The technical and economic efficiency analyses of performance of brown trout (*Salmo trutta fario* l., 1758) fed by the commercial diets enriched with different levels of linolenic acid (lna; 18:3 n-3)

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Abstract

This study was designed to determine the technical and economic efficiency levels of the commercial basal feeds enriched with 10%, 5% and 0% rates of LNA (LNA10, LNA5 *and* LNA0) on the growth performance of brown trout by analyzing the marginal factor cost (MFC) and the marginal revenue of physical product (MRPP). A total of 300 brown trout with an initial individual weight of 4±0.05 g were randomly divided in 12 cages (25 fingerlings in each cage), and kept under 24L:0D (light/dark) photoperiod condition for 9 weeks treated by LNA10, *LNA5* and *LNA0*. The results of the study showed that LNA0 and LNA10 of the effective feed sources, respectively on the growth performance of brown trout were more suitable to produce as the homogeneous products for the consumers and differentiated those for the drug industry in view of the economic and technical efficiencies.

Keywords: Feed intake, Gowth performance, *Salmo trutta fario*, Technical and economic efficiency levels.

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Introduction

Fish growth is directly influenced by some factors such as feed nutritional value and availability and intake, fish age, size and genetics, and water quality. Of these factors, feed intake based on feed type and feeding frequency is perhaps the principle factor affecting growth rate of fish (Peterson and Small, 2006; Lee and Pham, 2010). Practically, the feeding ratio and frequency are adjusted during the production cycle, and thus the relationships between the feed intake and the fish growth in recirculating water systems have been the focus of the research and development efforts for decades. Therefore, the effects of feed types prepared from various feed ingredients and feeding frequencies on the performance traits of some cultured fishes have been investigated in recent years (Johnston *et al.,* 2003; Schnaittacher *et al.,* 2005; Peterson and Small 2006; Nanninga and Engle, 2010; Lee and Pham, 2010; Arslan *et al.*, 2012). However, although there are a limited number of scientific reports on the alternative feed intakes and the growth performance of brown trout *(S. trutta fario* L. 1758*)*, there is a lack of research on the technical and economic efficiencies of these two parameters.

Feed and feeding costs have been reported to account for approximately 50-70% of the total production cost of many cultured fish species including brown trout and rainbow trout (Webster *et al.*, 2001; Arslan and Aras, 2010; Nanninga and Engle, 2010). Many fish species had achieved the highest weight gain at a feeding frequency of three or two times daily, when fed by various types of commercial diets to satiation (Cho *et al.,* 2000; Johnstone *et al.,* 2003; Lee and Pham, 2010).

The efficiency of dietary energy and protein level of diets are also important factors on the growth performance of fishes which can be maintained by inclusion of good quality and high energy sources (lipids, linolenic acid *(LNA; 18:3 n-3)* etc.) into fish diets. (Lee *et al.,* 2000). Dietary lipids and *LNA* could be used as a source of the energy, and provide essential fatty acids which are vital for the normal growth, reproduction, metabolic functions and general wellbeing of fish. Like other vertebrates, fish require n-3 and n-6 polyunsaturated fatty acids (PUFA) at certain concentrations (Williams *et al.*, 2001). Biologically active forms of essential fatty acids are arachidonic acid (ARA; 20:4 n-6), eicosapentaenoic acid (EPA; 20:5 n-3), and docosahexaenoic acid (DHA; 22:6 n-3), which can be synthesized from their precursors linoleic acid (LA; 18:2 n-6) and linolenic acid (LNA; 18:3 n-3) in freshwater fishes (Arslan *et al.,* 2012).

If fish were fed by the commercial basal feeds enriched with supplemental *LNA*, they could consume less metabolic energy for the synthesis of essential fatty acids, and convert it to EPA and DHA with fatty acid composition in favor of n-3/n-6 fatty acids of the lipids accumulated in their fat tissues. Then, they could use less energy for their growth performances. When fish are fed with the optimal commercial basal diets combined by the supplemental LNA as an energy source, their growth may vary increasingly as a result of feed intake concentration. On the other hand, when they are fed with the deficient diets in terms of energy; dietary protein is utilized as an energy source, and this could increase excessively the production cost (Lee *et al.,* 2000; Williams *et al.,* 2001). For this reason, the marginal factor cost (MFC) and marginal revenue of the physical product (MRPP) must be analyzed in order to be able to determine the economic optimum production levels based on the fish growth and feed composition including the commercial basal diets enriched with various levels of the LNA.

