Fish Sci (2009) 75:1275–1283
DOI 10.1007/s12562-009-0133-x

ORIGINAL ARTICLE Aquaculture

Evaluation of recycled food waste as a partial replacement of fishmeal in diets for the initial feeding of Nile tilapia *Oreochromis niloticus*

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Received: 16 February 2009 / Accepted: 2 June 2009 / Published online: 14 July 2009

Abstract A 70-day feeding trial was conducted to evaluate the suitability of recycled food wastes [food industry waste (FIW) and soy sauce waste (SSW)] as protein sources in the diet of *Oreochromis niloticus* fry. Diets were formulated that contained 0 and 20–22%, respectively, recycled food wastes, namely D1 (0% recycled food waste), D2 (20% FIW), D3 (10% FIW and SSW, respectively), D4 (20% FIW and tryptophan), and D5 (22% SSW). Although feed efficiency, net protein retention, and protein efficiency were not significantly different among fish on the different diets ($p > 0.05$), those on D3 had a better growth performance than the controls (D1). Fish fed diet D4 (tryptophan supplement) had a higher final weight gain than those fed D2, in addition to the other growth parameters, but these differences were not significant ($p > 0.05$), with the exception of total feed intake. D1 produced fish with higher carcass protein, while fish fed on D3 had the highest lipid content. There was no significant difference between groups in terms of carcass moisture and ash contents. These findings show that the proper combination of recycled food waste is suitable for use in the production of fish feed and may ultimately result in reductions in the level of fishmeal in aquafeeds.

Keywords Food industry waste · Growth performance · Recycled food waste · Soy sauce waste · Tilapia fry

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Introduction

Traditionally, the development of aquafeeds has relied on fishmeal as the main protein source due to its high protein content and balanced essential amino acid (EAA) composition, digestible energy, minerals, and vitamins. However, fishmeal is the most expensive protein source in animal and aquaculture feeds, and its increasing cost combined with an unpredictable necessitates the search for cheap and abundantly available plant protein feed materials as a replacement. Soybeans, rape seed meal, and sorghum are good candidates due to their availability and affordability [1], but the competitive demand for such conventional crops by the food and livestock sectors as well as by industry introduces potential increases in costs, thereby making them a non-viable option for fish farmers or producers of aquafeeds [2]. Therefore, in order to attain a more economically sustainable, environmentally friendly, and viable production of aquafeeds, researchers should focus on evaluating the use of unconventional protein sources, such as plant seeds, leaves, and agricultural by-products as protein sources [3–5]. However, at present, only limited information is available on the utilization prospects of recycled domestic waste as an alternative or additional protein source in fish feed. Dependent on the source, organic wastes are known to be a nutritious and cheap source of supplementary protein, and they may be a good feed source for fish larvae.

Tilapia production, the third most intensively cultured finfish among the cultured fresh water fishes, is on the increase [6]. This increase may be attributed to their tolerance of stressors imposed in routine aquaculture practices, marketability, and ability to utilize nutrients from a wide variety of sources. Consequently, they are able to utilize nutrients from plant products in their feed [7]. While the diversity of acceptable feedstuffs is an asset in culture, several challenges remain in feeding tilapia.

A basic concept of Japanese society is recycling, with an emphasis on the minimization of associated biodegradable waste by-products by recycling waste and using it effectively. While there is abundance of recycled domestic waste materials [soy sauce waste (SSW), food industry waste (FIW)], there is little or no information on the utilization of this recycled waste as fish feed. In the study reported here, we used growth performance and body composition as indicators and evaluated the suitability of recycled food waste and suitable combinations of recycled food wastes as a partial source of protein in the diet of Nile tilapia *Oreochromis niloticus* fry.

Materials and methods

Diet formulation and preparation

Soy sauce waste

Soy sauce waste was produced by Yamasa Corporation (Choshi, Japan) and processed by Nippon Formula Feed Mfg. Co. Ltd (Yokohama, Japan). After the fermentation of soybeans and soy sauce extraction, the residual cake, which is a waste product, was collected, dried, and recycled by dehydration to reduce the moisture to a low level. Tables 1 and 2 show the proximate composition, fatty acid composition, and amino acid composition of the SSW.

Food industry waste

The FIW used in this study was obtained from Nippon Formula Feed Mfg. Co. Ltd after being processed. It includes leftover food from convenient stores, food waste residues discharged during processing, hotel waste, restaurant cooking waste, tofu waste, and bread production waste.

