Effects of light source, photoperiod, and intensity on technical and economic performance of meagre, *Argyrosomus regius*, on intensive land-based farms

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Abstract. This study was performed to investigate the effects of light source, photoperiod, and intensity on the bio-economic performance of meagre (*Argyrosomus regius*). Juveniles (10.0 g) were exposed to an artificial light source at two photoperiod levels, 12 dark (D):12 light (L) and 8D:16L, and three light intensity levels, 200, 400, and 600 lux. The results were compared with the results for fish exposed to a natural light source, photoperiod, and light intensity (control). The results demonstrated the superiority of natural light on fish performance, where significant improvements in specific growth rate - SGR (109.9%), feed conversion ratio - FCR (26.2%), protein productive value - PPV (97.7%), and energy utilization - EU (112.6%) were detected. Improvements in fish performance of meagre were observed under 8D:16L, and 36.0% (SGR), 20.6% (FCR), 54.2% (PPV), and 76.9% (EU) were recorded. Increasing light intensity from 200 to 400 lux improved the overall evaluated parameters for both photoperiods; however, 600 lux showed positive results under the 12D:12L photoperiod and negative results under the 8D:16L photoperiod. The natural light source resulted in the best economic indices. It is recommended to benefit from the results of this experiment, in the engineering design and construction of intensive land-based meagre farms to achieve the best productivity and highest profitability.

Key Words: *Argyrosomus regius*, light source, photoperiod, light intensity, growth, economic assessment.

Introduction. In recent decades, the mariculture industry has become more efficient in growing fish in terms of nutrition and water quality management. However, to maximize the potential production of fish, recommended levels of environmental factors (water quality, temperature, photoperiod, and light intensity) are essential to improve profitability and reduce physiological stress on fish. Light significantly influences fish growth, behavior, immune response, and physiological activities (Villamizar et al 2011). Light manipulation in the aquaculture industry involves three different aspects: wavelength (color), intensity, and photoperiod (duration). Lighting regimes affect many aspects of fish behavior, physiology, health, blood chemistry, ocular development, and behavior (Boeuf & Le Bail 1999). As marine fish are considered visual feeders, fish need specific light qualities and quantities to grow (Villamizar et al 2009; Guo et al 2012). Additionally, many authors have determined that photoperiod and intensity have a significant effect not only on growth performance but also on fish physiology (Yasir & Qin 2009), larvae development (Gao et al 2017), skin color and pigmentation (Van der Salm et al 2004). Moreover, fish light intensity requirements differ from one stage to another for the same species (Villamizar et al 2011).

Light intensity is an essential factor which influences the growth performance and physiological status of fish and depends on fish habitat, water depth, and turbidity (Boeuf & Le Bail 1999). A perfect understanding and accurate manipulation of photoperiod may successfully contribute to improving productivity and support the sustainability of mariculture. In addition, the effects of light intensity/photoperiod on different production properties of fish, such as growth, survival, immunity (Trotter et al 2003; Tian et al 2015) and stress response (Tian et al 2015) have been examined. The optimum light intensity varies for different aquatic organisms, such as 1-10 lux for the Atlantic halibut *Hippoglossus hippoglossus* (Hole & Pittman 1995), 400 lux for the blunt snout bream *Megalobrama amblycephala* (Tian et al 2015), 600-1300 lux for the gilthead seabream *Sparus aurata* (Tandler & Mason 1983), 1000 lux for the black sea bass *Centropristis striata* (Copeland & Watanabe 2006), and 3000 lux for the leopard coral grouper *Plectropomus leopardus* (Yoseda et al 2008). Other species of fish are less sensitive to light intensity levels. For instance, the southern flounder *Paralichthys lethostigma* was observed at a light intensity in the range of 340-1600 lux and no significant effects on growth and metamorphosis were found (Daniels et al 1996). For some species, light intensities exceed their optimum ranges and are a source of stress (Wang et al 2013).

Meagre, *Argyrosomus regius*, has received considerable attention from Egyptian fish farmers because of its valuable selling price and consumer demand. Additionally, meagre fillet is in high demand in the European market because its meat has a low content of fat, even under intensive culture conditions (Kružic et al 2016), and even if the diet had a high-fat content (Piccolo et al 2008), the flesh is an excellent source of protein. Generally, meagre meat is of high quality. Consequently, the quality of meagre flesh is an issue of great importance to not only its easy marketability and profitable price (Monfort 2010) but also its nutritional value as a large segment of consumers are concerned with nutritional values (Poli et al 2003). The global production capacity of meagre from the aquaculture sector increased from 752 tons in 2007 to 23,440 tons in 2016 (FAO 2018). The top producers of meagre in Mediterranean countries are Turkey, Spain, Italy, Greece, and Egypt, and Egypt is the top producer of this species, at 16,162 tons, which represents 1.18% of Egyptian fish production according to 2016 statistics (GAFRD 2018). Therefore, research on this fish has focused on the manipulation of different factors, such as nutritional requirements (El-Dahhar et al 2016), photoperiod for larvae (Vallés & Estévez 2013), and flesh quality (Monfort 2010). However, the effect of the light source, photoperiod, and light intensity on the growth performance of juveniles and profitability has yet to be investigated. Thus, this study aimed to evaluate the effects of the previously mentioned light-related factors on the growth, feed utilization, proximate chemical analyses and economic efficiency indices of meagre, *A. regius*, reared in intensive land-based farming systems using ground saltwater.

