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RESEARCH PAPER

Cultural Energy Use and Energy Use Efficiency of a Small-Scale Rainbow Trout (*Oncorhynchus mykiss* Walbaum, 1792) Cage Farm in the Inland Waters of Turkey: A Case Study from Karacaören-I Dam Lake

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Abstract

The purpose of this study was to assess cultural energy (CE) use and energy use efficiency of a commercial small scale rainbow trout (*Oncorhynchus mykiss*) cage farm in the inland waters in Karacaören Dam Lake, Isparta, Turkey. Data collected for each production year were: number and total weight of fingerlings, amount of feed consumed, amount of antibiotics, vitamin, labor, diesel, oxygen used, number and total weight of marketed trout, distance for transportation of fingerlings, machinery, and equipment with their depreciation rate. Total CE use was the sum of CE expended on feed, general management, transportation, machinery, and equipment. CE expended on compound diet constituted 77.40% of total CE. CE expended for a kg of liveweight gain was 2.69 Mcal. Protein energy production efficiency in carcass and fillet was 4.30 and 7.49 Mcal, respectively. CE energy use efficiency for carcass and fillet were 4.21 and 6.89, respectively. Results showed that in order to compare the sustainability of aquaculture production systems energy use efficiency which is an indicator of sustainability should be determined.

Introduction

Share of rainbow trout (*Oncorhynchus mykiss*) in world aquaculture production quantity in the third millennium increased from 495,727 tons in 2000 to 811,590 tons in 2017, corresponding to a 63.7% increase and this quantity's value was 1,372,816,000 and 3,604,896,000 USD, in 2000 and 2017, respectively. According to FAO, Turkey's rainbow trout production was 44,533 tons in 2000 and 112,427 tons in 2018, and more than 90% of this production was obtained from the aquaculture activities in inland freshwaters (FAO, 2020). According to a report published in 2020 however reporting statistics in 2019 by General Directorate of Fisheries and Aquaculture of Turkey, , there are 1,178 project-based trout producing facilities with a yearly capacity of less than 50 tons which produce total of 19,110 tons of trout per year in Turkey's inland freshwaters (BSGM, 2020).

World primary energy production was 13,790 billion kilotonnes of oil equivalent (ktoe) in 2015 and global energy use by the end of 2016 was 13,147 billion ktoe (Koç *et al*., 2018). Energy demand will rise by 1.3% each year until 2040, thus with increasing demand for energy, further efforts to improve energy use efficiency should be sought (IEA, 2020). In this respect, studies on energy policies should support the holistic approach of sustainable development in determining sustainable energy infrastructure (Gatto & Drago, 2020).

In aquaculture, species, nutritional habits and aquaculture systems cause differences in energy use. This makes it difficult to establish basic rules in determining energy use efficiency (Pelletier *et al*., 2011). However, in aquaculture, the energy use efficiency of the species and production systems should be simplified and compared with other animal species (Boyd *et al*., 2007) and food production systems (Troell *et al*., 2004). In aquaculture, embodied energy can play an important

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role in economic and industrial energy analysis (IEA), especially in intensive farming (Troell *et al*, 2004).

Nowadays, food systems remain dependent on non-renewable energy sources. The relationships between the inputs to which we depend on energy and the efficiency of food systems have a complex nonlinear structure. Supporting the energy performance of food systems with current research is especially important in the evaluation of energy dependencies in developing countries (Pelletier *et al*., 2011). There are very few studies on energy use in fish production (Sarkar & Tiwari, 2006). On the other hand, fisheries and aquaculture need sustainable ecosystem management (Cahu, 2019). The use of energy in agriculture requires optimization that increases productivity, and that it can be implemented by managing correctly without affecting the productivity or energy efficiency of existing energy inputs. However, energy inputs are not used effectively in farms in the agricultural sector (Singh *et al*., 2004: Usubiaga-Liaño et al. 2020). The feed has the highest share in total cultural energy expenditure in animal agriculture production systems (Koknaroglu *et al*., 2006; Koknaroglu & Atilgan, 2007; Koknaroglu *et al*., 2007a; Çınar & Köknaroğlu, 2019). Energy use/unit calorie production is higher in intensive livestock and aquaculture production compared to agricultural products (Pelletier *et al.*, 2011).