The FIW was processed by fry cooking the waste with waste vegetable oil at a very low pressure and an initial temperature of between 80 and 100°C for 1 h, later increasing to between 100 and 110°C for about 30 min after which the product was allowed to cool off before being ground into a powdered form. The product was finally analyzed to determine moisture, crude protein, amino acid, lipid, and fatty acid contents, as shown in Tables 1 and 2.

Fishmeal

The fishmeal use in this experiment was obtained from Nippon Formula Feed Mfg. Co. Ltd. Tables 1 and 2 show the proximate composition, fatty acid composition and amino acids composition of the fishmeal.

Table 1 Proximate and fatty acid composition of the three experimental substances used as protein sources

Ingredients	Fishmeal	Food industry waste	Soy sauce waste
Proximate composition			
Moisture (%)	5.79	2.09	1.66
Crude protein (% d.b.)	63.50	19.63	26.13
Crude lipid (% d.b.)	11.79	11.34	11.93
Ash (% d.b.)	19.34	8.15	10.22
Fatty acids (g/100 g)			
14:0	0.90	0.67	0.54
16:0	2.03	2.59	1.90
16:1n-7	0.92	0.20	0.44
16:3n-6	0.05	0.05	0.07
16:3n-3	0.11	0.03	0.02
18:0	0.01	0.19	0.25
18:1 (OA)	1.98	4.25	3.05
18:2n-6 (LA)	0.43	2.64	3.40
18:3n-6	0.01	tr	0.10
18:3n-3 (LNA)	0.27	0.08	0.17
18:4n-3	0.20	0.17	0.32
20:0	0.04	tr	0.15
20:1	0.49	0.02	0.10
20:2n-6	0.01	0.05	0.08
20:3n-6	0.03	0.03	0.05
20:4n-6 (AA)	0.18	0.24	0.61
20:4n-3	0.16	0.02	0.19
20:5n-3 (EPA)	1.38	0.02	tr
22:0	0.03	tr	0.01
22:1	0.15	tr	tr
22:4n-6	0.24	tr	0.08
22:5n-6	0.08	tr	tr
22:5n-3	0.59	0.07	0.02
22:6n-3 (DHA)	1.38	nd	tr
Σ Monoenes	3.54	4.47	3.60
Σ Saturates	3.00	3.44	2.87
Σ n-3	4.09	0.40	0.72
Σ n-6	1.03	3.03	4.40
Σ n-3HUFA	3.51	0.11	0.21

d.b. dry basis, *OA* oleic acid, *LA* linoleic acid, *LNA* alpha linoleic acid, *AA* arachidonic acid, *DHA* docosahexaenoic acid, *HUFA*, highly unsaturated fatty acids, *tr* trace, *nd* not detected

Experimental diets

Based on the nutritional requirements of tilapia, we formulated five isonitrogenous diets of 40% crude protein and 8.5% lipid [8] using feed containing 20–22% of recycled food waste (FIW and SSW) in different proportions (Table 3). The experimental diets were designated D1 (0% inclusion of recycled food waste; fishmeal only; control); D2 (20% FIW; (9.5% fishmeal protein was replaced with

Table 2 Constitutional amino acid composition of the three experimental substances used as protein sources

Ingredients	Fishmeal	Food industry waste	Soy sauce waste
Essential amino acid			
Arginine	4.85	2.00	1.93
Lysine	4.47	0.45	0.80
Histidine	2.96	0.52	0.68
Phenylalanine	2.79	0.96	1.98
Leucine	5.50	2.95	3.21
Isoleucine	2.63	0.85	1.33
Methionine	1.98	0.33	0.31
Valine	2.92	0.81	1.29
Threonine	2.64	0.68	1.99
Tryptophan	0.48	0.04	0.26
Non-essential amino acid			
Taurine	0.70	0.02	0.04
Alanine	4.94	1.14	1.87
Glycine	4.93	1.62	1.97
Glutamic acid	8.92	3.47	2.69
Serine	4.75	1.94	2.14
Aspartic acid	5.89	1.56	2.89
Sum	61.33	19.34	25.37

Values are given as percentage dry basis

Table 3 Formulation of the experimental diets for *Oreochromis niloticus* fry

Diet code	D1	D2	D3	D4	D5
Fishmeal	630	570	560	545	540
Food industry waste	0	200	100	200	0
Soy sauce waste	0	0	100	0	220
α-Starch	150	150	150	150	150
Vitamin premix[a]	20	20	20	20	20
P-free mineral mixture[b]	30	30	30	30	30
$Ca(H_2PO_4)_2 \cdot H_2O$	30	30	30	30	30
Soybean oil	15	0	0	0	0
L-Tryptophan	0	0	0	15	0
Cellulose	125	0	10	10	10