Material and Method

Experimental site, fish and facilities. This experiment was conducted at the Fish Rearing Laboratory, El-Max Research Station, National Institute of Oceanography and Fisheries (NIOF), Alexandria, from July to September 2016. This location is 1.2 km from the Mediterranean Sea. Therefore, the only available sources of saltwater, with a salinity of 32‰, are deep wells (approximately 100 m depth). Egypt has no fish hatchery for meagre, *A. regius*, and researchers do not have the financial ability to import juveniles from other countries. Thus, the researchers of this study collected wild fingerlings from the El-Meadia region, El-Beheira Governorate, which is located on the coast of the Mediterranean Sea, Egypt, to perform this study. Fish health was examined, and a prophylactic dose of formalin (20 ppm for one hour) and copper sulfate (0.5 ppm for one hour) was used for daily disinfection for six days. Fish were acclimatized to the artificial diet and rearing salinity level for four weeks before starting the study.

Experimental treatments. Juvenile meagre were exposed to artificial light source with two photoperiods, 12 dark (D):12 light (L) and 8D:16L, and three light intensity levels: 200, 400, and 600 lux (six treatments). The results were compared with those from other fish reared under a natural light source, photoperiod and light intensity (control treatment). The seven tested treatments are as follows: T1: artificial light, 12D:12L, 200 lux - abbreviated as A12-12-200; T2: artificial light, 12D:12L, 400 lux - abbreviated as

A12-12-400; T3: artificial light, 12D:12L, 600 lux - abbreviated as A12-12-600; T4: artificial light, 8D:16L, 200 lux - abbreviated as A8-16-200; T5: artificial light, 8D:16L, 400 lux - abbreviated as A8-16-400; T6: artificial light, 8D:16L, 600 lux - abbreviated as A8-16-600; and T7: natural light, 12D:12L, 742 lux - abbreviated as N12-12-742. To obtain light intensities of 200, 400, and 600 lux, one, two, and three lamps, respectively, were fixed 1.2 meters over fish tanks. The lamp type was a Philips 27359-9 - F40T12/DX/ALTO – 40 Watt fluorescent tube - T12 - 6500K - 900 Series Phosphors - Lumens (light output): 2325, which gives ~200±10 lux on the water surface of fish rearing tanks. Lux values over the water surface of the fish tanks were measured and adjusted using the Luxmeter HI 97500 by HANNA. For the control treatment, the lux values of the natural light source varied between the hrs of the days, and the following values were recorded: 742, 811, 814, 751, 720, 750, 614, 761, 749, and 711 lux, with an average of 742.3 lux. Additionally, the photoperiod during the experimental period varied between 12D:12L and 11D:13L. After the acclimation period for the artificial diet, fish with an average weight of 10.0±0.30 g and total length of 11.2±0.5 cm were stocked in the experimental fiberglass tanks (21 tanks, each with 4 tons of water) at a stocking density of 40 juveniles /tank. The water exchange rate was 20% daily. Figure 1 illustrates many photos for fish tanks, photoperiod control unit, measuring light intensity, fish sampling, etc.

Feed formulation and feeding protocol. Juveniles were fed a pelleted diet manufactured in a nutrition laboratory. All the feed ingredients were purchased from a local market; then, the ingredients were finely ground using a Lab Mill, sieved, and then homogenized in a large bucket for 10 minutes using electric kitchen mixers. After the addition of the dietary oil source and hot water, the diets were cold pressed using an electric kitchen meat grinder (Moulinex ME605131 - HV8 - 1600 W, France). Feed pellets were then dried at room temperature in a ventilated room using an electric fan for 3 hrs. Additionally, the feed strands were hand-cut into bite-size pellets and dried at 45°C for 12 hrs. The dried pellets were sieved to appropriate sizes using different feed sieves. The dried pellets were packaged and stored at -20°C until use. The experimental dry feed contained 47.39% crude protein and 17.10% crude lipid, 2.35% crude fiber, 20.77% gross energy (MJ kg^{-1} diet), and a 104.67 energy/protein ratio (kcal g^{-1} protein), as recommended in a previous experiment (El-Dahhar et al 2016). The feed formulation and proximate composition are described in the previous reference. Juveniles were fed to satiation with four meals daily for 42 days.

Data collection, sample collection, and analytical procedures

Water analysis. Temperature, pH, dissolved oxygen (DO), and total ammonia nitrogen (TAN) were measured weekly in the tested treatments. Temperature, together with pH, was measured by a portable pH meter (PH-8424) (HANNA Instrument). DO was measured by a HI-9142 (HANNA Instrument). Salinity was measured using a YSI EcoSense EC300 conductivity/salinity meter. TAN and un-ionized ammonia-N were monitored using a YSI 9300 photometer and YSI Professional Plus, respectively.

Fish and feed analytical methods. At the beginning and end of this trial, samples of the fish (5 fish/tank) and feed were collected to analyze the proximate compositions of the diets and fish, including the moisture, protein, lipid and ash contents, according to the AOAC International (2000) methodology.

Fish and feed analytical methods. At the end of this experiment, fish were counted and weighed. The parameters of growth performance and feed utilization were calculated as follows:

$$\text{Weight gain (WG; g)} = FW - IW$$

$$\text{Average daily gain, (ADG; g fish}^{-1}\text{ day}^{-1}) = FW - IW / \text{experimental days}$$

$$\text{Specific growth rate (SGR; \% fish}^{-1}\text{ day}^{-1}) = 100 * [(\text{Ln } FW) - (\text{Ln } IW)] / \text{experimental days}$$

where: FW = final fish weight (g);
IW = initial fish weight (g).