Similarly, feeding schedules for fish are mainly determined by feeding activities reflecting the attitude and behavior of the growers ignoring feed efficiency and weight gain, and feeding fish to satiety. Therefore it is very difficult to determine the technical and economic efficiency levels because of overfeeding given to satiate fish species frequently. When they are overfed, the economic losses and deterioration of water quality, suppressing their growth will be inevitable, resulting the increase of production cost. For these reasons, the fish growers must analyze the technical and economic efficiency levels of their feed based on the relationships between fish growth and feed intake.

Brown trout is a highly regarded cultured fish species in Turkey, and there has been a great interest in utilizing this species in commercial aquaculture in recent years. Even though the growth rate of brown trout is relatively lower than rainbow trout, the local market value of this species is approximately four folds the value of rainbow trout in Turkey (Arslan *et al.*, 2012), and thus brown trout could be considered as an important species in efforts to increase the diversity in Turkish aquaculture production.

The main goal of the fish farmers is to provide the maximum output, and achieve the benefit maximization by effective use of the scarce production sources among alternative activity units. The best effective way to maximize the benefit is to analyze the relationships between the techniques minimizing the production cost and their expenditures. According to the relationships, the technique and economic optimum levels could be determined by comparing the MFC and MRPP at each production level. In order to reach these aims, this study was designed to analyze the MFC and the MRPP, and then to determine the technical and economic optimum production levels of the commercial basal feeds enriched with LNA on the body weight gains of brown trout.

Materials and methods

Experimental diets

The proximate composition and the formulation of the commercial based

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diet and the fatty acid composition of three diets enriched with three different levels (0, 5 and 10%) of LNA are presented in Table 1. The first experimental diet (LNA0) contained the commercial based diet without LNA. The second and third experimental diets, supplemented with 5 and 10% LNA, respectively. LNA were purchased from MP Biomedical (catalog number: 021202118; Aurora, OH, USA). LNA were added to the diets gradually mixing with the other ingredients.

Diets were prepared with a laboratory pelleting machine after adding 35-40 g distilled to 100 g mixture of the ingredients, and freeze-dried. After that diets were crushed to the approximate size of 0.7-2 mm and kept at -20°C until used.

Fish, facilities, sampling

This study was carried out at the Fisheries and Aquarium Research and Application Center of the Faculty of Fisheries of Ataturk University. A total of 300 brown trout fingerlings with an initial individual weight of 4±0.05 g (mean±SD) were randomly distributed in 12 cages (42 cm width x 42 cm depth x 50 cm height). Then four replicates of 700 L polypropylene aquaria were set up, and 3 cages (each containing 12 fingerlings) were put in each of them and kept under 24L:0D (light/dark) photoperiod condition for 9 weeks. Each cage received one of the three dietary profiles referenced above. Water was supplied from a well at a rate of 1 L/min, and a semi-recirculation system with partial sedimentation and bio-filtration was used to maintain stable conditions.

Table 1: The proximate and fatty acid compositions of the experimental diets (%).

	Experimental diets		
	LNA0	**LNA5**	**LNA10**
Proximate composition (%)			
Moisture	12.00	12.00	12.00
Crude protein	45.00	45.00	45.00
Crude lipid	20.16	+	+
Crude cellulose	3.00	3.00	3.00
Crude ash	12.00	12.00	12.00
Starch	8.00	8.00	8.00
Gross energy	4.71 kcal g^{-1}	4.94 kcal g^{-1}	5.17 kcal g^{-1}
Digestible energy	4.14 kcal g^{-1}	4.35 kcal g^{-1}	4.55 kcal g^{-1}
Metabolic energy	3.85 kcal g^{-1}	4.04 kcal g^{-1}	4.24 kcal g^{-1}
Fatty acid composition (mg 100 mg^{-1})			
∑ SFA	36.67	28.20	26.88
∑ MUFA	29.59	26.00	25.99
∑ n-3	20.16	27.75	31.05
∑ n-6	6.22	9.85	11.69
∑ n-3/n-6	3.24	2.82	2.66
EPA+DHA	21.33	18.98	12.96