Values are given as grams per kilogram

[a] Composition (mg/100 g): thiamine HC,l 6; riboflavin, 10; pyridoxine, HCl 4; cyanocobalamin, 0.01; ascorbic acid, 500; niacin, 40; Ca-pantothenate, 10; inositol, 200; biotin, 0.6; folic acid, 1.5; *p*-aminobenzoic acid, 5; vitamin K3, 5; vitamin A acetate, 4000 IU; vitamin D3, 4000 IU

[b] Composition (g/100 g): NaCl, 5.0; $MgSO_4 \cdot 7H_2O$, 74.5; $FeC_6H_5O_7 \cdot nH_2O$, 12.5; trace element mixture [(composition (mg/g): $ZnSO_4 \cdot 7H_2O$, 353; $MnSO_4 \cdot 5H_2O$, 162; $CuSO_4 \cdot 5H_2O$, 31; $AlCl_3 \cdot 6H_2O$, 1; KIO_3, 3; cellulose, 440] 5.0; cellulose, 3.0

FIW); D3 (20% recycled food waste in the proportions 10% FIW and 10% SSW; 11% of fishmeal protein was replaced with FIW and SSW); D4 (20% FIW and tryptophan; 13% of fishmeal protein was replaced with FIW and tryptophan); D5 (22% SSW; 14% fishmeal protein was replaced with SSW). The D4 diet was formulated to evaluate the effect of tryptophan, which was found to be at a very low level in the FIW when an amino acid analysis was carried out. All of the ingredients were mixed in a domestic feed mixer together with a mineral and vitamin premix dissolved in a small quantity of distilled water. During the mixing, a small quantity of distilled water was added to enhance its palatability. The diets were pelleted using a laboratory pelletizer (AFZ12M; Hiraga-Seisakusho, Kobe, Japan) and dried using a vacuum freeze drier (RLE-206; Kyowa Vacuum Tech, Saitama, Japan). The pelleted diets were then crumbled using a mortar and pestle. The diet was sieved through a 500-μm mesh and stored at 4°C until use.

Experimental system and fish

Newly hatched tilapia *O. niloticus* larvae were obtained from pure-bred stock and maintained in the Laboratory of Fish Culture, Tokyo University of Marine Science and Technology. The feeding experiment was conducted using 13-day-old tilapia fry having an initial standard length (SL) of 8.0 ± 0.01 mm and a wet body weight of 0.01 g at the onset of exogenous feeding [9].

Fresh filtered dechlorinated tap water was supplied to the flow-through system, which consisted of 15 aquariums, each with an approximate capacity of 30 l, at a flow rate of 250–300 ml/min. The water temperature was maintained at 28 ± 0.5°C using electric heaters placed in each tank. The aquariums were illuminated by overhead fluorescent lights to maintain a constant photoperiod of 12 light (0800–2000 hours)/12 h dark throughout the study. The aquariums were provided with continuous aeration through an air compressor. The water quality parameters in the system were monitored weekly, and the ranges were dissolved oxygen 6.5–7.2 mg/l, total ammonia 0.1–0.25 mg N/l, and pH 6.9–7.5. No critical values were detected for nitrite and nitrate.

Three replicates of each treatment using 60 fish per aquarium were reared on each of the five diets. Feed was manually administered. The fish were fed six times daily at 30% (on dry basis) of body weight at 0900, 1100, 1300, 1500, 1700 and 1900 hours. Feeding rates were subsequently adjusted according to their growth rate per aquaria. The fish were denied feed 24 h prior to sampling. Five fish were randomly sampled on a weekly basis, and weights were measured using a digital electronic weighing balance (AW220; Shimadzu, Kyoto, Japan). Total length and SL were measured using digimatic calipers (CD-20CP; Mitutoyo, Tokyo, Japan).

Biochemical analyses

About 15 g initial samples and 10 g of final samples from each aquarium were pooled separately and then homogenized using a mincing machine (ZM200; Retsch, Haan, Germany). The experimental diets and fish body samples were subjected to chemical analysis. Proximate analysis and lipid analysis were performed according to the methods detailed in Takeuchi [10] and Folch et al. [11]. For the fatty acid profile analysis, crude lipid was saponified using 50% KOH, then methyl esterified with 7% boron trifluoride in a methanol solution (BF_3–methanol), and the fatty acid profile was determined using gas liquid chromatography (GC-14A; Shimadzu). Amino acids were determined according to the method of Simpson et al. [12] using an amino acid autoanalyzer (JLC-500V; JEOL, Tokyo, Japan).