Fish survival (%) = 100 * [final number of fish / initial number of fish]

Feed intake (FI, g fish^{-1}): FI is the amount of feed given or supplied during the experimental period for each fish per gram.

Feed conversion ratio (FCR) based on dry matter (DM) = feed intake (g) as dry weight / weight gain (g)

Protein efficiency ratio (PER) = fish weight gain (g) / protein intake (g)

Protein productive value (PPV; %) = 100 × (Pt –P0 / protein intake (g))
where: P0 = protein content in a fish carcass at the start of the experiment;
P = protein content in fish carcass at the end of the experiment.

Energy gain, EG (Kcal): EG = Et - E0
where: E0 is the energy content in the fish carcass (Kcal) at the start of the experiment;
Et is energy content in the fish carcass (Kcal) at the end of the experiment.

Energy utilization, EU (%): EU = 100 × (energy gain (Kcal) / energy intake (Kcal)]

NFE (nitrogen-free extract) = 100 - (crude protein + ether extract + crude fibre + ash)

Gross energy (MJ kg^{-1} diet) = (% crude protein×23.6) + (% crude lipids×39.5) + (% carbohydrates×17.3).

Economic efficiency. The economic efficiency was estimated using FCR, the actual price of laboratory-made feed; the estimated cost of electricity used in light usage, water pumping, and aeration; and the local price of selling meagre according to the prices in 2017. The cost of light was calculated based on the price of one kW of electricity according to the government; the retail price was 1.35 LE/kW = 0.075 US$/kW. The total income was calculated based on the price of one kg of fish meat gain = 250 LE/kg (~13.8 US$). The feeding cost, cost of light, other variable costs, total variable cost, capital cost, total production costs, total income, net profit or loss, and benefit-cost ratio were calculated as follows:

Feeding cost (US$/tank) = FCR * feed price (US$/kg feed); abbreviated as [A]

Cost of light, (US$/tank) = (total electricity usage for lighting during the experimental period (KW) * 0.075 US$/kW); abbreviated as [B]

Other production costs (US$/tank) = (all other costs including labor, the electricity of water pumping, and aeration); abbreviated as [C]

Total variable costs (US$/tank) = A + B + C; abbreviated as [D]

Total production costs (US$/tank) = D + capital cost; abbreviated as [E]

Total income (US$/tank) = weight gain (kg/tank) * 13.8 US$; abbreviated as [F]

Net profit or losses (US$/tank) = F – E; abbreviated as [G]
Benefit-cost ratio, % = G/E

Statistical analysis. The data of the investigated traits (growth, feed utilization, biochemical and economic analyses) were analyzed with one-way analysis of variance (ANOVA) using SPSS version 22 statistical package (SPSS Company Inc., Chicago, IL. USA) to evaluate the differences between treatments. The differences within each experimental treatment were assessed using Duncan’s multiple range test at $p \leq 0.05$.

Indoor Tanks; Light Intensity; 400 lux

Indoor Tanks; Light Intensity; 200 lux

Photoperiod Control Unit

Indoor Tanks; Light Intensity; 600 lux

Outdoor Tanks; Natural Light; 751 lux

Outdoor Tanks; Natural Light; 720 lux

Indoor Tanks; Artificial light; Fish Sampling

Indoor Tanks; Artificial light; Fish Sampling

Outdoor Tanks; Natural Light

Outdoor Tanks; Natural Light; Fish Sampling;

Outdoor Tanks; Natural Light; Fish Sampling

Fish Sampling; Length

Figure 1. Realistic photos of the experiment for fish tanks, photoperiod control unit, measuring light intensity, and fish sampling.

Results

Water quality parameters. The water quality parameters were monitored, and the results were recorded. The mean values of water temperature (°C), pH, DO (mg L^{-1}), TAN (mg L^{-1}), and un-ionized ammonia (NH_3-N, µg L^{-1}) were 27.6^{o}C, 8.03, 5.82 mg L^{-1}, 0.247 mg L^{-1}, and 10.6 µg L^{-1}, respectively, without significant ($p > 0.05$) differences among the treatments.

Survival, and growth performance indices. The growth performance indices and survival of the meagre tested with different light sources, photoperiods, and light intensities are illustrated in Table 1. The tested light parameters significantly ($p \leq 0.05$) influenced the survival and growth of juvenile meagre. In comparison to fish reared under an artificial light source, fish reared under a natural light source exhibited a 7.73% higher survival rate (Figure 2). Fish reared under the photoperiod 8D:16L exhibited a 7.3% higher survival rate than those reared under the photoperiod 12D:12L (Figure 3). The survival rate improved by 1.6, 2.8, and 19.3% under the photoperiod 8D:16L than under photoperiod 12D:12L treatments for 200, 400, and 600 lux, respectively (Figure 4).

