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Endocrine mediators of seasonal growth in gilthead sea bream (*Sparus aurata*): the growth hormone and somatolactin paradigm

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Abstract

Regulation of somatolactin (SL) and the somatotropic axis was examined year-around at three different stocking times (spring, summer, and autumn) in a Mediterranean fish, the gilthead sea bream (*Sparus aurata*). The overall timing of plasma growth hormone (GH) increase was similar among trials (late spring–early summer), but the range of variation year-around was different and followed changes in food intake. Total plasma insulin-like growth factor-I primarily followed changes on growth rates, and a close positive correlation between IGF-I and thermal-unit growth coefficient (TGC) was found irrespective of fish stocking time. Thus, the activation of the somatotropic axis preceded always warm growth spurts, whereas the rise of SL in concurrence with low plasma cortisol levels was found at late autumn. This up-regulation of circulating SL titres preceded the winter inhibition of feeding, and it was more severe in big fish (spring and summer stocking times) than in small fish (autumn stocking time), growing with a relative high efficiency during the cold season despite of a severe hypertriglyceridemia and a high hepatosomatic index. These new insights provide good evidence for a different timing of GH and SL increases, and it is likely that the dominant role of SL in energy homeostasis is to be a mediator of the adaptation to fasting after replenishment of body fat stores, whereas GH and IGF-I are perceived as growth-promoting signals in times of food intake and increasing temperature and day-length.

Keywords: Somatolactin; Growth hormone; Insulin-like growth factor-I; Cortisol; Triglycerides; Stocking time; Growth; Fasting; Feeding behaviour; Gilthead sea bream; Teleost

1. Introduction

Information on daily and seasonal calendar is provided by changing patterns of melatonin secretion, which also reflect changes on temperature to ensure that young fish are produced when environmental conditions are most suitable for their survival and growth (see Bromage et al., 2001). Thus, first-feeding fry of mid and higher latitude species are produced when temperature and day-length are increasing in spring, whereas corresponding stages of tropical and sub-tropical fish appear to be timed by rainfalls or movements in oceanic currents. Life-history decisions are, however, not fixed and depend on critical size and energy sufficiency at a specific stage "opportunity window" several months prior to transformation itself. For instance, the decision in salmonids to become smolt or sexually mature (Shearer and Swanson, 2000; Silverstein et al., 1998, 1997) is linked to growth and fat deposition at mid summer and spring. The fine tuning of these decisions needs to be resolved, but circumstantial evidence indicates that the growth hormone (GH)-insulin-like growth factor-I (IGF-I) axis provides an integrated signal for growth and nutrient partitioning year-around. Thus, plasma

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GH levels commonly peak at late spring and summer (Beckman and Dickhoff, 1998; Pérez-Sánchez et al., 1994), and its increase by transgenesis or exogenous GH supply is able to extend the growing period over the cold season (Devlin et al., 2000; Silverstein et al., 2000). However, growth response is strongly influenced by genetic background, and the insertion of GH transgenes into highly domesticated fish (rapidly growing fish farm animals) does not necessarily result in further growth and food intake enhancement, which indicates that growth selection and transgenesis are not always additive processes (Devlin et al., 2001).

In fish and higher vertebrates, GH secretion is controlled by a negative feedback loop involving IGF-I (Blaise et al., 1995; Pérez-Sánchez et al., 1992; Weil et al., 1999), but it remains unclear whether fish GH-IGF-I axis should include other peripheral feedback signals like leptin. This protein has a stimulatory effect upon the mammalian hypothalamus-GH axis, whereas directly or indirectly GH inhibits the synthesis and release of leptin, which has been considered a fuel gauge that broadcasts the level of energy storage (Ahima and Flier, 2000; Reidy and Weber, 2000; Wauters et al., 2000). However, the issue of leptin variation in vertebrate phylogeny is not resolved, and a fish leptin-like protein remains to be fully identified and characterised. Furthermore, both insulin and mammalian leptin preparations have no apparent effects on fish feeding at physiological concentrations, and it has been speculated that metabolic hormones may not be fully integrated in the regulation of feeding in fish (Silverstein and Plisetskaya, 2001).

Regulation of energy balance in fish may also differ from mammals, and the contribution of somatolactin (SL) remains to be established in this regard. This new member of GH and prolactin (PRL) family is produced by the *pars intermedia* of fish pituitary glands, and its involvement on energy mobilisation has been suspected on the basis of plasma changes during reproduction (Kakizawa et al., 1995b; Rand-Weaver et al., 1992; Taniyama et al., 1999), acute stress (Rand-Weaver et al., 1993) and exhaustive exercise (Kakizawa et al., 1995a). A recent study in a Mediterranean fish like gilthead sea bream (*Sparus aurata*) indicates that, in contrast to GH, plasma SL levels increase with the increase in ration size and fatness (Company et al., 2001). In the same study, circulating SL increased during short-term fasting returning to control values when the rise of plasma GH levels was fully accomplished. The regulation of circulating GH and SL is, therefore, opposite and the goal of the present study is to determine whether the timing of seasonal GH and SL elevations also differs. For this purpose, consistency of growth, and endocrine-metabolic changes in GH-IGF-I axis, SL, cortisol, and triglycerides was examined year-around at three different fish stocking times (spring, summer, and autumn).