Cook *et al* (1976) defines cultural energy as "the energy included in fossil fuels or other sources of energy that supplements solar energy in the production of food. This energy comes from labor, transportation, and electricity to produce and process foods. The energy required to manufacture machinery, fertilizers, and pesticides that are used in agriculture is also considered energy that subsidizes solar energy in producing plant growth". Or in another words, cultural energy is the energy other than solar energy needed to produce food and fiber. Energy output/input ratio is one of the most useful methods to examine the potential long-term sustainability of various agricultural practices. This analysis is performed to quantify the energy return from products produced relative to the cultural energy invested to produce the product (Heitschmidt *et al*., 1996). There has been research examining energy use efficiency in livestock production (Koknaroglu *et al*., 2006; Koknaroglu & Atilgan, 2007; Koknaroglu *et al*., 2007a; Çınar & Köknaroğlu, 2019), however, there is not any study on energy use efficiency of fish production in Turkey. Thus, the purpose of this study was to determine cultural energy use and energy use efficiency of small-scale rainbow trout cage farm in the inland waters of Turkey.

Materials and Methods

Rainbow Trout (*Oncorhynchus mykiss*) Farming and Management

Rainbow trout production was carried out in cages of Canlar Alabalık enterprise located in Karacaören-I Dam Lake in Sütçüler district of Isparta province in Turkey (37^0 24′ 47.3010′′ N, 30^0 52′ 26.8255′′ E and altitude: 258.1 m.). Enterprise had a capacity of 49 tons per year. The cage dimensions were 125 m^3 (5m × 5m × 5m). Rainbow trout fingerlings on average weighing 34, 45, and 47 g and 120-150 DAH (days after hatching) were stocked on November 15, November 20, and November 20 in the 2016-2017 (first), 2017-2018 (second), and 2018-2019 (third) production year, respectively. In the beginning, fingerlings were stocked in 20 cages, but later as they grow they were distributed to 30 cages by feeding protocol, and were marketed at liveweight of 200-300 g. (Table 1). In 2016-2017 production year, the feeding period lasted for 120-150

Table 1. Feeding and rearing information of rainbow trout

Days fed	T ^{0}C	O_2	Size weight (g)	Σbiomass (kg)	Stock (number)	Live (number)	Dead (number)	Diet	Σdiet (kg)	A&V (kg)	FCR
First year (2016-2017)											
30	14-16		30-50	4,250	125,000	122,000	3.000	D1	5,000		1.05
30-60	14-10		60-120	9,000	122,000	121,948	52	D2	7,500		1.0
60-90	9-10	≤9	120-180	16,500	121,948	121,915	33	D3	9,000	5.0&5.0	1.0
90-120	9-12		150-200	25,500	121,915	121,877	38	D4	10,000		1.05
120-150	12-16		200-300	35,000	121,877	121,800	77				1.02
								Σ	31,500		
Second year (2017-2018)											
30	13-15.5		45	4,275	95,000	92,150	3.850	D1	3,000		1.0
30-60	13-10		60-85	7,275	92,150	92,000	150	D2	4,000		1.0
60-100	9-10	≤9	100-135	11,250	92,000	91,975	25	D3	5,000	5.0&7.5	1.0
90-130	9-12		150-180	16,250	91,975	91,968	7	D4	6,250		1.0
130-160	12-14		200-250	22,500	91,968	91,950	18				0.99
								Σ	18,250		
Third year (2018-2019)											
30	12-15		25	4,000	85,000	82,300	2.700	D1	2,500		0.94
30-50	12-10		50-60	6,500	82,300	82,277	23	D1	2,000		
50-80	9-11		80-120	8,000	82,277	82,255	22	D2	4,000		1.0
80-120	12-14	≤9	100-150	12,000	82,255	82,250	5	D3	4,000	4.0&5.0	1.0
120-150	14-15		200-230	16,000	82,252	82,252	0	D4	4,250		0.94
150-175	14-16		230-250	20,000	82,252	82,252	0				0.96
								Σ	16,750		