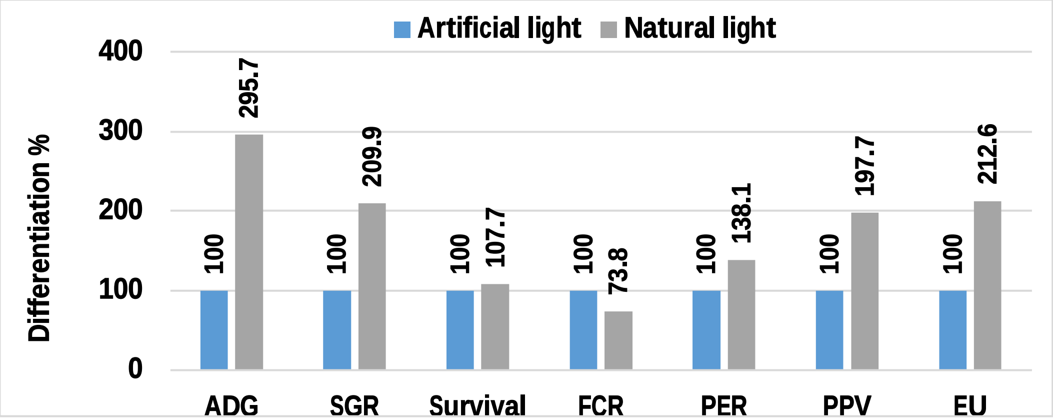

Figure 2. Differentiation (%) between the effects of both natural and artificial light sources on ADG, SGR, survival, FCR, PER, PPV, and EU of meagre, *Argyrosomus regius*, reared under an intensive culture system. Note: Differentiation % = (Natural/Artificial*100).

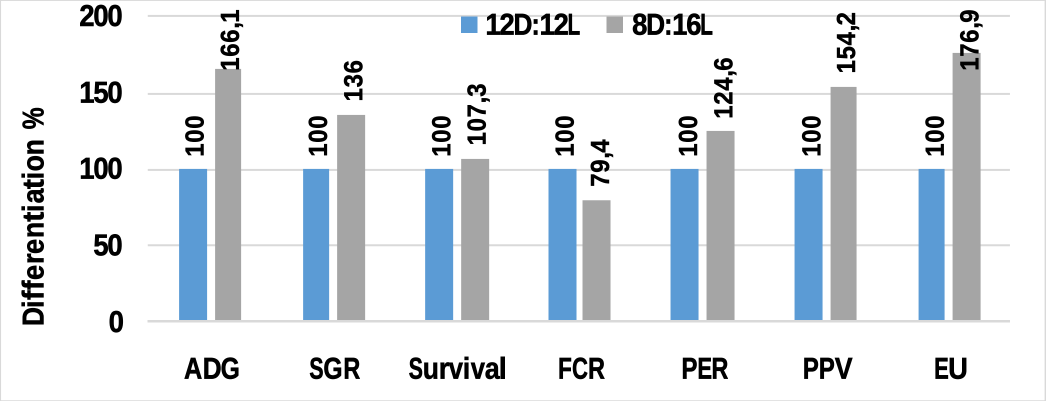

Figure 3. Differentiation (%) between the effects of both photoperiods (12D:12L and 8D:16L) on ADG, SGR, survival, FCR, PER, PPV, and EU of meagre, *Argyrosomus regius*, reared under an intensive culture system. Note: Differentiation % = (8D:16L /12D:12L*100).

Feed efficiency indices. Table 2 illustrates highly significant ($p \leq 0.05$) differences in feed efficiency indices among the treatments with a remarkably better trend towards the natural source of light. In comparisons to juveniles reared under artificial light sources, juveniles reared under the natural light source exhibited 26.2% lower FCR, 38.1% higher PER, 97.7% higher PPV, and 112.6% higher EU (Figure 2). In comparison to the 12D:12L photoperiod, the 8D:16L photoperiod exhibited 21.6% lower FCR, 24.6% higher PER, 54.2% higher PPV, and 76.9% higher EU (Figure 3). Additionally, the light intensity had a highly significant effect on the feed utilization of meagre. In comparison to juveniles reared under the 12D:12L photoperiod, those reared under photoperiod 8D:16L had their FCR, PER, PPV, and EU improve by (-26.5, 27.0, and 5.6%), (36.4, 36.4, and 5.6%), (144.9, 66.8, and 0.3%) and (187.9, 97.4, and 16.9%) for 200, 400, and 600 lux, respectively (Figure 4).

Table 1

The growth performance and survival rate of the juvenile meagre *Argyrosomus regius* tested with different levels of light source, photoperiod, and light intensity and reared under an intensive land-based culture system. Data are mean±standard error

Treatments			*Initial BW (g fish^{-1})*	*Final BW (g fish^{-1})*	*ADG (g fish^{-1} day^{-1})*	*SGR (% day^{-1})*	*Survival, (%)*
Light source	*Photoperiod (D: L)^{1}*	*Light intensity (Lux)*					
Artificial	12D:12L	200	10.41±0.07	14.00±0.12^{e}	0.085±0.004^{e}	0.71±0.035^{d}	80.00±0.00^{c}
		400	9.25±1.04	14.73±0.19^{de}	0.130±.029de	1.12±0.299^{cd}	88.75±01.25^{a}
		600	9.28±0.55	15.88±0.46^{cd}	0.157±0.002^{cd}	1.28±0.072^{bc}	71.25±1.25^{d}
	8D:16L	200	10.89±0.13	19.40±0.46^{b}	0.203±0.008^{bc}	1.38±0.029^{bc}	81.25±1.25^{c}
		400	10.40±0.24	20.85±1.05^{b}	0.249±0.031^{b}	1.65±0.174^{b}	91.25±1.25^{a}
		600	10.61±0.34	17.59±0.42^{c}	0.166±0.002^{cd}	1.20±0.019^{bc}	85.00±0.00^{b}
Natural	~12-13 hrs light	~ 742	10.54±0.04	28.83±0.50^{a}	0.435±0.011^{a}	2.40±0.032^{a}	88.75±1.25^{a}

Means in the same column not sharing the same letter are significantly different at $p \leq 0.05$; ^{1} D:L = (dark:light) hrs.