2. Materials and methods

2.1. Source and maintenance of fish

Gilthead sea bream fingerlings (6–7 months-old, 10–20 g) were obtained from an Atlantic French producer (FMD, Bordeaux). Fish were fed to visual satiety for 3–4 weeks before being randomly and equally allocated into fibreglass tanks supplied with well-aerated running sea water (two renovations per hour). Oxygen content of outlet water was never below 80% saturation, and rearing density of finishing fish varied between 15 and 20 kg/m^3. Day-length and temperature followed natural cycles (40°5′N; 0°10′E) with a water temperature range of 11–14 °C in winter and 20–27 °C in summer. Fish were fed over the full study with a commercial fish-meal based diet (Proaqua-Spain; fixed percentage of body weight), spatially distributed through rearing tanks by hand once (cold season) or twice (warm season) per day. Size of dry pellets increased (1.5, 2, 3, and 5 mm diameter) as fish grew, without changes in proximate composition (dry matter 92%; protein: 49% DM; lipid 22% DM).

2.2. Growth trials

Three long-term growth trials (trial 1: March 1999–May 2000; trial 2: July 1999–August 2000; trial 3: November 1999–October 2000) were carried out at the experimental facilities of the Instituto de Acuicultura de Torre de la Sal, Spain. At each stocking time, 240 fish (average body weight: 22–28 g) were distributed into three replicate tanks of 500 L (0.9 m of diameter, 0.8 m of water depth). On the basis of previous feeding trials, food intake was adjusted weekly to assure a high food conversion ratio (FCR: dry food intake/wet weight gain) and active feeding behaviour. It was determined that this occurs when the entire meal was practically eaten at the water surface.

At monthly intervals following overnight fasting, animals were lightly anaesthetised with 3-aminobenzoic acid ester (100 μg/ml) and collectively weighed to the nearest 0.1–1 g. Thermal-unit growth coefficient (Cho, 1992) was used as a growth descriptor ($\mathrm{TGC} = (W_1^{1/3} - W_0^{1/3}) \times (\sum D^0)^{-1}$, where W_0 and W_1 are the respective initial and final fish weight, and $\sum D^0$ is the thermal sum measured at 10 a.m.). Blood was taken with heparinised syringes from caudal vessels (5 animals per tank; 15 animals per sampling time), and centrifuged at $3000g \times 20$ min at 4 °C. Plasma was collected and separate aliquots were frozen at −30 °C for further analyses. Hepatosomatic index was calculated as follows: (100 × liver weight/fish weight).

2.3. Analyses

Plasma GH and SL levels were assayed by homologous radioimmunoassays (RIA), using recombinant GH

(Martínez-Barberá et al., 1995) and SL (Company et al., 2001) as tracers and standards. Sensitivity and midrange of assays were 0.1–0.15 ng/ml and 2.1–2.3 ng/ml.

The total amount of circulating IGF-I was determined by RIA after acid-ethanol cryoprecipitation of plasma (Shimizu et al., 2000). Recombinant bream (*Pagrus auratus*) IGF-I (100% amino acid similarity with gilthead sea bream IGF-I) was purchased from GroPep, and it was used as tracer and standard. Anti-barramundi (*Lates calcarifer*) IGF-I serum (GroPep) was used as a first antibody (1:8000). The cross reactivity of this antibody with bream IGF-I is near to 100%, as evidenced by curve displacements of bream and barramundi IGF-I. Sensitivity and midrange of the assay were 0.05 and 0.75 ng/ml, respectively.

Plasma cortisol levels were assayed by an enzyme immunoassay kit (Diagnostic Systems Laboratories), based on the competition between unlabelled cortisol and cortisol-horseradish peroxidase for a fixed number of antibody binding sites. Tetramethylbenzidine was used as a chromogen solution with a sensitivity of 1 ng/ml. Plasma triglyceride levels were determined by an enzymatic and colorimetric kit (Sigma No. 337-B).

2.4. Statistics

Data (mean ± SEM) were analysed by one way analysis of variance followed by Student–Newman–Keuls test at a significance level of $P < 0.05$. Tank average values of growth, food intake, and FCR were used as experimental units. Correlation analyses were made by Pearson Product Moment correlations.

3. Results

Fish in trial 1 (spring to spring) grew fast from March 1999 (24.5 ± 0.1 g) to October 1999 (285 ± 1.5 g), reaching 372 ± 3 g in May 2000 (Fig. 1B). At the beginning, food intake increased from 0.9% at early spring to 1.95% at mid summer with an overall FCR of 1.10 ± 0.01. Then, food intake decreased and remained at the maintenance level during late autumn and winter, reaching FCR an overall value of 1.5 ± 0.01 at mid spring. Trial 2 was carried out from summer to summer (Fig. 1C), and fish grew actively from July 1999 (28.03 ± 0.1 g) to October 1999 (129.9 ± 0.5 g), decreasing food intake from 2.5% to 1.2%. Fish then grew slowly during late autumn and winter (FCR = 1.7 ± 0.06), reaching a final body weight of 427.5 ± 8.9 g in August 2000. Food intake of these finishing fish increased from 0.6% at early spring to 1.1% at mid summer with a FCR of 1.27 ± 0.02, which achieved an overall value of 1.31 ± 0.01. Trial 3 was performed from autumn to autumn (Fig. 1D), and food intake of starting fish (22.5 ± 0.1 g) was maintained at 0.6% from November