Description: O_2: oxygen (ppm), T: temperature, Diet: commercial compound diet (D), D1 (46% Crude Protein and 19% Crude Oil), D2, D3, D4 (45% Crude Protein and 20% Crude Oil), A&V: antibiotic&vitamin, FCR: feed conversion ratio.

days, at the beginning stocking rate for fingerlings was 50 fish per m^3 thus adding to 1.70 kg fish per m^3 and at harvest 32.50 fish per m^3 thus adding to 9.33 kg fish per m^3 were stocked in each cage. In 2017-2018 production year, the feeding period lasted for 130-160 days, at the beginning stocking rate for fingerlings was 38 fish per m^3 thus adding to 1.71 kg fish per m^3 and at harvest 24.52 fish per m^3 thus adding to 6.00 kg fish per m^3 were stocked in each cage. In 2018-2019 production year, the feeding period lasted for 150-175 days, at the beginning stocking rate for fingerlings was 34 fish per m^3 thus adding to 1.60 kg fish per m^3 and at harvest 21.93 fish per m^3 thus adding to 5.33 kg fish per m^3 were stocked in each cage (Table 1). Rainbow trout feeding protocol is provided in Table 1. In 2016-2017, 2017-2018, and 2018-2019 production years, rainbow trout fingerlings were purchased from hatcheries being 60, 9, and 100 km away from the farm, respectively. Depending on the carrying capacity of the truck, total of 240, 36, and 400 km was traveled in 2016-2017, 2017-2018, and 2018-2019 production year, respectively. Rainbow trout were sold at the farm and purchased compound diet was delivered to the farm.

Cultural Energy Analysis

Cultural energy inputs and outputs for cage farming were calculated based on the values reported in Table 2. When commercial diets' feed information was examined, it was noted that Diet-1 provided 46% CP, 19% CO, 10% CA, 1.5% CF, 4,000 Mcal ME kg^{-1}, and Diet-2, 3 and 4 provided 45% CP, 20% CO, 9.5% CA, 1.7% CF, 4,000 Mcal ME kg^{-1} and to formulate this diet, fish meal, fish oil, soybean meal, wheat grain, wheat by-products, vitamin, and mineral were used (Table 3). The cultural energy values of Diet-1, 2, 3, and 4 were calculated by multiplying the amount of feed ingredients by the amount of unit cultural energy value obtained from the literature (Table 4). Cultural energy expended on consumed compound diet was calculated by multiplying the total amount of diet consumed by cultural energy value of the diet. Cultural energy expended on general management included cultural energy expended for antibiotics, vitamin, labor, diesel, and oxygen. Transportation energy was also included in the analysis and, shipping fingerlings from hatcheries to the farm accounted for transportation energy. When calculating transportation energy, 0.00083 Mcal value reported by Pimentel (1980) for transporting 1 kg mass for 1 km was used. Cultural energy expended on machinery and equipment was calculated by multiplying the amount of machinery and equipment by cultural energy value of the item divided by the depreciation rate. Total cultural energy expended was the summation of energy expended on feed, general management, transportation, machinery, and equipment (Table 5). When calculating energy deposited in the carcass and fillet it was assumed that dressing percentage was 81 and 57.5%, respectively, and carcass and fillet content would have 17.96% protein and 2.47% fat (Tatıl, 2019). Energy values of 1 g of protein and fat were taken as 5.7 kcal and 9.4 kcal, respectively. Total energy deposited in the carcass was calculated as carcass energy, Mcal = (carcass weight × carcass protein ratio × unit protein

Table 2. Cultural energy values for inputs and outputs of the rainbow trout cage production