Table 2

The feed efficiency indices of the juvenile meagre *Argyrosomus regius* tested with different levels of light source, photoperiod, and light intensity and reared under an intensive land-based culture system. Data are mean±standard error

Treatments			*Feed intake (g fish^{-1})*	*FCR*	*Protein utilization*		*Energy gain (Kcal)*	*Energy utilization (%)*	*Carcass energy (Kcal/100 gm)*
Light source	*Photoperiod (D:L)^{1}*	*Light intensity (Lux)*			*PER (g)*	*PPV (%)*			
Artificial	12D:12L	200	9.25±0.75^{d}	2.57±0.08^{a}	0.825±0.03^{d}	7.38±0.25^{e}	2.26±0.28^{e}	4.63±0.19^{e}	526.6±3.3^{b}
		400	12.50±2.50^{cd}	2.30±0.06^{b}	0.920±0.02^{d}	11.72±1.02^{d}	5.47±1.96^{de}	8.05±1.37^{d}	531.7±1.5^{ab}
		600	13.00±0.00^{cd}	1.97±0.03^{c}	1.075±0.02^{c}	15.14±0.37^{c}	7.73±0.29^{cd}	11.31±0.43^{c}	530.2±4.3^{ab}
	8D:16L	200	16.00±0.00^{bc}	1.89±0.08^{cd}	1.125±0.05^{bc}	18.07±1.30^{bc}	11.22±0.51^{bc}	13.33±0.61^{bc}	529.6±3.0^{ab}
		400	17.50±1.50^{b}	1.68±0.06^{de}	1.255±0.05^{b}	19.55±0.82^{b}	14.67±1.82^{b}	15.89±0.61^{b}	534.5±0.7^{ab}
		600	13.00±0.00^{cd}	1.86±0.02^{cd}	1.135±0.02^{bc}	15.18±0.48^{c}	9.04±0.30^{cd}	13.22±0.44^{bc}	537.5±0.3^{a}
Natural	~12-13 hrs light	~ 742	27.00±1.00^{a}	1.48±0.09^{e}	1.430±0.09^{a}	25.83±1.17^{a}	28.13±0.64^{a}	19.86±1.18^{a}	535.4±2.8^{ab}

Means in the same column not sharing the same letter are significantly different at $p \leq 0.05$.

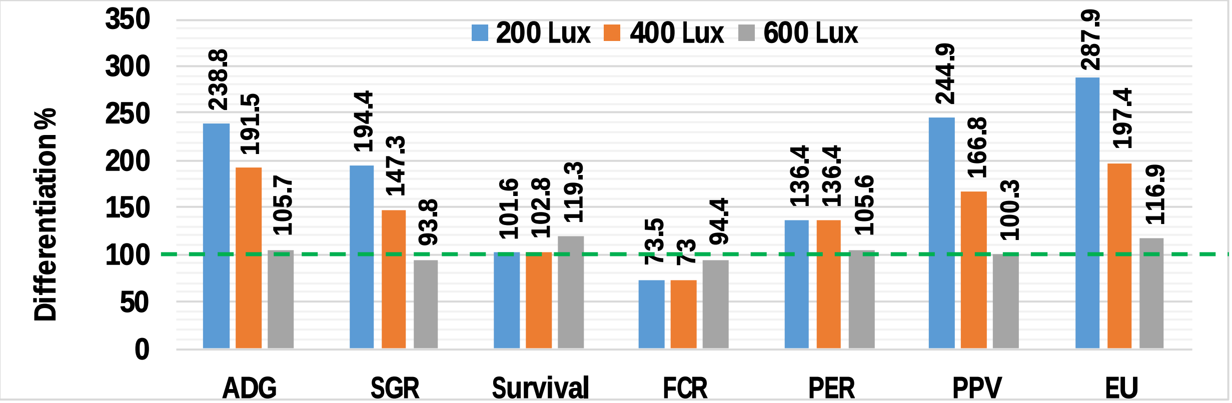

Figure 4. Differentiation (%) among the effects of 200, 400, and 600 lux under photoperiod 8D:16L compared with those under 12D:12L on ADG, SGR, survival, FCR, PER, PPV, and EU of meagre, *Argyrosomus regius*, reared under an intensive culture system. Note: Differentiation % = (8D:16L/12D:12L*100). The green dashed line represents the data of photoperiod 12D:12L (as the denominator, 100%).

Whole-body proximate composition. The chemical composition of the entire body of meagre fish is illustrated in Table 3. Significant ($p \leq 0.05$) differences among all treatments were detected. Dry matter content was improved when the fish were exposed to natural light followed by the treatments with artificial light 8D:16L and then 12D:12L. The highest protein value was recorded for fish exposed to natural light rather than for those exposed to artificial light. However, there was a fluctuation in the protein values of the fish exposed to artificial light. There were no significant ($p > 0.05$) differences in the ether extracts of the treatments, except fish under the artificial light (8D:16 L) and for the light intensity groups (400 and 600 lux). In comparison to natural light sources, artificial light sources exhibited higher ash content. Significant ($p \leq 0.05$) differences were detected in the ash content of the artificial light treatments with high intensity without a specific trend.