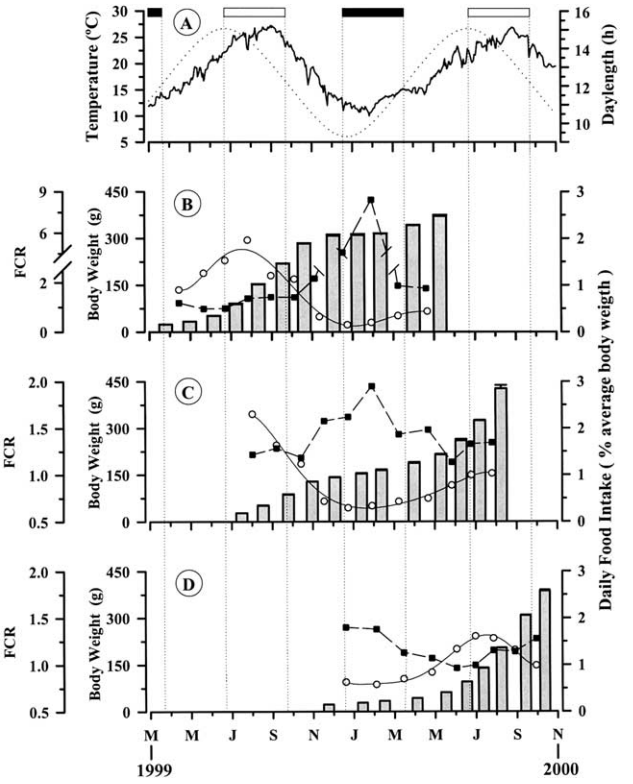

Fig. 1. Seasonal changes on environmental cues (A). Body weight (bars), food intake (white circles), and FCR (black squares) of growing fish during all the experimental period (B, trial 1; C, trial 2; D, trial 3). Data are the means ± SEM of three replicate tanks. Black and white boxes at the top of figure refer to summer and winter period.

1999 to February 2000 with a FCR of 1.38 ± 0.01. Food intake increased then with a maximum at early summer (1.7%), decreasing up to 1% at early autumn. Body weight of finishing fish was 385.9 ± 2 g with a FCR of 1.06 ± 0.01 from February 2000 to August 2000 that reached an overall value of 1.13 ± 0.01 in October 2000. In all trials, size variation for a given rearing tank (11–15% coefficient of variation) did not increase over the full experimental period.

In trial 1, plasma GH levels increased progressively during the first spring period, and a consistent peak was observed at the first half of summer. During the autumn–winter period, circulating GH remained low, increasing again at spring (Fig. 2A). In trial 2, timing of GH increase was similar, and a consistent augmentation in circulating GH titres was observed at the two summer periods (Fig. 2B). In trial 3, the average plasma GH concentration over the full experimental period was the same than in trials 1 and 2, but the range of variation year-around was lower, and its increase at late spring–early summer was not statistically significant (Fig. 2C). Within and among trials, GH responsiveness followed changes in feeding behaviour, and a positive relationship ($r = 0.62$; $P < 0.0001$) between food intake and plasma GH levels was found when correlation analyses were made (Fig. 3).

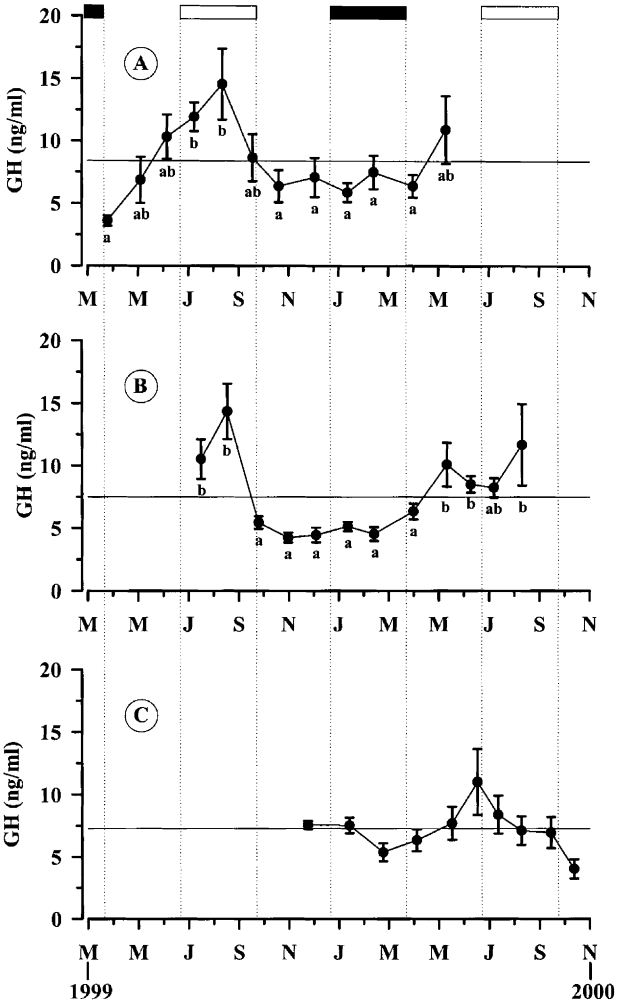

Fig. 2. Seasonal changes on plasma GH levels (A, trial 1; B, trial 2; C, trial 3). Data are the means ± SEM of 12–15 animals per sampling time. Different case letters indicate significant differences at $P < 0.05$ (Student–Newman–Keuls). Black and white boxes at the top of figure refer to summer and winter period. Horizontal line is the average value of data.