Each aquarium cage was equipped with continuous aeration and the water temperature was 9.6±1.0°C (mean±SD). Fish were fed three times daily at a readjusted-restricted rate (5% body weight/day) for 9 weeks, with intermittent body weight and feed intake amounts measurements taken every one week. Mortality was recorded every day during the trial. Aquaria cages were cleaned and feces discarded by siphoning daily. At the conclusion of the nine-week feeding trial, survival, weight gain and feed consumption amounts were calculated, and two fishes from each aquarium were sampled for lipid and fatty acids measurement. Two additional fishes from each aquarium were also sampled and stored at -80°C for proximate analysis.

Proximate analysis

Whole-body lipids were extracted according to procedures pioneered by Folch *et al.* (1957). Other proximate analysis of diets and fish were performed according to the standard methods of AOAC (1990): dry matter after drying in an oven at 105°C until constant weight, crude protein (N x 6.25) by Kjeldhal method after acid digestion, ash content by incineration in a muffle furnace at 600°C for 12 h, and minerals by microwave digestion with HNO3 followed by Inductively Coupled Plasma (ICP) emission spectrometry.

Lipid and fatty acid analysis

Dietary and whole-body lipids were extracted according to the procedure of Folch *et al.* (1957). After extraction, whole body lipids were separated into polar (phospholipids) and neutral (mostly triglycerides) lipids using Sep-Pak silica cartridges (Waters, Milford, MA, USA). The mobile phases were chloroform and methanol for neutral and phospholipids, respectively (Juaneda and Rocquelin, 1985). Fatty acid methyl esters (FAME) were prepared according to protocols established by Metcalfe and Schmitz (1961) and analyzed as described earlier in the text (Czesny and Dabrowski, 1998). The FAMEs obtained were determined by gas chromatography (Agilent 6890 N), equipped with a flame ionization oven and fitted with a DB 23 capillary column (60 m, 0.25 mm i.d. and 0.25 µm) ejector. The detector temperature program was set at 190°C for 35 minutes, and then increased at a rate of 30°C/minute up to 220°C, where the temperature was maintained for five minutes. Carrier gas was hydrogen (2mL/min and split ratio was 30:1). The individual fatty acids were identified by comparing their retention times to that of a standard mix of fatty acids (Supelco 37 component FAME mix), and quantification of the individual fatty acids was made against a C19:0 internal standard from Sigma (USA). Fatty acids were expressed as percent of total identified FAME.

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Technical and economic efficiency analyses

The effects of feed intake including LNA10, LNA5 and LNA0 on body weight (BW) gains of brown trout were analyzed by taking into consideration the following production function:

$$TPP_{in} = f(F_{in}) \quad (1)$$

Where F_{in} is the daily feed intake amount based on the feed types (if ration covers feed types such as LNA10, LNA5 and LNA0; n presents from 1 to 3 numbers, and i refers to production levels of BW), and TPP_{in} refers BW calculated as a function of the F_{in}.

In order to measure the relationships between the feed intake amounts and *BW* gains of brown trout, and then to determine the optimal levels of BW gain, the technical production analyses including in Marginal Physical Product (MPP), Average Physical Product (APP) and Production Elasticity (E_P) were used (Topcu, 2013).

MPP is the extra output amount produced by using one more unit of the production factors (inputs), holding all other inputs fixed (caeteris paribus). MPP of a given experimental diet was expressed as follows:

$$MPP_{1,2in} = \frac{\Delta TPP_{1,2in}}{\Delta F_{1,2in}} \quad (2)$$

Where $\Delta F_{1,2in}$ and $\Delta TPP_{1,2in}$ are the changes in the feed amounts consumed and total physical product produced, respectively.