Items	Unit	Mcal $unit^{-1}$	References
		Inputs	
Fish fingerling	kg	1.45	Mehrabi *et al*. (2012)
Feed ingredients			
fish meal	kg	4.45	Davulis & Frick (1977)
fish oil	kg	2.38	Davulis & Frick (1977)
Soybean meal	kg	0.93	Smith *et al*. (2007)
wheat grain	kg	0.95	Davulis & Frick (1977)
wheat by-products	kg	0.08	Davulis & Frick (1977)
Vitamin	kg	0.09	Chatvijitkul *et al.* (2017)
Mineral	kg	0.09	Chatvijitkul *et al.* (2017)
Diet-1	kg	2.89	Calculated
Diet-2, 3, 4	kg	2.89	Calculated
Antibiotic	kg	239	Stone *et al*. (2011)
Vitamin	kg	0.09	Chatvijitkul *et al.* (2017)
Labour	h	0.544	Cook *et al*. (1980)
Diesel	L	11.414	Cervinka (1980)
Oxygen	L	1.79	Frischknecht *et al.* (2007)
Cage net and rope	kg	0.40	Pimentel *et al*. (1996)
Iron	kg	6.63	Tiwari (2003) Sarkar *et al*. (2007)
Boat (*sheet iron*)	kg	1.43	Miró *et al*. (2015)
Boat (*engine iron*)	kg	6.63	Tiwari (2003)
Styrofoam flotation	kg	27.99	Baird *et al*. (1997)
Vault (*cement* -)	kg	0.10 -	Baird *et al*. (1997)
Vault (*iron*)	kg	6.63	Tiwari (2003)
		Outputs (1 kg of processed fish as)	
Carcass		1.02	Tatıl (2019)
Fillet		0.72	Tatıl (2019)

energy) + (carcass weight × carcass fat ratio × unit fat energy). In calculating total energy deposited in the fillet, the same formula used for carcass energy was used. Since this study aims to analyze cultural energy input of the production system, it is important to know the whole-body energy of fingerlings. When calculating whole-body energy of fingerlings, it was assumed that fingerlings would have 8.16% protein and 10.51 % fat (Mehrabi *et al*., 2012), and the same formula used for carcass and fillet energy was used. Energy deposited in the carcass during feeding was calculated as total carcass energy subtracted by fingerling whole-body energy. The energy required to produce protein energy for carcass or fillet was calculated by dividing total cultural energy expended by carcass or fillet protein energy content. Cultural energy use efficiency for carcass or fillet, defined as cultural energy input per energy output, was calculated by dividing total cultural energy expended by energy deposited in carcass or fillet (Table 5). Cultural energy input for total production, kg and 1,000 marketed fish and output for production years are provided in Table 5.

Results and Discussion

Cultural energy expenditure and energy use efficiency values of kg marketed or 1,000 marketed rainbow trout are given in Table 5. Cultural energy expended on the compound diet per kg of marketed fish for first, second, third year, and the average of three

Table 3. Proximate composition of feed ingredients and formulation of compound Diet-1 (46% CP, 19% CO, 10% CA, 1.5% CF, 4,000 Mcal ME kg^{-1}), and Diet-2, 3, and 4 (45% CP, 20% CO, 9.5% CA, 1.7% CF, 4,000 Mcal ME kg^{-1}) *

Proximate composition of feed ingredients								
P	Fish Meal	Fish Oil	Soybean Meal	Wheat Grain	Wheat Middlings	Vitamin	Mineral	∑
CP	66.95	0	46.40	13.08	15.81			
CO	8.83	100	1.09	2.10	3.00			
CA	15.40	0	7.95	2.06	3.64	100	100	
CF	0.70	0	6.08	3.11	6.97			
ME	3,559	8,766	2,712	2,789	2,623			
Constituent of Diet-1 providing (46.0% CP, 19.43% CO, 10.86% CA, 3,994.60 ME kg^{-1})								
%	50.47	14.48	23.15	9.23	1.67	0.50	0.50	
CP	33.79	0	10.74	1.21	0.26			46.00
CO	4.46	14.48	0.25	0.19	0.05			19.43
CA	7.77	0	1.84	0.19	0.06	0.50	0.50	10.86
CF	0.35	0	1.41	0.29	0.12			2.16
ME	1,796.23	1,269.32	627.83	257.42	43.80			3,994.60
Constituent of Diet-2, 3, and 4 providing (44.99% CP, 20.08% CO, 10.69% CA, 4,031.97 ME kg^{-1})								
%	50.31	15.12	20.54	10.36	2.67	0.50	0.50	
CP	33.68	0	9.53	1.36	0.42			44.99
CO	4.44	15.12	0.22	0.22	0.08			10.69
CA	7.75	0	1.63	0.21	0.10	0.50	0.50	10.69
CF	0.35	0	1.25	0.32	0.19			2.11
ME	1,790.53	1,325.42	557.04	288.94	70.03			4,031.97

*The proximate composition of the feed ingredients is taken from Feedipedia (2020) and the proximate compositions of the formulation are arranged. P: proximate; CP: crude protein; CO: crude oil; CA: crude ash; CF: crude fibre; ME: metabolic energy. The difference is reflected in the calculation due to rounding.