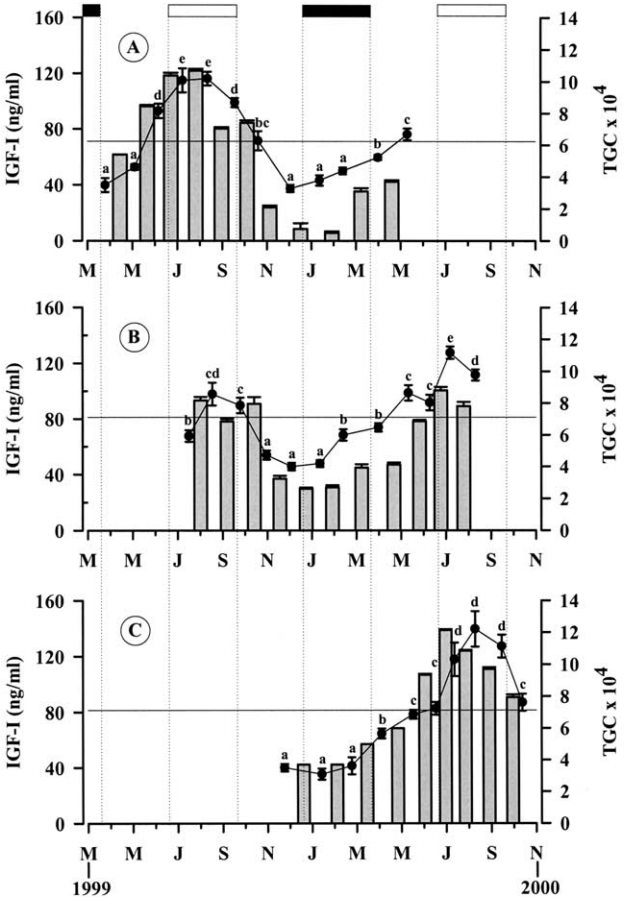

Fig. 4. Seasonal changes on total plasma IGF-I levels (A, trial 1; B, trial 2; C, trial 3). Data are the means ± SEM of 12–15 animals per sampling time. Different case letters indicate significant differences at $P < 0.05$ (Student–Newman–Keuls). Black and white boxes at the top of figure refer to summer and winter period. Horizontal lane is the average value of data.

As shown in Fig. 4, significant changes in plasma IGF-I levels occurred in all trials, and a 2–3-fold increase was found year-around in coincidence with the

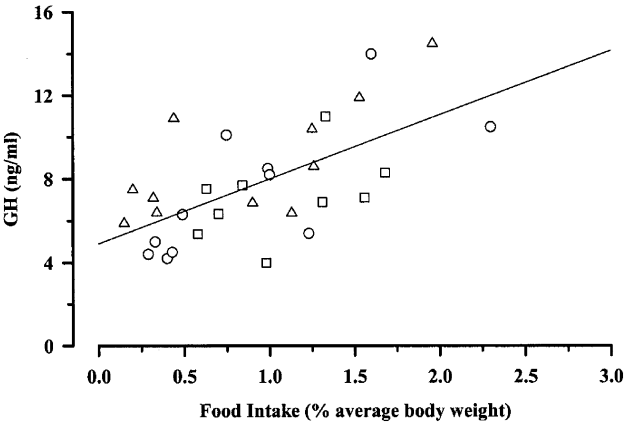

Fig. 3. Correlation analysis of plasma GH levels (average values) and food intake (trial 1: ∇; trial 2: ◯; trial 3: □). Pearson product moment correlation ($r = 0.62$; $P < 0.0001$).

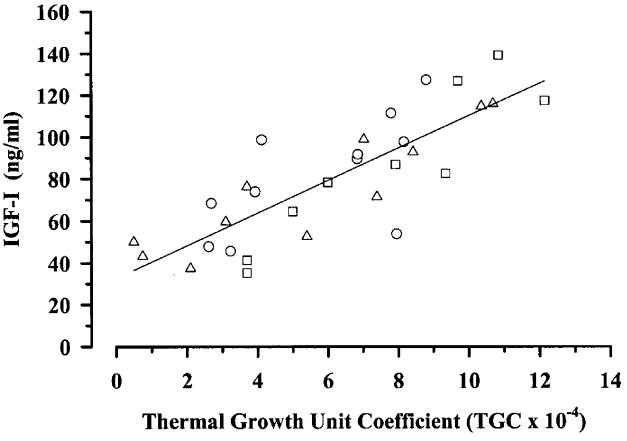

Fig. 5. Correlation analysis of total plasma IGF-I levels (average values) and thermal-unit growth coefficient (TGC) (trial 1: ∇; trial 2: ◯; trial 3: □). Pearson product moment correlation ($r = 0.82$; $P < 0.0001$).