Evaluation of growth parameters

Growth performance and diet nutrient utilization were analyzed in terms of weight gain (WG), feed efficiency (FE), specific growth rate (SGR), feed intake (FI), protein efficiency ratio (PER) and protein retention (PR). The following formulas were used:

Weight gain (%) = [final weight (g) − initial weight (g)]/initial weight (g) × 100

Feed efficiency (%) = [weight gained (g)/feed fed (g)] × 100

Specific growth rate (%) = {[ln final weight (g) − ln initial weight (g)]/feeding period (day)]} × 100

Feed intake (g/fish per day) = dry feed (g) given/number of fish/feeding period (day)

Protein efficiency ratio = wet body weight gain (g)/protein intake (g)

Protein retention (%) = protein gain/protein fed × 100.

Statistical analyses

Data were analyzed using one-way analysis of variance (ANOVA) using Statistica ver. 6.0 (Statsoft, Tulsa, OK). Differences between treatments were compared by Tukey's test. The level of significance was tested at $p < 0.05$.

Results

Chemical analysis of the feed ingredients and experimental diets

The proximate analysis, fatty acid and amino acid profiles of the fishmeal, and recycled domestic waste ingredients are shown in Tables 1 and 2. The fishmeal had the highest protein content and of the two recycled domestic waste used, FIW had the lower protein content [19.6 vs. 26.1% (SSW)]. Fishmeal was also higher in moisture content than the two recycled food waste materials. Tables 4 and 5 show the results of the proximate analysis and the fatty acid and amino acid profiles of the formulated experimental diets. There was no significant difference among the fatty acid and the amino acid compositions of the diets.

Growth and feed conversion

There was no feed rejection among the fish fed the experimental diets, and the fish vigorously ingested all of

Table 4 Proximate and fatty acid composition of the experimental diets

Diet code	D1	D2	D3	D4	D5
Proximate composition					
Moisture (%)	2.69	3.16	3.35	3.51	4.71
Crude protein (% d.b.)	41.13	40.02	40.38	40.79	40.68
Crude lipid (% d.b.)	8.25	8.25	8.20	8.15	8.51
Ash (% d.b.)	15.87	17.08	16.88	16.28	15.51
Fatty acids (g/100 g)					
14:0	0.54	0.58	0.54	0.57	0.62
16:0	1.57	1.97	1.69	1.94	0.91
16:1n-7	0.32	0.38	0.40	0.40	0.88
16:3n-6	0.18	0.27	0.27	0.27	0.21
16:3n-3	0.02	0.01	0.02	0.02	0.02
18:0	0.54	0.64	0.53	0.62	0.57
18:1 (OA)	1.78	2.10	1.88	2.07	1.56
18:2n-6 (LA)	1.12	0.74	1.06	0.74	1.06
18:3n-6	0.14	0.11	0.12	0.11	0.14
18:3n-3 (LNA)	0.13	0.05	0.05	0.05	0.05
18:4n-3	0.05	0.01	tr	0.01	tr
20:0	0.01	0.03	0.03	0.03	0.03
20:1	0.14	0.15	0.13	0.14	0.09
20:2n-6	0.01	0.02	0.02	0.02	0.02
20:3n-6	0.02	0.01	0.01	0.01	0.01
20:4n-6 (AA)	0.01	0.09	0.09	0.09	0.09
20:4n-3	0.04	0.03	0.02	0.03	0.03
20:5n-3 (EPA)	0.30	0.26	0.26	0.25	0.26
22:0	0.03	0.01	0.02	0.01	0.03
22:1	0.10	0.08	0.07	0.08	0.07
22:4n-6	0.15	0.01	0.01	0.01	0.01
22:5n-6	0.05	0.06	0.04	0.05	0.03
22:5n-3	0.08	0.06	0.06	0.06	0.06
22:6n-3 (DHA)	0.80	0.58	0.75	0.63	0.63
Σ Monoenes	2.34	2.71	2.48	2.68	2.60
Σ Saturates	2.67	3.22	2.81	3.16	3.17
Σ n-3	1.28	0.99	1.16	1.04	1.06
Σ n-6	1.78	1.32	1.62	1.30	1.58
Σ n-3HUFA	1.20	0.92	1.10	0.97	0.99