Table 3

The proximate chemical analyses of the juvenile meagre *Argyrosomus regius* tested with different levels of light source, photoperiod, and light intensity and reared under an intensive land-based culture system[1]. Data are mean±standard error

Treatments			*Dry matter (%)*	*Crude protein (%)*	*Ether extract (%)*	*Ash (%)*
Light source	*Photoperiod (D:L)*	*Light intensity (Lux)*				
Artificial	12D:12L	200	25.95±0.15^{d}	59.10±0.55^{cd}	20.48±0.02^{c}	19.20±0.10^{a}
		400	26.15±0.05^{d}	60.43±0.21^{ab}	20.22±0.28^{c}	18.55±0.15^{b}
		600	27.05±0.15^{c}	59.56±0.35^{bc}	20.59±0.25^{c}	19.00±0.10^{a}
	8D:16L	200	28.10±0.20^{b}	60.10±0.37^{abc}	20.19±0.54^{c}	18.50±0.00^{b}
		400	28.30±0.10^{b}	58.45±0.08^{d}	21.70±0.12^{b}	18.85±0.15^{ab}
		600	27.75±0.25^{b}	57.23±0.06^{e}	22.74±0.01^{a}	19.10±0.10^{a}
Natural	~12-13 hrs light	~ 742	29.30±0.20^{a}	60.93±0.23^{a}	20.32±0.43^{c}	18.00±0.20^{c}

Means in the same column not sharing the same letter are significantly different at $p \leq 0.05$.

[1] Initial proximate analyses: DM = 29.9%, CP = 58.58%, EE = 22.44%, and Ash = 17.75%.

Economic and profitability analysis. Figure 5 presents data on the feed cost, capital cost, light cost, variable costs, total production costs, total income, net profit, and benefit-cost ratio per fish rearing tank. Increasing light intensity (lux) and photoperiod significantly increased ($p \leq 0.05$) the cost of lighting. Notably, the cost of artificial lighting compared with the total variable costs varied between 43.1 and 68.7% for the 12D:12L photoperiod and between 47.6 and 73.8% for the 8D:16L photoperiod, while the total cost of natural lighting was 0%. The total income under a natural light source, T7 (N12-12-742), varied between 1.7fold and 5.6-fold compared with that T5 (A8-16-400) and T1 (A12-12-200), respectively. Clearly, the high cost of artificial lighting negatively affected both net profit and the benefit-cost ratio, with losses varying between 48.6% and 78.6%.