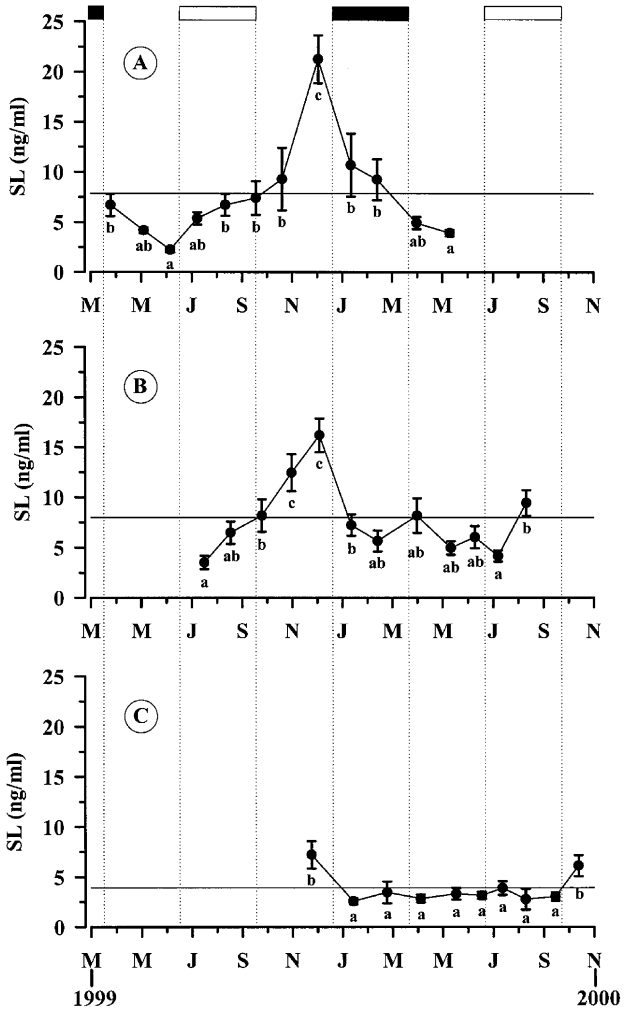

Fig. 6. Seasonal changes on plasma SL levels (A, trial 1; B, trial 2; C, trial 3). Data are the means ± SEM of 12–15 animals per sampling time. Different case letters indicate significant differences at $P < 0.05$ (Student–Newman–Keuls). Black and white boxes at the top of figure refer to summer and winter period. Horizontal lane is the average value of data.

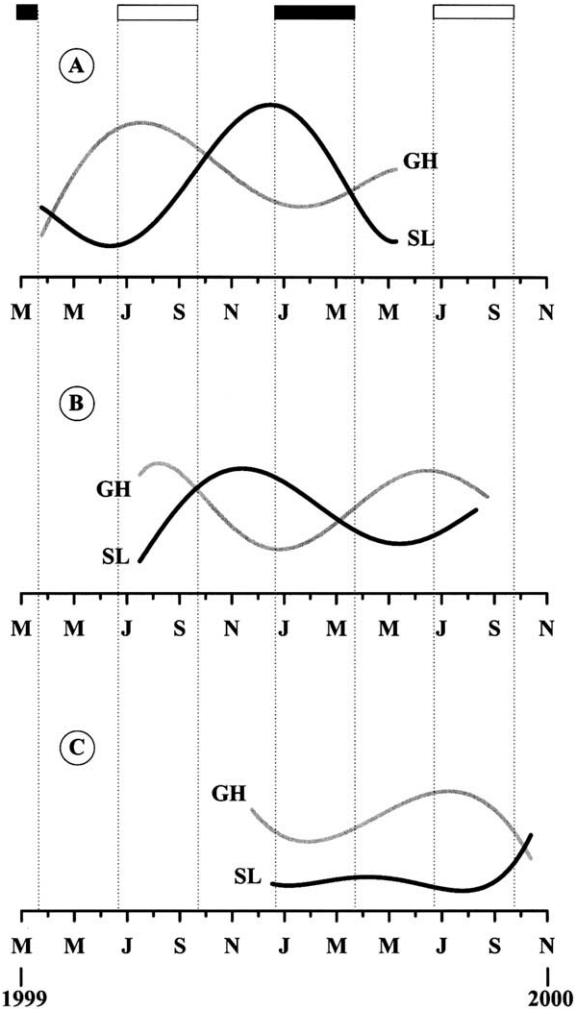

Fig. 7. Summary graph of seasonal GH (grey line) and SL (black line) cycles (A, trial 1; B, trial 2; C, trial 3). Black and white boxes at the top of figure refer to summer and winter period.

increase in growth rates. The highest growth and circulating IGF-I titre was achieved at summer. Indeed, taken together all data, a strong positive relationship ($r = 0.82$; $P < 0.0001$) between IGF-I and TGC was found (Fig. 5).

The overall plasma SL concentration in growing fish of trial 3 was lower than in trials 1 and 2, and minor changes occurred through the experimental period (Fig. 6C). However, both in trial 1 (Fig. 6A) and trial 2 (Fig. 6B), plasma SL levels showed a clear seasonal pattern, which was markedly opposite to that of GH. Thus, the lowest plasma SL concentration was found during the warm period with a 5–10-fold increase at late autumn. The different timing of seasonal GH and SL elevations are summarised in Fig. 7.