tr trace

Table 5 Constitutional amino acid of the experimental diets

Diet code	D1	D2	D3	D4	D5
Essential amino acid					
Arginine	3.06	2.97	3.11	2.96	3.04
Lysine	3.82	3.65	3.63	3.53	3.59
Histidine	1.87	1.76	1.78	1.78	1.75
Phenylalanine	1.75	1.86	1.85	1.88	1.94
Leucine	3.46	3.26	3.70	3.12	3.68
Isoleucine	1.65	1.56	1.69	1.59	1.71
Methionine	1.25	1.18	1.18	1.17	1.14
Valine	1.84	1.73	1.86	1.76	1.86
Threonine	1.66	1.76	1.75	1.69	1.83
Tryptophan	0.68	0.29	0.42	1.77	0.32
Non-essential amino acid					
Taurine	0.44	0.41	0.40	0.39	0.39
Alanine	3.09	2.96	3.07	2.95	3.08
Glycine	3.21	2.92	3.12	2.93	3.09
Glutamic acid	5.82	5.36	5.61	5.29	5.41
Serine	3.19	2.99	3.07	2.99	3.03
Aspartic acid	3.71	3.69	3.74	3.43	3.81
Sum	40.51	38.36	39.98	39.23	39.67

Values are given on a percentage dry basis

the different feeds. The growth performance data of *O. niloticus* fry fed the experimental diets for 70 days are summarized in Table 6. Although no significant differences ($p > 0.05$) were found in FE among fry fed the tested diets, D3 consistently produced better results than the other four diets, including D1 (control), in terms of all growth parameters measured. A proportional inclusion of recycled FIW, SSW, and fishmeal gave a better final body WG, percentage WG, higher SGR, higher FE, and higher survival rate. Similarly, the net PR and protein efficiency of fry fed D3 were higher than those fed the other diets. Fry fed D5 had the lowest final WG, percentage WG, SGR, FE, and survival rate, and net PR and protein efficiency were the lowest. Fry fed diet D4 produced a higher final WG than those fed diet D2, although along with the other growth parameters, these differences are not significant ($p > 0.05$), with the exception of total FI. The results show that there were no significant differences between fish fed diet D3 and those fed the control diet (D1).

Chemical compositions of the tilapia fry

Proximate compositions and fatty acid and amino acid profiles of the whole fish body, which were sampled at the start and the end of the feeding trial, are given in Tables 7, 8, and 9. Although the highest moisture content was observed in fish fed diet D5 and the lowest value in those fed diet D3, these values were not significantly different among the different treatments. Fish fed diet D1 had the highest protein content, and the difference was significant when compared with fish fed the other treatments. Fish fed the D3 diet had the highest lipid content, and the difference was significant relative to fish fed diet D1 but not significant compared to those fed diets D2, D4, and D5. There were no significant differences among all of the treatments in terms of ash content.

No relative significant difference was observed in the fatty acid and EAA contents of the final fish body fed the experimental diets.

Discussion

Under the experimental conditions described here, recycled food waste materials (FIW and SSW) were acceptable replacements for fishmeal in aquafeed for *O. niloticus* fry. These ingredients, which used in different proportions and in various combinations, replaced fishmeal in the experimental diet without adversely affecting growth, as shown in Table 6.

The suitability of various fishmeal replacements in terms of growth performance has been shown to vary greatly among fish species and experimental conditions [4]. Figure 1 depicts the growth pattern of the fish on the different diets under our experimental conditions. The best growth responses were obtained in tilapia fed diet D3, which was a proportional combination of FIW, SSW, and mixed fishmeal.

Table 1 shows that there were no major differences in lipid contents of the various experimental ingredient sources, i.e. fish meal, FIW, and SSW, and that the high lipid content value of FIW could be attributed to the waste vegetable oil used in recycling the materials. The FIW, similar to the other experimental ingredients, was rich in nutrients and was within the proximate composition range of recycled waste materials in Japan [13]. While fishmeal tends to be richer in all of amino acids than FIW and SSW, these latter two ingredients also have acceptable levels of amino acid. The FIW was found to be low in tryptophan, while SSW was also low in methionine and tryptophan; these low levels may be attributable to the original constituents of both the recycled waste material and SSW. This suggestion is in agreement with the findings of El-Sayed [4] that plant-based protein sources are usually low in tryptophan and methionine. All of the experimental ingredients were rich in saturates and monoene fatty acids. Fishmeal was higher in all of the fatty acids except for the n-6 fatty acids, but FIW was higher in monoene. The FIW had the highest starch content, 35%, while SSW had 13% starch content; the crude starch in SSW may originate in the wheat grain used during the production of the soy sauce.