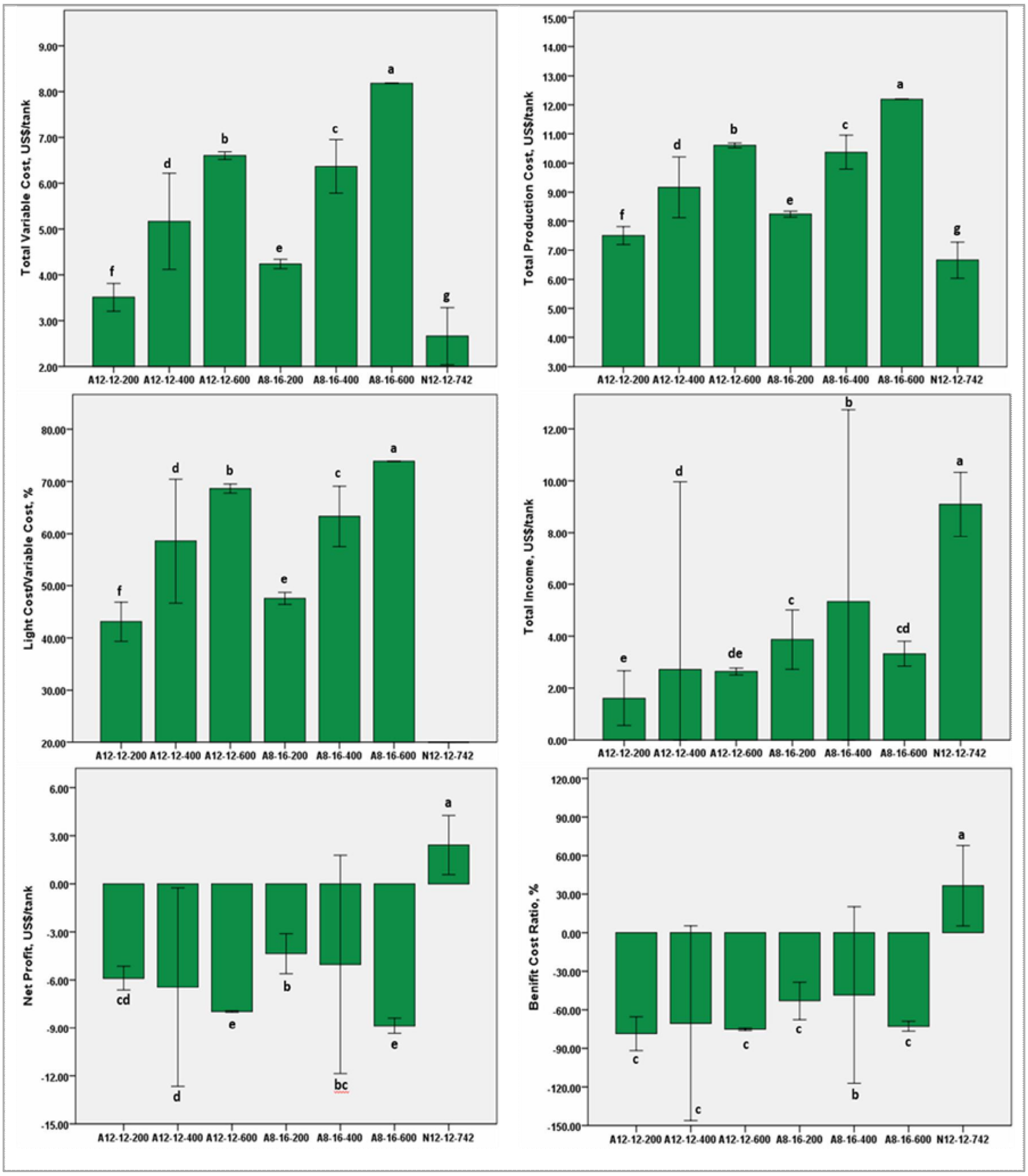

Figure 5. Total variable cost and total production cost (US$/tank), total income and net profit (US$/tank), light cost/variable cost (%) and benefit-cost ratio (%) of meagre, *Argyrosomus regius*, tested with different light sources, photoperiods and light intensities. A12-12-200 = artificial light, 12D:12L, 200 lux; A12-12-400 = artificial light, 12D:12L, 400 lux; A12-12-600 = artificial light, 12D:12L, 600 lux; A8-16-200 = artificial light, 8D:16L, 200 lux; A8-16-400 = artificial light, 8D:16L, 400 lux; A8-16-600 = artificial light, 8D:16L, 600 lux; and N12-12-742 = natural light, 12D:12L, 742 lux.

Discussion. Data on water quality were within the acceptable range for marine fishes according to several references (APHA 1998; Swann 2007; PHILMINAQ 2008). Increasing light intensity from 200 to 400 lux increased the survival rate under both photoperiods. This result is congruent with the result of Copeland & Watanabe (2006), who stated that inadequate light intensity might cause elevated fish mortality and weak growth. Based on the data from the current study, increasing light intensity from 400 to 600 lux reduced the survival rate under both photoperiods. In this context, excessively intensive illumination may potentially result in stress or even death for some fish species (Boeuf & Le Bail 1999).

Growth performance and feed efficiency indices among treatments showed a remarkably better trend towards the natural source of light, followed by the 8D:16L photoperiod (long photoperiod). Under the natural light regime, with a very slow increase/decrease in light intensity from zero to 850 lux during daylight hrs, meagre gradually acclimatized to the ambient light intensity. This scientific result is in agreement with that of Villarreal et al (1988), who proposed that fish are incapable of synchronizing their endogenous rhythms when an artificial photoperiod rapidly increases and/or decreases. The current results demonstrated that a prolonged photoperiod regime enhanced meagre growth. This growth was coupled with higher feed intake and nutrient utilization. The positive effect of a long photoperiod (8D:16L) on meagre growth was comparable to a related species such as the gilthead sea bream *Sparus aurata* and the red sea bream *Pagrus major*, where long and constant photoperiods of both 1600 lux of light (8D:16L) and a continuous light regime (0D:24L) improved growth (Jonassen et al 2000; Simensen et al 2000; Kissil et al 2001). The results were attributed to improved appetite, greater feed consumption, and higher feed efficiency and digestibility, and this concurs with the findings of Biswas et al (2006, 2010, 2016).

Photoperiod manipulation and the combination of photoperiod and a self-feeder could significantly improve the growth performance of striped knifejaw (*Oplegnathus fasciatus*) without causing a stress response (Biswas et al 2008a, 2008b, 2010, 2016). A long photoperiod can stimulate growth efficiency in different species (Boeuf & Le Bail 1999; Kissil et al 2001; Trippel & Neil 2003). A photoperiod is categorized as a directive factor; it stimulates the endocrine system, such as by circulating growth hormones (McCormick et al 1995). Light intensity has a direct effect on fish behavior (Marchesan et al 2005). A significant effect of low and/or high light intensity on growth has been demonstrated in many species (Copeland & Watanabe 2006; Yoseda et al 2008; Tian et al 2015). The optimum range of light intensity varies from species to species and is species-specific because of the difference in fish habitats. Liu et al (2012) found that juvenile Brazilian flounder (*Paralichthys brasiliensis*) presented higher growth at a low light intensity (10-70 lux) than at a high light intensity. Additionally, juvenile haddock, *Melanogrammus aeglefinus*, grew better at 30 lux than at other light intensities (Trippel & Neil 2003). In addition, the grouper *Epinephelus coioides* exhibited higher growth at a range of light intensities from 320 to 1150 lux (Wang et al 2013). In our study, light intensity (400 lux) had the best effect on growth, and this result is consistent with that of Taylor & Migaud (2009), who suggested that the earlier the exposure and the longer the duration of light are, the higher the degree of growth improvement in rainbow trout (*Oncorhynchus mykiss*). Similarly, a more prolonged photoperiod maintains a higher growth rate in Atlantic salmon, *Salmo salar* (Taranger et al 1999; Endal et al 2000). Some species, such as striped knifejaw, *Oplegnathus fasciatus* (Biswas & Takii 2016), southern flounder, *Paralichthys lethostigma* (Daniels et al 1996) and Atlantic salmon (Stefansson et al 1993), seem to be less sensitive to light intensity within the range of 50-1500 lux with light intensities tested in ranges of 340-1600 and 27-715 lux. Benthopelagic fish at a low water depth of 1-10 m (Mundy 2005) may efficiently self-acclimate to a range of light intensities.