In all trials, plasma cortisol levels were low (>5 ng/ml) from late autumn–early spring, increasing largely during the warm season (25–100 ng/ml) (Fig. 8). Circulating triglycerides always peaked during the cold season, although hypertriglyceridemia was more pronounced in small fish (autumn stocking time; trial 3) than in big fish (spring and summer stocking times; trials 1 and 2) (Fig. 9). Correlation analysis with all data showed a strong positive relationships between triglyceridemia and hepatosomatic index ($r = 0.95$; $P < 0.0001$), which achieved a maximum winter value of 3.5% in trial 3 (trial 1, trial 2: 2–2.5%).

4. Discussion

Gilthead sea bream has become one of the most important species for the Mediterranean aquaculture industry, and eggs and larvae are now available year-around for grow-out farmers (Smart and Prickett, 1997). This fish exhibits a diurnal feeding behaviour that shifts its activity from a daylight fluctuation in warm periods

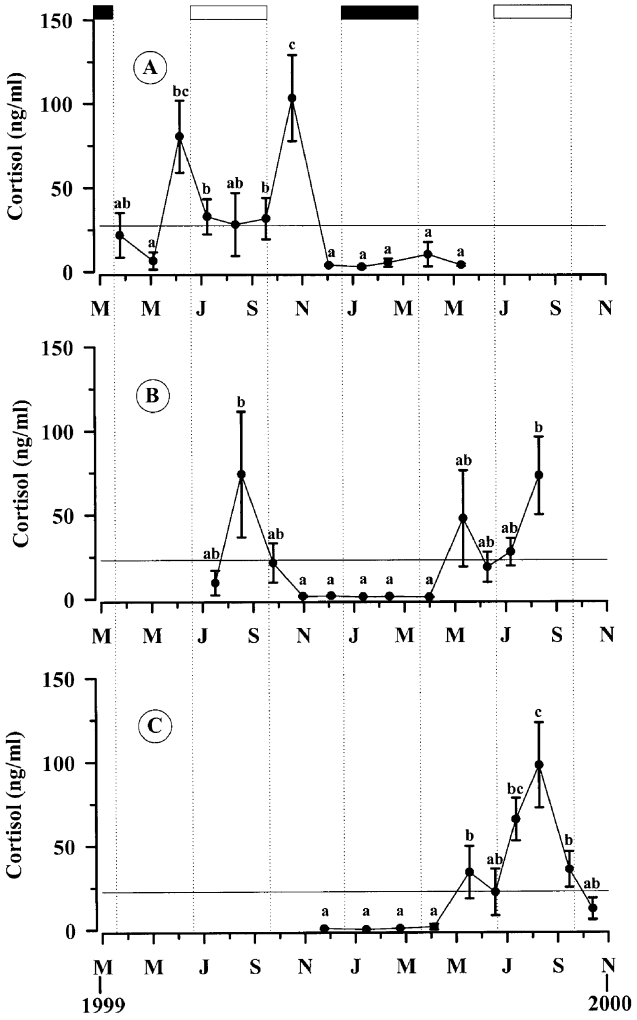

Fig. 8. Seasonal changes on plasma cortisol levels (A, trial 1; B, trial 2; C, trial 3). Data are the means ± SEM of 12–15 animals per sampling time. Different case letters indicate significant differences at $P < 0.05$ (Student–Newman–Keuls). Black and white boxes at the top of the figure refer to summer and winter periods. Horizontal lane is the average value of data.