APP is the amount of total physical product produced per unit of the feed intake as a variable input. In other word, APP is found by dividing the total physical product by the amount of the variable feed, and was calculated by using the following mathematical notation:

$$APP_{in} = \frac{TPP_{in}}{F_{in}} \quad (3)$$

Where TPP_{in} and F_{in} explain the total physical product and the feed amount consumed, respectively.

The production elasticity (E_p) indicates approach, around how much per cent the production amount of the TPP changes, if the feed intake is increased by a per cent. In other word, it is the percentage change of the TPP divided by the percentage change of a feed intake. It was determined as follows:

$$E_p = \frac{\frac{\Delta TPP_{1,2in}}{TPP_{1in}} \cdot 100}{\frac{\Delta F_{1,2in}}{F_{1in}} \cdot 100} = \frac{\Delta TPP_{1,2in}}{TPP_{1in}} \cdot \frac{F_{1in}}{\Delta F_{1,2in}} \quad (4)$$

If the equation 4 could rearrange as follows:

$$E_p = \frac{\Delta TPP_{1,2in}}{\Delta F_{1,2in}} : \frac{TPP_{1in}}{F_{1in}} = \frac{MPP_{1,2in}}{APP_{1in}} \quad (5)$$

E_p was calculated by dividing the $MPP_{1,2in}$ (the equation 2) by the APP_{in} (the equation 3). It is used as a major measurement tool to reach to an optimal production level technically in terms of production economics. Moreover, it must be greater than 0, but less than 1 ($0<E_p<1$) to reach to the beginning and end limits of the rational production region determined by the maximum point of the APP_{in} equaling to the $MPP_{1,2in}$ (E_p=1) and the minimum point equaling to the zero of the $MPP_{1,2in}$ (E_p=0).

In order to be able to determine the economic optimum level, on the other hand, assessing the income and cost effects of BW based on the feed intakes of brown trout; Marginal Revenue of Physical Product (MRPP) and Marginal Factor Cost (MFC) were firstly calculated. If *MRPP* is equal to MFC or a little greater than MFC $(MRPP \geq MFC)$, it is assumed to have been reached to the economic optimum level (Yaylali, 2004; Topcu and Demir, 2005). MRPP and MFC were formulated by using the following equations:

$$MRPP_{1,2in} = \frac{\Delta TRPP_{1,2in}}{\Delta F_{1,2in}} = \frac{P_{pp}(\Delta TPP_{1,2in})}{\Delta F_{1,2in}} = P_{pp}(MPP_{1,2in}) \quad (6)$$

Where $\Delta TRPP_{1,2in}$ and P_{pp} indicate the change in the total revenue of physical product and the price of physical product ($ 4.3 giving the average of the producer prices collected per kg), respectively (FAOSTAT, 2012; TSI, 2012).

$$MFC_{1,2in} = \frac{\Delta TFC_{1,2in}}{\Delta F_{1,2in}} = \frac{P_{F_n}(\Delta F_{1,2in})}{\Delta F_{1,2in}} = P_{F_n} \quad (7)$$

Where $\Delta TFC_{1,2in}$ and P_{F_n} present the change in the total feed resource cost and the prices of the experimental feed considering the average of the producer prices collected per kg (P_{LNA0} = $6, P_{LNA5} = $27.5, P_{LNA10} = $47) (FAOSTAT, 2012; TSI, 2012).

Results

The technical and economic production levels of BW affected by feed consumptions of brown trout fed LNA10 diet were presented in Table 2. With 7.99 g BW gained in response to 6.54 g LNA10 feed intake, it was reached to the closest economic optimum level $(MRPP = 47.04 \geq MFC = 47.00)$. On the other hand, 13.06 g BW gains calculated for 8.39 g LNA10 feed consumption provided the technical optimum levels (the rational production region) with Ep_{LNA10} = 0.77 .

Table 3 shows the technical and economic production levels of relationships between BW and the feed intakes of brown trout fed by LNA5 referring as the commercial basal feed combined by 5% LNA. The closest economic optimum level $(MRPP = 27.89 \geq MFC = 27.50)$ was provided by 10.54 g BW gain achieved for 8.65 g LNA5 feed consumption. On the other hand, 7.50 g BW gain obtained per 7.56 g LNA5 feed intake made it possible to produce at the technical optimum level (the rational production region) with Ep_{LNA5} = 0.61.