Table 4. Cultural energy value of kg of Diet-1, 2, 3, and 4*

FI	Cultural energy value (Mcal kg^{-1}) (A)	Diet-1 Percent in compound diet (%) (B)	Diet-1 Value (Mcal kg^{-1}) (A*B)/100	Diet-2, 3, 4 Percent in compound diet (%) (C)	Diet-2, 3, 4 Value (Mcal kg^{-1}) (A*C)/100
FM	4.45	50.47	2.-24	50.31	2.24
FO	2.38	14.48	0.34	15.12	0.36
SM	0.93	23.15	0.22	20.54	0.19
WG	0.95	9.23	0.09	10.36	0.10
WM	0.08	1.67	0.00	2.67	0.00
V	0.09	0.50	0.00	0.50	0.00
M	0.09	0.50	0.00	0.50	0.00
		Σ	2.89	Σ	2.89

*FI: feed ingredients; FM: fish meal, anchovy; FO: fish oil; SM: soybean meal; WG: wheat grain; WM: wheat middlings; V: vitamin; M: mineral. The difference is reflected in the calculation due to rounding.

years was 2.60, 2.34, 2.42, and 2.46 Mcal, respectively (Table 5). On average, cultural energy expended on feed constituted 77.40% of total cultural energy expenditure (Figure 1). This ratio is similar to that reported by Pelletier *et al*. (2011) who found that feed constituted 53-86 % of energy input in aquaculture. However, this ratio was higher than those reported by Demircan & Koknaroglu (2007), Koknaroglu (2008), Koknaroglu & Hoffman (2019) who conducted research on feedlot beef cattle and Koknaroglu (2010), Çınar & Köknaroğlu (2019) who conducted research on dairy cattle. However, this ratio was similar to Koknaroglu & Atilgan (2007) who conducted research on broiler production. The reason for rainbow trout to have a higher ratio of expenditure on feed is being carnivorous and requiring higher quality of feed (fish meal, fish oil, soybean meal, etc). Koknaroglu (2008) and Çınar & Köknaroğlu (2019) reported that kg of concentrate feed for beef cattle and dairy cattle had cultural energy value of 1.13 and 1.30, respectively, whereas in this study kg of compound Diet-1 and other diets had cultural energy value of 2.89, respectively. The reason trouts having similar ratio of expenditure on feed with broiler is that broiler also require high-quality feed ingredients (Koknaroglu & Atilgan, 2007). Cultural energy expended on the general management per kg of marketed fish and per 1,000 marketed fish is provided in Table 5. The average of three years for cultural energy expended on the general management per kg of marketed fish and per 1,000 marketed fish was 0.53 and 135.44, respectively (Table 5). Diesel contributed to most of the cultural energy expended on general management. Cultural energy expended on transportation per 1,000 marketed fish for first, second, third year, and the average of three years was 7.36, 1.46, 18.16, and 9.00 Mcal, respectively (Table 5). Cultural energy expended on transportation varied among production years and the reason for this was that as mentioned in the materials and methods section, the distance of hatchery varied for years and compound diet was delivered to the farm, and fish were marketed at farm meaning that no transportation was involved. The average of three years for cultural energy expended on machinery and equipment per kg of marketed fish and per 1,000 marketed fish was 0.20 and 50.93, respectively (Table 5). Cultural energy expended on general management and machinery and equipment per kg of marketed fish and per 1,000 marketed fish were lowest for the first year and highest for the third year and the reason for this was that production amount decreased as the year proceeded. Total cultural energy expended per kg of marketed fish and per 1,000 marketed fish are given in Table 5. Total cultural energy expended per kg of marketed fish for first, second, third year, and the average of three years was 3.13, 3.15, 3.40, and 3.22 Mcal, respectively. And total cultural energy expended per 1,000 marketed fish for the first, second, third year and the average of three years was 898.96, 770.29, 826.41, and 831.88 Mcal, respectively. Total cultural energy expended per kg of marketed fish increased as years proceeded and the reason for the first year to have lower total cultural energy expenditure per kg of marketed fish is that it had lower cultural energy expended on general management. Production size (amount) directly affects the cultural energy expended on general management and this brings the importance of production size to be questioned. This farm has a full capacity of 49 tonnes and in the first, second, and third year they used 71.43, 45.92, and 40.82% of the full capacity.

