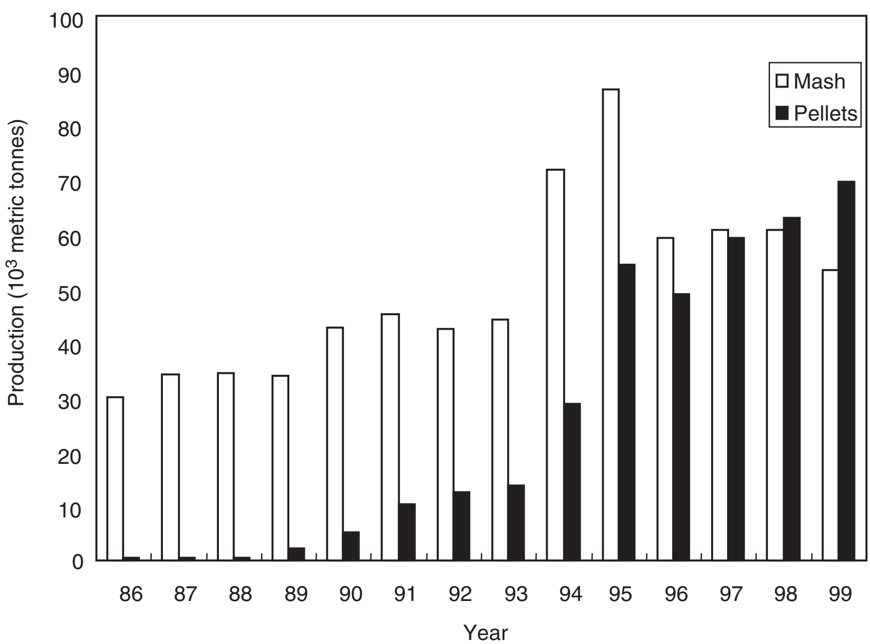


**Fig. 10.3.** Diet production (mash and pellets) for yellowtail (source: Japan Fish Feed Association, Tokyo, Japan).

**Table 10.8.** Typical diet selection pattern for yellowtail production (from Isobe and Matsushita, 1994).

| Pattern | 1st year<br>Spring<br>Apr.–June | Summer<br>Jul.–Sep. | Autumn<br>Oct.–Dec. | Winter<br>Jan.– Mar. | 2nd year<br>Spring<br>Apr.–June | Summer<br>Jul.–Sep. | Autumn<br>Oct.–Dec. | Winter<br>Jan.–Mar. |
|---|---|---|---|---|---|---|---|---|
| 1 | EP | FF | | | | | | |
| 2 | EP | OMP* | FF | | | | | |
| 3 | EP | OMP | | | | | FF | |
| 4 | EP | | | OMP | | | FF | |
| 5 | EP | | | OMP | EP | | FF | |
| 6 | EP | | | | | | FF | |

* Wet portion of OMP is frozen feed fish. The inclusion level of frozen fish depends on fish farmer and water temperature. The frozen fish are partially thawed, ground and combined with a dry mash.
EP, extruded pellets; FF, frozen fish (chopped sardine or sand-lance); OMP, Oregon-type moist pellets.

yellowtail culture during the growing season (high water temperature) is popular. However, the use of fish or moist pellets is still common when water temperatures are reduced (< 15°C) because yellowtail particularly dislike a dry-type diet at such a low temperature. In yellowtail culture, the type of diet used depends on economic factors and culture conditions (for example, winter water temperature) of each fish farm (Table 10.8). It was estimated that formulated diets now account for about 40% of the total food used for yellowtail production. Typical diet composition and recommended feeding rates are shown in Tables 10.9 and 10.10, respectively.

Mechanical methods of delivering diet have recently been introduced into some large-scale yellowtail farms. One important factor in the use of automatic feeders is the setting of the delivery rate. Feed delivery rate was tested for yellowtail (2.6 kg BW) by feeding an extruded pellet (11 mm in diameter, with an average pellet weight of 1.31 g). Fish were fed one meal daily at a water temperature of 28°C and 18°C or one meal every other day at 18°C; the diet-delivering rates were 3.6, 3.4 and 3.9 kg diet 1000 $kg^{-1}$ fish $min^{-1}$, respectively (Talbot *et al*, 1999a,b). This means that the yellowtail consume seven to eight pellets per minute. Moreover, under these conditions, the yellowtail ate more than 80% of the total feed amount within 10 min. This feeding activity is similar to the feeding activity of salmon and trout.