Table 4 summarized the technical and economic production levels of relationships between BW and the feed intakes of brown trout fed by LNA0 called as the commercial basal feed. Both the economic optimum production level $(MRPP = 6.03 \geq MFC = 6.00)$ and the technical one (Ep_{LNA0} = 0.43) was provided by 10.68 g BW gain reached with 7.70 g LNA0 feed consumption.

Table 2: Determining the technical and economic production levels of BW based on LNA10 feed of brown trout.

BW	LNA10	ΔBW	ΔLNA10	MPP	APP	Ep_{LNA10}	MFC	MRPP
4.005	2.206	-	-	-	-	-	-	-
4.088	4.761	0.089	2.556	0.035	0.859	0.040	47.000	0.347
5.912	5.587	1.824	0.826	2.209	1.058	2.088	47.000	22.089
7.204	6.371	1.292	0.784	1.647	1.131	1.457	47.000	16.474
7.992	**6.539**	**0.788**	**0.168**	**4.704**	**1.222**	**3.849**	**47.000**	**47.038**
10.039	5.879	2.046	-0.660	-3.099	1.708	-1.815	47.000	-30.987
13.060	***8.390***	***3.021***	***2.511***	***1.203***	***1.557***	***0.773***	47.000	12.030
14.003	7.686	0.943	-0.704	-1.338	1.822	-0.735	47.000	-13.385
15.948	7.619	1.945	-0.067	-28.973	2.093	-13.841	47.000	-289.730

*Bold and italic bold numbers refer the economic optimum and technical optimum levels, respectivly.

Table 3: Determining the technical and economic production levels of BW based on LNA5 feed of brown trout.

BW	LNA5	ΔBW	ΔLNA5	MPP	APP	Ep_{LNA5}	MFC	MRPP
4.300	1.500	-	-	-	-	-	-	-
4.612	4.797	0.156	1.649	0.095	0.961	0.098	27.500	0.946
4.857	5.556	0.123	0.379	0.324	0.874	0.370	27.500	3.236
5.952	6.527	0.547	0.486	1.127	0.912	1.235	27.500	11.265
6.315	5.577	0.182	-0.475	-0.382	1.132	-0.337	27.500	-3.821
7.503	***7.560***	***0.594***	***0.991***	***0.599***	***0.992***	***0.604***	27.500	5.991
10.538	**8.649**	**1.518**	**0.544**	**2.788**	**1.218**	**2.288**	**27.500**	**27.885**
10.931	7.126	0.197	-0.761	-0.258	1.534	-0.168	27.500	-2.583
13.060	7.160	1.064	0.017	62.084	1.824	34.037	27.500	620.843

*Bold and italic bold numbers refer the economic optimum and technical optimum levels, respectively.

Table 4: Determining the technical and economic production levels of BW based on LNA0 *(*commercial basal diet) feed of brown trout.

BW	LNA0	ΔBW	ΔLNA0	MPP	APP	Ep_{LNA0}	MFC	MRPP
4.581	2.221	-	-	-	-	-	-	-
4.127	2.707	-0.453	0.486	-0.933	1.525	-0.612	6.000	-9.332
3.893	4.747	-0.235	2.040	-0.115	0.820	-0.140	6.000	-1.151
6.003	6.006	2.110	1.259	1.677	0.999	1.677	6.000	16.766
6.043	6.250	0.040	0.244	0.164	0.967	0.169	6.000	1.637
7.759	5.249	1.716	-1.001	-1.714	1.478	-1.159	6.000	-17.136
10.133	6.793	2.375	1.544	1.538	1.492	1.031	6.000	15.377
10.680	***7.700***	***0.547***	***0.907***	***0.603***	***1.387***	***0.434***	**6.000**	**6.026**
12.856	7.227	2.176	-0.473	-4.602	1.779	-2.587	6.000	-46.018

*Bold and italic bold numbers refer the economic optimum and technical optimum levels, respectively.

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Table 5: Fatty acid compositions (mg 100 mg^{-1}) of lipids accumulating in fat tissue of brown trout fed by the diets with three alternatives of LNA under a photoperiod condition of 24L:0D for 9 weeks.