Table 6 Growth performances of *O. niloticus* fry fed experimental diets for 70 days

Diet code	Body weight (g)		Weight gain (%)	Feed efficiency	Survival rate (%)	Specific growth rate (%)	Total feed intake (g)	Protein retention (%)	Protein efficiency
	Initial	Final							
D1	0.01 ± 0.00	6.34 ± 0.03 a	63300 ± 300 a	1.32 ± 0.03	97.7 ± 1.2 ab	8.65 ± 0.03 a	4.80 ± 0.00 a	50.3 ± 1.3	3.33 ± 0.06
D2	0.01 ± 0.00	5.12 ± 0.04 bc	51100 ± 400 bc	1.31 ± 0.05	94.0 ± 1.2 b	8.37 ± 0.05 bc	3.90 ± 0.00 c	45.4 ± 1.2	3.19 ± 0.04
D3	0.01 ± 0.00	6.50 ± 0.03 a	65200 ± 300 a	1.46 ± 0.07	99.7 ± 0.6 a	8.69 ± 0.05 a	4.52 ± 0.00 a	51.2 ± 0.9	3.35 ± 0.04
D4	0.01 ± 0.00	6.02 ± 0.03 ab	60100 ± 300 ab	1.40 ± 0.02	98.7 ± 1.1 a	8.59 ± 0.02 ab	4.29 ± 0.00 b	49.0 ± 0.8	3.34 ± 0.05
D5	0.01 ± 0.00	4.33 ± 0.04 c	43200 ± 400 c	1.30 ± 0.06	94.0 ± 1.0 b	8.15 ± 0.06 c	3.33 ± 0.00 d	46.2 ± 1.5	3.17 ± 0.07

Values in the same column followed by different letters are significantly different ($p < 0.05$) from each other ($n = 3$)

Table 7 Proximate composition analyses of *O. niloticus* fed experimental diet for 70 days

Component (%)	Initial	Final				
		D1	D2	D3	D4	D5
Moisture	75.4	74.1 ± 1.2	74.3 ± 1.3	73.5 ± 0.5	74.2 ± 1.2	74.5 ± 1.4
Protein	56.7	60.2 ± 1.1 a	56.4 ± 1.1 b	58.1 ± 1.1 b	57.0 ± 1.2 b	57.2 ± 1.1 b
Lipid	20.3	21.2 ± 0.9 b	22.6 ± 0.7 ab	23.4 ± 0.6 a	22.9 ± 0.7 ab	22.7 ± 0.8 ab
Ash	12.8	12.7 ± 0.2	13.2 ± 0.3	13.2 ± 0.1	13.2 ± 0.3	12.9 ± 0.2

Final values in the same row followed by different letters are significantly different ($p < 0.05$) from each other ($n = 3$)

The proximate analysis and fatty acid and amino acid profiles of the formulated experimental diets are shown in Tables 4 and 5. All diets were formulated to meet the EAA requirement for Nile tilapia based on the standard ingredient composition table [8]. The good growth rate of tilapia fed the test diets in our study indicate that the EAA values of these diets were good despite being lower than those reported by Santiago and Lovell [14] for Nile tilapia fry. All of the experimental diets met the fatty acid minimum requirements of *O. niloticus* specified by Takeuchi [15].

The experimental fish became acclimatized to the experimental diets within 2–3 days of the start of the feeding trial. However, the acceptability of the diets was not the same, and this difference may have affected the FI and growth. The control diet (D1) and diet containing both a proportion of FIW and SSW (D3) were generally more easily accepted by the tilapia fry than the other diets. The diet containing SSW only (D5) showed the lowest acceptability, and FIW-based diets (D2 and D4) were moderately accepted. The survival of the fish fry was recorded daily throughout the experimental period based on the number count after each sampling and ranged from 99.7 (D3) to 94.0% (D2 and D5). A significant difference in survival rate was observed between fish fed some of the dietary treatments during the experimental period, with the exception of those fed diets D3 and D4.

There was no significant difference between fish fed diets D3 and D1 when their FI was compared ($p > 0.05$), but fish fed diet D5 had the lowest FI. This may be related to the low palatability of SSW as a result of the production process of soy sauce. In particular, the SSW has a very strong odor. Proper processing of feed ingredients usually increases the palatability of a diet. It has therefore been suggested that the texture and palatability or taste of experimental diets are related to the level of plant material incorporated, which may affect the acceptability of the feed and, consequently, retard growth [16–19]. Another factor affecting palatability may be the use of high salt content during the production process. Hano et al. [20] reported that one of the major constraints of using soy sauce cake for livestock feeding is the presence of high amounts of salt in the cake, which is usually about 5–7%; this may have also affect the ability of the fish to effectively fed on the diet. The results of this study show that the methodology used in fry cooking domestic waste do not reduce the nutritive quality of the ingredients. The differences in WG among *O. niloticus* fry fed the experimental diets were significant, with *O. niloticus* fry fed diet D3 showing the highest final body WG value, which was comparable to those fed the control diet (D1), while *O. niloticus* fed diet D5 showed the lowest value. This difference may be due to the effect of FI and result from the palatability of the diet. No significant difference ($p > 0.05$) was observed in SGR and total FI between tilapia fry fed diets D1 and D3. All of the tilapia fed the experimental diets gave comparable feed efficiencies, demonstrating that the significant differences observed in the WG may not be due to differences in protein intake but be a result of total FI. The PR and protein efficiency followed the same pattern as the FE as there was no significant difference ($p > 0.05$) observed among the