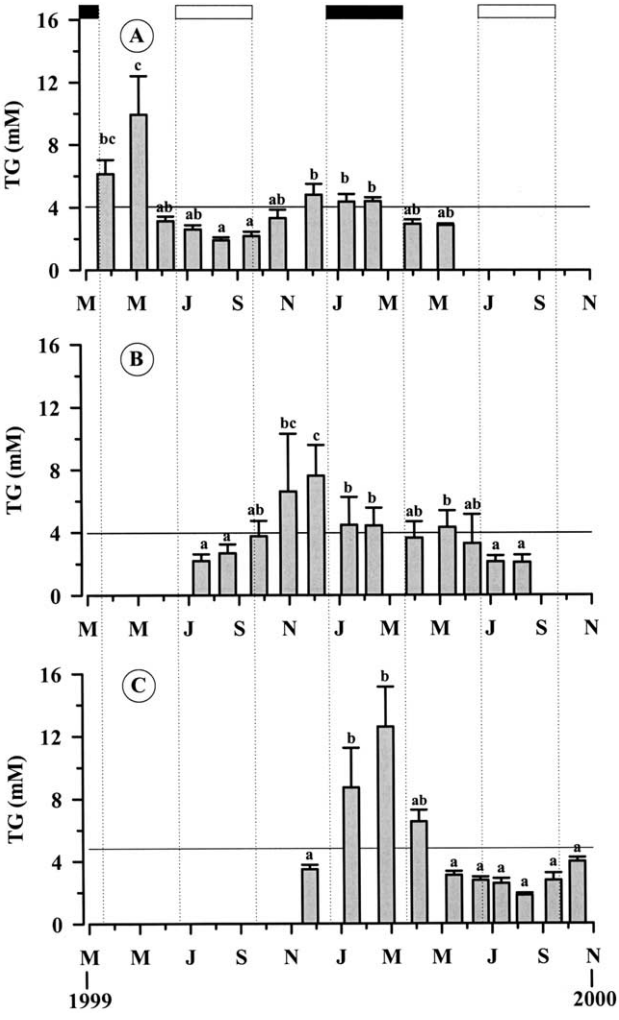

Fig. 9. Seasonal changes on plasma triglycerides (A, trial 1; B, trial 2; C, trial 3). Data are the means ± SEM of 12–15 animals per sampling time. Different case letters indicate significant differences at $P < 0.05$ (Student–Newman–Keuls). Black and white boxes at the top of the figure refer to summer and winter periods. Horizontal lane is the average value of data.

to an afternoon peak in cold periods. However, food intake is poor at temperatures below 16 °C, and there is little growth in our latitude from November to April. Thus, our growing cycles were 1–3 months longer than those found with an average yearly water temperature of 21–23 °C (Canary Islands, Red Sea). However, summer TGCs were clearly in the upper range, when comparisons are made with reference values ($6–10 \times 10^4$; see Kaushik, 1998), which suggests that some compensatory growth occurs after a cold growth stop period. In addition, predetermined rations did not increase size variation, although gilthead sea bream remains still genetically wild and has not been systematically selected for culture suitability (Gorshkov et al., 1997; Knibb et al., 1997). Homogenous growth under restricted fed conditions is also found in other schooling fish, such as European sea bass (*Dicentrarchus labrax*) (Boujard et al., 1996) and whitefish (*Coregognus lavaretus*) (Jobling et al., 1999). However, this is in contrast to observations made in rainbow trout (*Onchorhynchus mykiss*) and salmonids (Jobling and Kosela, 1996; Ryer and Olla, 1996), which are territorial and establish social dominance hierarchies exacerbated when faced with fed restriction.

Fish growth involves an increase in the number and size of muscle fibres, coinciding the fast growth phase of the live cycle with the period of fibre recruitment. In gilthead sea bream, this process is practically stopped at 100 g of body weight (Rowlerson et al., 1995), but fibre recruitment and hypertrophy varies among genetic strains and with a wide variety of nutritional and environmental factors, like temperature and day-length (see Johnston, 1999). Thus, both in this and previous studies (Petridis and Rogdakis, 1996), the autumn season was

the most advantageous time for gilthead sea bream stocking due to the improvement of the overall FCR, which supports the idea that muscle cellularity and final growth performance depend on size and life background history. Indeed, the overall timing of GH increase was similar among trials, but the range of variation year-around was different, probably due to a different energy status and perception of environmental cues. In salmonids, photoperiod has been considered the primary environmental factor affecting GH dynamics, and increasing day-length augments circulating plasma GH during smoltification (McCormick et al., 2000; Nielsen et al., 2001). In gilhead sea bream, plasma GH levels primarily follow changes in day-length (Pérez-Sánchez et al., 1994), but the present study gives evidence for a close relationship between food intake and GH availability, and the up-regulation of circulating GH titres during the warm growing season may be perceived as an energy need rather than a growth signal. This point of view is consistent with previous gilthead sea bream studies, in which plasma GH levels diminished progressively and significantly with dietary energy supply (Company et al., 1999). In tilapia, an inverse relation between food intake and GH has also been reported (Toguyeni et al., 1996), but studies in salmonids failed to demonstrate a down-regulation of GH at greater than maintenance ratios (Pierce et al., 2001; Storebackken et al., 1991). Fine tuning of somatotropic axis varies therefore among fish species, but in vivo and in vitro studies in goldfish (*Carassius auratus*) indicate that neuropeptide Y (NPY) may be an important factor to integrate stimulation of feeding and GH secretion (see Lin et al., 2000).

Seasonal changes on the GH receptor (GHR) population also occur, and the recent molecular cloning of GHRs in turbot (*Scophthalmus maximus*) (Calduch-Giner et al., 2001), goldfish (Lee et al., 2001), and gilthead sea bream (Calduch-Giner et al., 2002) should provide a useful tool to better understand the transcriptional regulation of fish GHRs. In gilthead sea bream, there is, however, evidence that the equinoctial increase in hepatic GH-binding is delayed in relation to GH peak, following changes on growth rates and total plasma IGF-I-like immunoreactivity (Pérez-Sánchez et al., 1994). In the present study, total plasma IGF-I was positively correlated with growth rates, and the persistence of high plasma IGF-I titres over all the warm period may mediate the decrease of plasma GH levels at the second half of summer, overriding other hypothalamic and peripheral GH-stimulatory signals. These findings agree with an increasing number of studies in salmonids, in which total plasma IGF-I is correlated with growth and ration size (Beckman and Dickhoff, 1998; Pierce et al., 2001). However, this relationship is not always found (Devlin et al., 2000; Silverstein et al., 1998), and disappointing results have been attributed to disturbing effects of IGF binding proteins (IGFBP), which inhibit or potentiate IGF-I actions (Duan, 1998; Shimizu et al., 1999). In any case, many of the established hypothesis regarding the GH-IGF-I axis need to be re-examined, since mice with a liver-specific deletion of IGF-I gene grow at a normal rate (see Le Roith et al., 2001). Furthermore, specific measurements of free circulating IGF-I demonstrate similar levels in knockout and control mice, addressing this animal model the question of which tissues secrete the IGF-I that accounts for the remaining total IGF-I and the normal free IGF-I.