Since the objective of the study was to evaluate cultural energy analysis of the production systems, energy that the fingerlings had deposited in their muscle and fat tissue when they were bought had to be known. For this purpose, values in literature were used to calculate it and for a kg of marketed fish it was a constant number of 1.45 Mcal (Table 5). Cultural energy

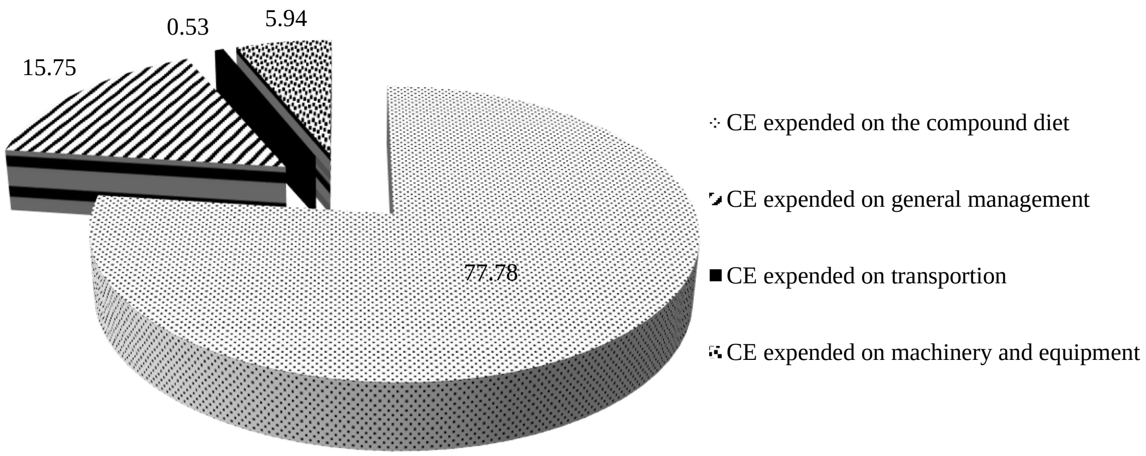

Figure 1. Cultural energy (CE) shares of the total expended cultural energy according to the three-year average values (%)

expended for compound diet per day was found by dividing cultural energy expended on the consumed compound diet to days fed (Table 2). Cultural energy expended for compound diet per day for 1,000 marketed fish for first, second, the third year, and average of three years was 6.28, 4.45, 4.09, and 4.94 Mcal, respectively. Explanation on how to calculate total carcass energy was given in the materials and methods section and the energy content of marketed carcass and fillet were a constant value of 1.02 and 0.72 which were derived from the literature (Tatıl, 2019). Energy deposited in carcass during feeding is found by subtracting fingerlings' whole-body energy content from marketed fish's carcass energy content. Energy deposited in carcass during feeding was 0.84, 0.74, 0.73, and 0.77 for first, second, third year, and the average of three years, respectively. Energy deposited in fillet during feeding was 0.55, 0.45, 0.43, and 0.47 for first,

Table 5. Cultural energy input for total production, kg and 1,000 marketed fish and output for production years