Table 8 Fatty acid composition of the whole tilapia fry fed experimental diets

Treatment	Initial	D1	D2	D3	D4	D5
14:0	0.99	0.80	0.70	0.69	0.81	0.81
16:0	4.33	4.98	5.37	5.60	5.50	5.59
16:1n-7	2.00	1.73	1.96	1.61	1.98	1.96
16:3n-6	0.45	0.13	0.11	0.14	0.11	0.11
16:3n-3	0.68	0.16	0.14	0.18	0.14	0.13
18:0	1.68	1.29	1.17	1.36	1.29	1.21
18:1 (OA)	5.50	5.91	6.09	6.27	6.28	6.53
18:2n-6 (LA)	0.15	1.15	1.21	1.21	1.21	1.21
18:3n-6	0.05	0.32	0.34	0.38	0.37	0.42
18:3n-3 (LNA)	0.05	0.82	0.88	0.90	0.89	0.75
18:4n-3	0.08	0.05	0.07	0.06	0.08	0.06
20:0	0.37	0.71	0.81	0.23	0.56	0.80
20:1	0.04	0.34	0.33	0.39	0.06	0.19
20:2n-6	0.30	0.36	0.45	0.17	0.41	0.09
20:3n-6	0.03	0.19	0.06	0.07	0.06	0.01
20:4n-6 (AA)	0.27	0.20	0.22	0.21	0.22	0.18
20:3n-3	0.06	0.02	0.07	0.03	0.06	0.02
20:4n-3	0.12	0.11	0.10	0.10	0.10	0.09
20:5n-3 (EPA)	0.16	0.13	0.14	0.15	0.14	0.12
22:0	0.83	0.36	0.40	0.46	0.28	0.40
22:1	0.05	0.08	0.06	0.07	0.12	0.12
22:4n-6	0.32	0.08	0.02	0.06	0.02	0.08
22:5n-6	0.04	0.10	0.07	0.09	0.08	0.10
22:4n-3	0.02	0.11	0.09	0.09	0.10	0.10
22:5n-3	0.84	0.53	0.53	0.55	0.53	0.65
22:6n-3 (DHA)	2.75	1.72	1.67	1.82	1.73	1.69
Σ Monoenes	7.59	8.06	8.45	8.35	8.44	8.80
Σ Saturates	6.39	7.06	7.24	7.65	7.60	7.61
Σ n-3	4.73	3.56	3.59	3.78	3.67	3.52
Σ n-6	1.60	2.52	2.48	2.34	2.47	2.20
Σ n-3HUFA	3.93	2.52	2.50	2.64	2.56	2.57

Values are given as grams per 100 g

Table 9 Constitutional amino acid of *Oreochromis niloticus* whole body fed experimental diets

Treatment	Initial	D1	D2	D3	D4	D5
Essential amino acid						
Arginine	3.89	3.37	3.34	3.36	3.32	3.24
Lysine	4.90	4.47	3.97	3.99	3.88	3.67
Histidine	1.19	1.09	0.96	0.99	0.92	0.93
Phenylalanine	2.27	2.19	2.04	2.09	2.05	2.07
Leucine	3.65	3.43	3.25	3.32	3.19	3.38
Isoleucine	2.90	2.26	2.13	2.24	2.14	2.10
Methionine	2.61	1.85	1.13	1.57	1.16	1.15
Valine	2.79	1.98	1.82	1.96	1.85	1.86
Threonine	3.77	2.59	2.19	2.36	2.12	2.14
Tryptophan	0.72	0.58	0.48	0.58	0.74	0.51
Non-essential amino acid						
Taurine	2.15	2.11	2.10	2.10	2.14	2.12
Alanine	3.67	3.45	3.00	3.48	3.09	3.13
Glycine	4.57	3.83	3.60	3.75	3.60	3.44
Glutamic acid	7.66	7.36	7.24	7.28	7.19	7.23
Serine	4.20	5.83	5.50	5.98	5.50	5.39
Aspartic acid	5.58	5.44	5.42	5.33	5.24	5.20
Sum	56.53	51.83	48.17	50.37	48.12	47.59