Fatty acid composition (mg 100 mg^{-1})	Experimental diets		
	LNA0	**LNA5**	**LNA10**
∑ SFA	25.45	23.41	29.75
∑ MUFA	28.84	26.17	32.19
18:3 n-3	11.32	16.27	2.43
20:5 n-3	3.81	3.57	5.23
22:5 n-3	1.38	1.24	1.67
22:6 n-3	15.07	13.30	17.65
∑ **n-3**	**35.08**	**38.03**	**40.22**
∑ n-6	9.90	11.84	6.99
∑ **n-3/n-6**	**3.51**	**3.21**	**4.32**
EPA+DHA	**18.89**	**16.88**	**22.88**

Discussion

The results of this study showed that the equations between MFC and MRPP calculated by taking into account the 7.99 g, 10.54 g and 10.68 g BW gains of brown trout fed by three experimental diets including the 6.54 g LNA10, 8.65 g LNA5 and 7.70 g LNA0 feed intakes, were reached to the closest economic optimum production levels with about 47, 27.5 and 6, respectively. However, the Ep at the economic optimum levels calculated for LNA10, LNA5 and LNA0 were determined as 3.85, 2.29 and 0.43 respectively. While the 3.85 and 2.29 (Ep>1) of these results were supported by a few limited number studies of Ep>1 calculated as 12.29 of Ep at the economic efficiency level of the relationships between the poultry diets treated by supplementary ingredient and the poultry production (Alabi and Uruna 2006); they were found fairly different from the findings of the others reported as 0<Ep<1 of *Eps* with the range 0.4 and 0.98 (Oladeebo and Ambe-Lamidi, 2007; Begum *et al.*, 2011; Mohaddes, 2011; Topcu *et al.*, 2013), however, 0.43 of those was compatible with the results of the second group research with the range 0.4 and 0.98 Ep.

The production at the economic efficiency levels of brown trout for LNA10 and LNA5 intakes mean that took place at the stage I of total physical product (TPP) curve (the inefficient region is the rapidly increasing production region), and that occurred a bigger increase than one percent increase in BW gains of brown trout in response to one percent increase in their LNA10 and LNA5 feed intakes. Therefore, the pressure on the total factor cost (TFC) of the additional LNA10 and LNA5 purchased from the higher prices prevented progress to the rational production region due to the low market price of brown trout. In other words, the higher the ratios of MFCs or the prices of LNA10 and LNA5 within total production cost, the

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lower the growing period or their additional feed intakes with much higher effects on the growth of brown trout as compared with LNA0 consumption on that, and then the fish farms' limited production budgets as a scarce source would be used at the inefficient production stage and a smaller production scale preventing the profit maximization.

When such a production was carried out for LNA10 and LNA5 intakes, it was not utilized from the advantages of the scale economics, and the cost factor may cause the cost per product to increase dramatically as a result of the inefficiency of the scarce production sources. The competitiveness power and penetration rate of brown trout farms at the target market, therefore, will decrease considerably, and they could have to withdraw from relative sectors in the middle and long terms resulting in continuous decrease of the assets and liabilities, especially liquid capitals, based on farm current performance.

On the other hand, the firms having a much lower ratio within the TFC of the MFC for LNA0 intake with a much less effect on the growth of brown trout could have a sustainable competitiveness power through the technical and economic efficiencies (Ep=0.43) at the target markets, and thus achieve more assets at the long term by increasing their net profits at the current production period due to producing at the stage II (0<Ep<1) of TPP curve.

The result of the present study also indicated that the technical efficiency levels (0<Ep<1) with 0.77, 0.60 and 0.43 Ep calculated by being considered 13.06 g, 7.50 g and 10.68 g BW gains of brown trout fed by 8.39 g LNA10, 7.56 g LNA5 and 7.70 g LNA0 intakes were determined. The results of the present study are similar to those of the previous research conducted on the technical efficiency levels restricted by the Eps varying between 0.10 and 0.99, and considering the relationships between hens' performances and their feed intakes (Ojo, 2003; Alabi and Uruna, 2006; Binuomote *et al.*, 2008; Change and Villano, 2008; Ashagidigbi *et al.*, 2011; Begum *et al.*, 2011; Heidari *et al.*, 2011; Mohaddes, 2011; Topcu *et al.*, 2013;).