Items	Unit*	First year	Second year	Third year	Average
CE expended on consumed compound diet, Mcal	Total	91,035.00	52,742.50	48,407.50	64,061.67
	kg	2.60	2.34	2.42	2.46
	1,000 fish	747.41	573.60	588.54	636.52
CE expended on general management	Total	12,671.47	13,060.41	13,179.90	12,970.59
	kg	0.36	0.58	0.66	0.53
	1,000 fish	104.04	142.04	160.24	135.44
CE expended on transportion	Total	896.40	134.46	1,494.00	841.62
	kg	0.03	0.01	0.07	0.04
	1,000 fish	7.36	1.46	18.16	9.00
CE expended on machinery and equipment	Total	4,890.53	4,890.53	4,890.53	4,890.53
	kg	0.14	0.22	0.24	0.20
	1,000 fish	40.15	53.19	59.46	50.93
Total CE expended	Total	109,439.39	70,827.89	67,971.92	82,764.40
	kg	3.13	3.15	3.40	3.22
	1,000 fish	898.96	770.29	826.41	831.88
Total energy of 30 g fish cultured on the farm	Total	6,175.51	6,211.83	5,812.24	6,066.53
	kg	1.45	1.45	1.45	1.45
	1,000 fish	49.40	65.39	68.38	61.06
CE expended for compound diet, Mcal day^{-1}	Total	765.00	408.86	336.16	503.34
	kg	0.02	0.02	0.02	0.02
	1,000 fish	6.28	4.45	4.09	4.94
Energy content of marketed carcass	Total	35,604.77	22,888.78	20,345.58	26,279.71
	kg	1.02	1.02	1.02	1.02
	1,000 fish	292.32	248.93	247.36	262.87
Energy deposited in carcass during feeding	Total	29,429.26	16,676.95	14,533.34	20,213.18
	kg	0.84	0.74	0.73	0.77
	1,000 fish	241.62	181.37	176.70	199.90
Energy content of marketed fillet	Total	25,274.99	16,248.21	14,442.85	18,655.35
	kg	0.72	0.72	0.72	0.72
	1,000 fish	207.51	176.71	175.60	186.61
Energy deposited in fillet during feeding	Total	19,099.48	10,036.37	8,630.61	12,588.82
	kg	0.55	0.45	0.43	0.47
	1,000 fish	156.81	109.15	104.93	123.63
CE expended for kg marketed carcass		3.86	3.89	4.20	3.98
CE expended for kg marketed fillet		5.44	5.47	5.91	5.61
CE expended for 1 kg liveweight gain		3.56	2.30	2.21	2.69
Energy conversion ratio for human consumption					
Protein energy production efficiency in carcass (Mcal input/Mcal protein energy output)		4.05	4.25	4.62	4.30
CE energy use efficiency for carcass (Mcal input / Mcal output)		3.72	4.25	4.68	4.21
Protein energy production efficiency in fillet (Mcal input / Mcal protein energy output)		5.88	9.73	6.86	7.49
CE energy use efficiency for fillet (Mcal input / Mcal output)		5.73	7.06	7.88	6.89

*Kg; per kg of marketed fish, 1,000 fish; per 1,000 marketed fish. CE: cultural energy. The difference is reflected in the calculation due to rounding. The difference is reflected in the calculation due to rounding.

second, third year, and the average of three years, respectively. Cultural energy expended for kg marketed carcass was found by total cultural energy expenditure to total carcass produced and it was 3.86, 3.89, 4.20, and 3.98 for first, second, third year and the average of three years, respectively. Cultural energy expended for kg marketed fillet was found by total cultural energy expenditure to total carcass produced and it was 5.44, 5.47, 5.91, and 5.61 for first, second, third year and the average of three years, respectively. Cultural energy expended for 1 kg liveweight gain is provided in Table 5 and was 3.56, 2.30, 2.21, and 2.69 for first, second, third year, and average of three years, respectively. Cultural energy expended for 1 kg liveweight gain is obtained by dividing total cultural energy expenditure to liveweight gain during the production period and it is influenced by the performance of fish and cultural activities.