**Table 10.9.** Example of ingredients and nutrient composition of extruded-type pellets for yellowtail (Sakamoto, 1994).

| | % |
|---|---|
| Ingredients | |
| Fish-meal | 55 |
| Krill meal | 10 |
| Wheat flour | 7 |
| Potato starch | 3 |
| Wheat gluten | 3 |
| Mineral mix | 2 |
| Vitamin mix | 2 |
| Feed oil | 18 |
| Nutrient content | |
| Crude protein | 47 |
| Crude lipid | 24 |
| Crude starch | 12 |
| Crude ash | 10 |
| Moisture | 8 |

**Table 10.10.** Suggested feeding rate (% of BW) for yellowtail (Sakamoto Feeds Co., Ltd).

| | Water temperature (°C) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BW (g) | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 10 | | | | | 8.3 | 8.8 | 9.3 | 9.6 | 9.8 | 10 | 10.2 | | | | |
| 20 | | | | | 7.6 | 7.9 | 8.3 | 8.5 | 8.8 | 9 | 9.3 | | | | |
| 30 | | | | | 6.3 | 6.7 | 7 | 7.5 | 7.7 | 7.8 | 8.1 | 8.3 | | | |
| 40 | | | | 4.9 | 5.3 | 5.8 | 6.1 | 6.4 | 6.6 | 6.8 | 7.1 | 7.2 | 7.4 | | |
| 50 | | | | 4 | 4.3 | 5 | 5.3 | 5.4 | 5.6 | 5.8 | 6 | 6.3 | 6.6 | 6.9 | |
| 100 | | | | 3 | 3.1 | 3.5 | 3.8 | 4 | 4.1 | 4.3 | 4.5 | 4.8 | 5.1 | 5.4 | 5.6 |
| 200 | | | 2.2 | 2.3 | 2.6 | 2.7 | 2.8 | 2.9 | 3.3 | 3.5 | 3.6 | 3.9 | 4.1 | 4.4 | 4.6 |
| 300 | | | 2 | 2.1 | 2.4 | 2.5 | 2.6 | 2.8 | 3.2 | 3.3 | 3.3 | 3.4 | 3.7 | 3.8 | 4.1 |
| 400 | | | 1.8 | 1.9 | 2.2 | 2.3 | 2.4 | 2.5 | 2.8 | 2.9 | 3.1 | 3.3 | 3.4 | 3.6 | 3.8 |
| 500 | 1.1 | 1.3 | 1.5 | 1.7 | 2 | 2.1 | 2.3 | 2.3 | 2.5 | 2.6 | 2.8 | 3 | 3 | 3.1 | 3.3 |
| 700 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 1.8 | 2 | 2.1 | 2.2 | 2.2 | 2.3 | 2.5 | 2.6 | 2.6 | 2.7 |
| 1000 | 1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.7 | 1.8 | 1.9 | 1.9 | 1.9 |
| 1250 | 1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.8 | 1.8 | 1.9 | 1.9 |
| 1500 | 0.9 | 1.1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.7 | 1.8 | 1.9 |
| 1750 | 0.9 | 1 | 1.1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.8 | 1.8 |
| 2000 | 0.8 | 0.9 | 1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.8 |
| 2500 | 0.8 | 0.9 | 1 | 1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.7 |
| 3000 | 0.7 | 0.8 | 0.9 | 0.9 | 1 | 1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 | 1.6 | 1.7 | 1.6 |
| 3500 | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 | 1.5 |
| 4000 | 0.6 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 1 | 1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.5 | 1.4 |
| 4500 | 0.5 | 0.7 | 0.7 | 0.8 | 0.9 | 0.9 | 1 | 1 | 1.1 | 1.1 | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 |
| 5000 | 0.5 | 0.6 | 0.7 | 0.8 | 0.8 | 0.8 | 0.9 | 1 | 1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.3 |
| 5500 | 0.4 | 0.6 | 0.6 | 0.7 | 0.8 | 0.8 | 0.8 | 0.9 | 1 | 1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 |
| 6000 | 0.4 | 0.5 | 0.6 | 0.6 | 0.7 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 1 | 1 | 1.1 | 1.1 | 1.1 |

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