However, the economic and technical efficiencies of LNA0 took place at the same production level, and thus the fish growers applying LNA0 had higher profit maximization through larger production scales and the scarce source effects when compared with those using LNA10 and LNA5 due to lower feed and feeding cost. This level with 0.43 Ep for LNA0 compared with LNA10 and LNA5, furthermore, provided higher increasing return to scale on the advantages of lower MFC (MFC for LNA0 is much lower than the others) and at the closest production scale to the maximum level of TPP at the stage II (rational region) of the TPP curve. On the other hand, although the technical efficiency levels with 0.77 and 0.60 Eps of LNA10 and LNA5,

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respectively, were at the stage II of TPP curve owing to MPP and APP, their scales with very low production volumes were the closest to the inefficient regions, and at the same time their economic efficiency levels were limited by the stage I of TPP (inefficient region).

The commercial feeds enriched by LNA10 and LNA5 effecting on the growth of brown trout, therefore, must not be used economically in the production of a homogenous product in terms of the technical and economic efficiencies at this stage (inefficient region) because of their very high MFCs (about 7.8 and 4.5 times higher than the MFC of LNA0). However, it could be accessed to the stage II (rational region) through the differentiated product strategies creating the price discrimination focused on the different sales prices at the monopolistic competitive and oligopoly markets by taking into account the various levels of LNA accumulated in fat tissues of brown trout, and then the MFCs of LNA10 and LNA5 could be equaled to the MRPPs at the stage II, maximizing the profit in terms of the technical and economic efficiencies.

In fact, the product differentiation subjected to 23 and 17 mg EPA+DHA as well as 4.3 and 3.2 n-3/n-6 existing in fatty acid compositions of brown trout fed by the diets enriched with 10 and 5% LNA, respectively (Table 5) will lead to the price discrimination, the MFCs equal to the MRPPs, at the stage II of the TPP curve. The prices of brown trout fed by LNA10 and LNA5, then, could calculate as $39 and $46, respectively, and thus LNA10 could be always preferred to LNA5 due to the advantages on the growth performance, higher n-3/n-6 ratio and EPA+DHA amount in the accumulated fatty acid composition of brown trout fed by LNA10 and a lower market price as a differentiated product.

As a result, the LNA0 and LNA10 preferred to LNA5 should be used for the production of brown trout demanded by the consumers as a homogenous product at the target markets, and for that needed by the drug industry focusing on the EPA+DHA and n-3/n-6 fatty acids as a differentiated product at the monopolistic competitive and oligopoly markets, respectively in terms of the technical and economic efficiencies limited by the stage II (rational region) of TPP curve.

The results of this study which was aimed to analyze the relationships between the growth and feed intakes of brown trout fed by LNA10, LNA5 and LNA0 indicated that their technical efficiencies took place at the stage II (the rational region) of TPP curve, and LNA0 was used in a much closer level to the scale maximizing the profit arising from much lower MFC, as compared with the others. On the other hand, the results also indicated that while the economic efficiencies of LNA10 and LNA5 occurred at the stage I (the inefficient region) of TPP curve;

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the economic efficiency of LNA0 was obtained at stage II considering the equations between MFC and MRPP. In order to be able to access the rational production regions from the inefficient regions of brown trout's farms producing with LNA10 and LNA5, therefore, the growers should be of the product prices with $39 and $46, respectively which the *MFC* equates to the MRPP through the product differentiation according to the ratios of EPA+DHA and n-3/n-6 fatty acid accumulated in the fat tissues of brown trout, and then whereas brown trout fed by LNA0 could supply to the target markets as a homogenous product, those consumed LNA10 preferred to LNA5 in terms of the economic efficiencies, could be used in the drug industry based on the EPA+DHA and n-3/n-6 fatty acids as a differentiated product. Consequently, the growers could achieve a major benefit in terms of the effective usage of the scarce source by producing at the technical and economic optimum levels.

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