The energy conversion ratio for human consumption header was created to discuss the relevance of energy obtained from consumed protein and total carcass and fillet energy. Protein energy production efficiency in carcass and fillet which is calculated as Mcal input/Mcal protein energy output is provided in Table 5. This value denotes the Mcal of cultural energy expended to receive Mcal of energy coming from protein in carcass and fillet. Protein energy production efficiency in carcass and fillet for average of three years was 4.30 and 7.49, respectively. These values are lower (better) than values reported by Koknaroglu *et al*. (2007a), Koknaroglu *et al*. (2007b), Demircan & Koknaroglu (2007), and Koknaroglu (2008) who conducted research on beef cattle. Pimentel *et al*. (1975) found that range cattle had lower CE per Mcal of protein-energy than feedlot fed cattle. Pimentel (2004) reported that kcal of fossil energy required to produce 1 kcal of animal protein was 40 and 20 kcal input/ kcal protein for beef cattle fed with grain and forage mixture and those fed only with forage, respectively. Compared to other animal species cultural energy per Mcal of protein-energy in this study was similar to those found by Koknaroglu & Atilgan (2007) who conducted research on broiler production and was lower (better) than those reported by Sağlam & Köknaroğlu (2016) who conducted research on dairy cattle. Cultural energy use efficiency in carcass and fillet which is calculated as Mcal input/Mcal energy output in carcass and fillet is provided in Table 5. This value denotes the Mcal of cultural energy expended to receive Mcal of energy coming from carcass and fillet. Cultural energy use efficiency in carcass and fillet for average of three years was 4.21 and 6.89, respectively. These values are lower (better) than values reported by Koknaroglu *et al*. (2007b) who conducted research on lamb production. Compared to other animal species cultural energy use efficiency in this study was higher (worse) than those reported by Koknaroglu *et al*. (2007a), Koknaroglu & Atilgan (2007), Koknaroglu (2010), Sağlam & Köknaroğlu (2016), and Çınar & Köknaroğlu (2019). The reason for trout production to have better protein energy production efficiency in carcass and fillet than beef, dairy cattle, and lamb production was that in trout carcass most of the energy came from protein (trout carcass had 17.96% protein and 2.47% fat). On the other hand, trout production to have worse cultural energy use efficiency than beef, broiler, and dairy cattle was that trout carcass had lower-fat content than beef (35%), broiler (15%), and milk (3.5%) and thus making total carcass and fillet energy content low.

In a study aiming to assess the energy use pattern of Indian major carp production in open and greenhouse pond, Sarkar & Tiwari (2006) found that specific energy which corresponds to our energy use efficiency was 12.88 and 11.09 for open and greenhouse structures and these values were higher than what we found in our study. In a study comparing embodied energy use which corresponds to cultural energy use in our study in seven common aquaculture species, Chatvijitkul *et al*. (2017), found that Atlantic salmon and rainbow trout which are carnivorous fish had higher embodied energy expenditure per kg of liveweight than other species (ictalurid catfish, tilapia, pangasius, whiteleg shrimp, and black tiger shrimp). Cultural energy expended on feed has the highest contribution in total cultural energy and as mentioned earlier carnivorous trout diets require high-quality feed ingredients that have higher cultural energy values. Thus, it is expected carnivorous fish to have worse cultural energy use efficiency than herbivore fish as supported by Chatvijitkul *et al*. (2017). Muir & Young (1998) also reported that aquaculture production heavily relied on energy use and they found similar energy input/energy output ratio to our values. Troell *et al*. (2004) stated that as the size of production increased energy used for unit production decreased, indicating the importance of size and full capacity stocking. Similarly, on a research examining the effect of farm sizes on energy use efficiency of beef cattle production Demircan & Koknaroglu (2007) found that as farm size increased energy use efficiency became better. In a study comparing the energy performance of selected food production systems, including fisheries and terrestrial crop and animal production, using a ratio of total industrial energy invested in the system relative to the edible protein energy return, Troell *et al*. (2004) reported that compared to other species intensive rainbow trout cage culture had low energy ratio, similar to that of tilapia and mussel farming and the values they reported were similar to our values.

Conclusion

Results support the idea that the intensive rainbow trout cage farming is in the upper group of the food pyramid that relies on carnivore nutrition in which the solar energy transmission decreases in the secondary or tertiary context. Since production size (capacity) directly affects the cultural energy expended for general management, in low capacity production systems, total cultural energy expended increases and cultural energy use efficiency becomes worse thus it is advised to use the full farming capacity of the enterprise. In addition, in aquaculture total cultural energy expended and cultural energy use efficiency values should be evaluated on species, production period, and production model basis within itself. This way we may get a better idea on the sustainability of aquaculture production. Nowadays, even though human dependence on protein source increases and cultural energy use efficiency of fish production is higher than that of beef and sheep production, fish production is still an important source of good quality protein. Contrary to other herbivore farm animals, the share of cultural energy expended on feed in total cultural energy expended is higher in carnivorous aquaculture species.

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