Values are given on a percentage dry weight basis

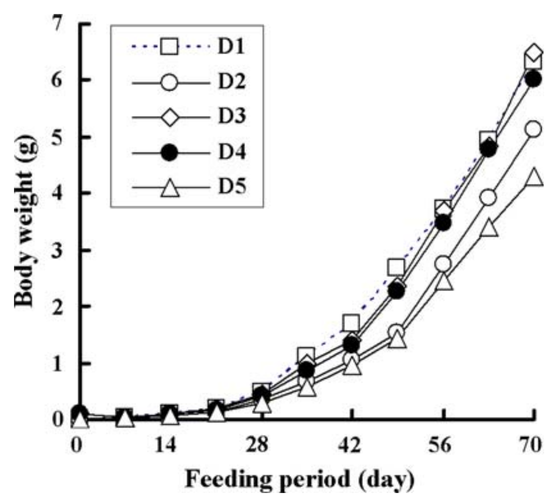

Fig. 1 Growth of *Oreochromis niloticus* fry fed the experimental diets for 70 days

fish fed the different experimental diets. Fish fed D2 did better than those on D5, possibly because the FIW in D2 was made up of different original constituents (leftover food from convenience stores as well as food waste residues discharged during food processing, hotel waste, restaurant cooking waste, tofu waste and bread production waste) while D5 was mainly SSW.

Another causal factor of the differences may also be the method the FIW was recycled. Protein and amino acids in the original constituents were not denatured by heat because the temperature and the pressure were kept below the level at which the nutrients in the recycled waste were be lost or denatured due to the applied heat. The use of waste oil to fry cook the waste during the processing of FIW may also have increased the fat content of the FIW, which invariably may also have increased the fatty acid content of the recycled FIW. The better performance of D4 over D2 implies that supplementation of recycled domestic waste with EAA can improve the growth of tilapia fed domestic waste.

The results of the analysis of carcass composition in this study are in accordance with the growth performance. No remarkable increase in the moisture composition of all the tilapia fed the experimental diet was observed, but significant differences in the protein and lipid composition of the tilapia fed the experimental diets were found ($p < 0.05$).

The higher carcass protein of D1 may be due to the ability of fish to easily digest and utilize fishmeal. Anderson et al. [21] and Wee and Wang [22] reported that the replacement of fishmeal by plant protein sources in the diet likely lead to a decline in the final carcass protein of the fish, mainly due to the lower digestibility and, consequently, the lower nutrient availability in the diets with high levels of plant protein. The initial and final lipid profile shown in Table 8 indicate that their chemical contents were closely related to the composition of the experimental diets, given that the essential fatty acids (EFA) of tilapia is Σn-6 fatty acids and the requirement for EFA in the diet is only 0.5–1% [23]. The availability and increase in the EFA of the tilapia fry carcass fed the experimental diets suggest that these diets met the tilapia EFA requirement and, hence, the EFA were well utilized. The analysis of the amino acids of the whole tilapia fry fed experimental diets reveals that there were no major differences in the carcass analysis of the experimental fry. This result indicates that the amino acids in the experimental diets were well utilized as there was an increase in the amino acids of the carcass of whole tilapia fry fed the experimental diets.

In summary, although differences in FE were not significant among fish fed the various diets ($p > 0.05$), those fed on diet D3 did better than those fed the remaining diets in terms of all growth parameters measured. A proportional inclusion of recycled FIW, SSW, and fishmeal produced better mean growth performances. Similarly, the net PR (49.2 ± 0.9) and protein efficiency (3.3 ± 0.1) of fish fed the D3 diet were higher than the others. This difference may be attributable to an appropriate combination of chemical and nutritional properties that a single ingredient cannot provide. We also observed that the addition of a pure amino acid (L-tryptophan) in D4 gave a better result than diet D2, thereby revealing that the supplementation of FIW with EAA can improve the growth of the fish fed FIW. Our results demonstrate that the proper combination of recycled domestic waste is suitable for tilapia feed production and that recycled domestic waste (FIW and SSW) could serve as (partial) replacements for fishmeal, thereby reducing the amount of fishmeal in the fish diet. As such, recycled domestic waste is a potential ingredient for use in aquaculture. Future studies should be conducted to evaluate the degree to which fishmeal could be reduced by the incorporation of waste materials and, if necessary, the supplementation with EAA and to evaluate the cost implication of using recycled waste. Long-term studies on fish approaching production size should be carried out and must include an analysis of consumer acceptance for taste and texture as the fish are destined for the market.

Acknowledgments This study was carried out with the financial support provided by a Grant-in-Aid for Scientific Research (A) from Japan Society for the Promotion of Science (No. 20248021).

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