According to the results of the present study, in comparison to all treatments with artificial light, natural light sources exhibited better results related to feed utilization. Increasing the photoperiod from 12D:12L to 8D:16L resulted in high values of feed utilization. This result is in agreement with the results of Villamizar et al (2009), who found that feed intake increased with increasing photoperiod when they investigated the effect of both photoperiod and spectrum on the development of European sea bass (*Dicentrarchus labrax*) larvae. The same results were obtained by Gines et al (2004) for immature gilthead sea bream (*S. aurata* L.) and by Biswas et al (2006) for red sea bream (*P. major*). Additionally, Elsbaay (2013) revealed that 24L:0D and 16L:8D enhanced the FCR of Nile tilapia (*Oreochromis niloticus*). Nile tilapia exposed to long photoperiods (18L:6D and 24L:0D) directed their energy into somatic growth and in turn to feed utilization (Luchiari & Freire 2009; Veras et al 2013). Feed efficiency, feed intake, protein intake and protein retention in rainbow trout were enhanced when fish were exposed to extended artificial photoperiods 24L:0D and 18L:6D (Turker & Yildirim 2011). However, increasing light intensity at photoperiod 12L:12D resulted in an increasing trend in protein and energy utilization. These results are in agreement with those of Biswas & Takii (2016), who stated that increasing light intensity > 200 lux exhibited an increasing trend in terms of the quantity of feed intake without a significant difference among the treatments. However, feed utilization was significantly reduced, especially in fish exposed to 800 and 1500 lux. Additionally, Rajeswari et al (2017) found that when the marine angelfish *Apolemichthys xanthurus* was exposed to 250-500 lux, it had the highest FCR value at the various light intensities of 20-500, 750-1000, 1500-2000 lux.

Meagre exposed to the natural light source showed better feed utilization than fish exposed to the artificial light source, which may have caused a balance between the metabolic activity and the retention of energy in the fish body. The photoperiod under artificial light source was critical because meagre is a carnivorous feeder, but with the availability of artificial diet, the fish shows less movement activity for feeding as long as the light intensity level is in the suitable level. However, when the light intensity range is out of the suitable level for a particular species, the scenario may be a source of stress. In this context, according to the conclusions of Appelbaum & Kamler (2000) and Trippel & Neil (2003), under low light intensity, fish exhibit less active movement, which may be reflected in a bit metabolic savings. In contrast, under high light intensity beyond the suitable range, fish shows overactivity in movement, which may dissipate energy, reduce the retention efficiency of nutrients, and subsequently reduces growth performance. That is what applies to the A8-16-600 treatment. Besides, Wang et al (2013) found that higher levels of plasma stress indicators (cortisol, glucose, lactate, etc.) were detected when fish were tested at both high and low light intensities.

Minimal research addresses the effect of light on the chemical composition of an entire fish, but in general, environmental conditions are mixed. The composition of an entire fish changes with diet (type or quality), temperature, fish size (the different stages of development) and environmental factors (Mozsár et al 2015; Castillo-Vargasmachuca et al 2017). In the present study, statistically significant changes in body dry matter contents were found in meagre juveniles exposed to different light sources. The data collected in the present study concerning the proximate contents of crude protein and ether extract in meagre appeared to be sensitive to the rearing photoperiod and light intensity. This conclusion is in agreement with those of Villamizar et al (2011).

According to the data of the present study, the excessive cost of artificial light significantly increased the total production costs and thus negatively affected the net returns and benefit-cost ratio, especially with increasing light intensity. On the other hand, under a natural light source, with no lighting costs, the economics of intensively farming meagre fish have been clearly and positively impacted. Excessively intensive light illumination requires more electric energy and leads to higher production costs (Boeuf & Le Bail 1999) but also reduces the profit margin. According to the present study, in comparison to that of 600 lux, the artificial light intensity of 400 lux resulted in better profit margins and better economic returns. This conclusion is in agreement with Biswas & Takii (2016), who stated that low light intensities would help to not only convert more feed but also reduce feed costs as well as lower electric energy consumption for intensive production of striped knifejaw. Additionally, the positive impacts of natural lighting on growth and feed utilization have had significant positive effects in terms of doubling economic returns. These impacts would have turned the benefit-cost ratio from a passive (loss) status for artificial light groups to a positive (profit) status for the natural light group.

Conclusions. The results demonstrate the superiority of natural sources of light, especially in terms of growth, feed efficiency and economic benefits. Increasing light intensity from 200 to 400 lux improved the overall evaluated parameters for both photoperiods; however, 600 lux showed positive results under the 12D:12L photoperiod and negative results under the 8D:16L photoperiod. In comparison to all artificial light treatments, the natural light source achieved the best economic indices. Therefore, using a natural source of light should be recommended in intensive meagre farming from a technical and economic point of view. Also, the results of this experiment can be utilized when developing the engineering designs of the intensive land-based farms of meagre, to maximize natural light exploitation.

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