Cortisol is the most commonly used indicator of stress in fish (see Wendelaar Bonga, 1997), and a rapid and often severe elevation of plasma cortisol titres occur in response to different stressors (e.g., handling, confinement, poor water quality, and toxicants). It is well-documented that chronic plasma cortisol elevation has negative effects on individual appetite, growth rate, condition factor, and food conversion (Fox et al., 1997; Gregory and Wood, 1999; Pottinger and Pickering, 1992). Furthermore, both in gilthead sea bream (Rotllant et al., 2000a,b) and other fish species (Auperin et al., 1997; Farbridge and Leatherland, 1992; Pickering et al., 1991), the stressful decrease of circulating GH titres follows the increase in plasma cortisol levels. Therefore, as in mammals, cortisol excess may be able to down-regulate fish GH secretion through the increase of hypothalamus-somatostain tone, overriding any concurrent stimulatory effect at the pituitary level (see Giustina and Wehrenberg, 1992). Indeed, corticotropin-releasing hormone (CRH) is a well-known stimulator of adrenocorticotropin-hormone (ACTH), α-melanophore-stimulating hormone (α-MSH), and β-endorphin (Rotllant et al., 2001), but in addition to its releasing action on POMC-peptides, goldfish studies evidence that CRH acts centrally as a potent anorectic substance (De Pedro et al., 1993, 1997). In the present study, fish grew efficiently without external symptoms of stress and disease, but we observed in all trials a consistent increase in plasma cortisol levels during the warm period. At this particular time of year, the activation of the hypothalamus-pituitary-adrenal (HPA) axis can represent a normal feature in our latitude, but this introduces a poorly predicable factor that acts upon feeding behaviour, growth performance, and somatotropic axis, increasing living costs, and shortening perhaps the fast growing period.

In red drum (*Sciaenops ocellatus*), Zhu and Thomas (1998) demonstrated that plasma SL levels are under the inhibitory control of light received by photoreceptive organs. Background adaptation does not affect plasma SL levels in rainbow trout (Kakizawa et al., 1995a), although seasonal changes in plasma SL titres appear more closely linked to increase in water temperature than to day-length (Rand-Weaver et al., 1995). In

rainbow trout, the increase in plasma SL levels also occurs in response to stressors (Rand-Weaver et al., 1993). However, in our experimental conditions, a consistent increase in plasma SL levels was found at late autumn in coincidence with low plasma cortisol titres. Therefore, other factors than increasing temperature and stressors are involved in the fine seasonal tuning of circulating SL in gilthead sea bream. Furthermore, the up-regulation of circulating SL titres at the beginning of the cold period (feeding inhibition) was particularly severe in big fish (spring and summer stocking time). In contrast, a low SL elevation was found in small fish (autumn stocking time), growing with a relative high efficiency during all the cold period despite a severe hypertriglyceridemia and a high hepatosomatic index, which revealed some state of insulin resistance. These findings are in line with a previous summer study, in which a short-term increase in plasma SL levels occurred after food deprivation, returning SL to control values when the fasting increase in GH (liver GH-desensitisation) was fully accomplished (Company et al., 2001). In the same work, we found a progressive and significant increase in plasma SL levels with the increase in ration size and fatness. Apparently, these things are contradictory, but we have observed in a larger study that the primary effect of overfeeding is to advance the autumn SL peak rather than further increase basal and stimulated SL levels (Mingarro et al., in preparation). According to this view, the dominant role of SL in energy homeostasis is likely to be a mediator of the adaptation to fasting and/or reduced food intake after replenishment of body fat stores.

In summary, the present study provides enough evidence for a different regulation of SL and the somatotropic axis. The functional implication of this finding is yet to be determined, although major changes year-around on hormonal, metabolic, and behavioural counterparts to maintain the supply of energy substrates, protect lean mass, and promote survival may be mediated by GH and SL axes. Thus, the ability to growth and store energy at times of food abundance and increasing temperature and day-length is evolutionarily advantageous, and the rise of GH at the beginning of the warm period may serve as a mediator of growth spurts, promoting the use of lipids as metabolic fuels and sparing dietary proteins for growth purposes. In contrast, when a critical size is achieved, the rise of SL at the beginning of the cold season (after replenishment of body fat stores) may act as a mediator of fasting and even reproductive processes, leading to maintain a lipolytic tonus. This point of view is consistent with a recent study, in which the intraperitoneal injection of recombinant SL to juvenile gilthead sea bream (autumn period) was able to decrease the respiratory quotient (CO_2 output/O_2 intake), inhibiting the hepatic activity of key metabolic enzymes of the lipogenic pathway (Vega-Rubín de Celis et al., 2002). However, mammalian SL counterparts remain to be identified, and several studies are underway to fully characterise fish SL target tissues.

Acknowledgments

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