The use of recycled human food waste and leftovers in the aquaculture industry for the partial replacement of commercial manufactured feed as a more sustainable and environmentally friendly practice: Recent research and findings

Petsas A.S.[1,*], Vagi M.C.[2]

[1]Department of Food Sciences & Nutrition, School of the Environment, University of the Aegean, Myrina, Lemnos, Greece
[2]Laboratory of Environmental Quality & Geo-spatial Applications, Department of Marine Sciences, School of the Environment, University of the Aegean, Mytilene, Lesvos, Greece

*corresponding author:Petsas S. Andreas: e-mail: apetsas@env.aegean.gr

Abstract
Food waste or leftovers generated by various raw or processed food materials that are not consumed but instead are usually disposed to waste landfills are regarded as a global issue which impacts human health and environmental sustainability. An enormous pressure in disposing of food wastes in landfill sites already exists and is predicted to be increased during the forthcoming years whereas simultaneously various environmental problems associated with solid wastes have to be solved. On the other hand, a percentage higher than 60% of the operational costs of any modern aquaculture industry concerns the supplies of protein-enriched- aquafeeds which among other characteristics are commercially manufactured sources of additional healthy nutritious and digestible proteins that tend to be expensive. Recent research and published data evaluating the use of recycled food wastes as a partial replacement of fishmeal-based feeds in diets of several species suggest that this can be considered as a more sustainable and environmentally friendly practice.
Keywords: Food waste, recycling, fish feed, aquaculture

1. Introduction

According to the USEPA, the term food waste defines the organic residues that are produced by several different treatments of any food substance (raw or cooked) and which are discarded or intended or required to be discarded during their handling, storage, sale, preparation, cooking, and serving practices [USEPA, 2012]. More than 40% of food produced for human consumption is wasted and most of it in restaurants [Nasser et al, 2018]. Specifically, around 1.3 billion tonne of food waste are generated per year, accounting for one-third of all edible food produced for human consumption [FAO, 2015; Gustavsson et al, 2011].

Consequently, a wide variety of urgent environmental issues regarding the safe disposal of food waste in landfills must be solved, such as landfill area limitations, generation of toxic gases and leachates, etc. Therefore, in order to reduce the quantity of food that is disposed to the landfills several strategies which value food waste as priceless and profitable resources have been proposed, such as the recycling, reusing and recovery of food waste and leftovers; the production of high quality fuels, fertilizers and animal feeds are included among many others [Wong et al, 2016].

Since more than half of the total cost in fish culture industry is attributed to fish feeds (estimated to reach 71 million tonne globally), the principle aim of the current study is to review all the recent scientific research published in the literature regarding the probability and practicability of utilizing food waste to produce aquaculture fish feeds.

2. Recent Trends and Main Findings

Based on the findings of the present review numerous surveys have been conducted regarding the use of a diverse and wide variety of food waste species from different sources (food industry, hotels, restaurants, domestic kitchens, etc.) and containing different nutritional compounds (of high crude protein and digestible carbohydrate and low non-digestible fibers) for the partial or complete substitution of manufactured fish feeds, such as industrial wastes and by-products of animal (e.g. poultry, fish, meat), fruit and vegetal origin (e.g. flours, wheat brans) [Gonzales et al, 2007; Bake et al, 2009; Mo et al, 2014].

Table 1 illustrates some selected examples of such investigations in detail. On the whole, it can be concluded that different combinations of recycled food wastes (based on the feeding modes of cultured species) can be used for the formulation of feed pellets that can be further upgraded by the addition of enzymes, probiotics, vitamins and minerals. Several assessments of the potential human health risk of fish cultivated by food waste based feeds have also been reported due to heavy metals and organics [Cheng et al, 2014, 2015].

Table 1. Selected references (in chronological order) evaluating the feasibility of using food waste to formulate fish aquaculture feeds

Tested fish	Type(s) of food waste	Food waste feed formulation & composition	Experimental design	Main findings-Highlights	Ref
• *Oreochromis niloticus* (Nile tilapia)	Postconsumer food waste (plate food waste) collected from local Mediterranean /Lebanese food restaurants in Beirut, Lebanon	Based on the composition of commercial and restaurant waste-based feed the commercial feed had almost twice the protein content of the waste-based feed (40.7% vs. 18.9%) whilst the waste-based feed contained around four times more lipids than the commercial feed (22.2% vs. 5.2%). Although both feeds were nearly iso-energetic (circa 20 kJ/g of diet), they differed in the amount of digestible energy as well as ash and fibre contents.	8-week feeding experiments Photoperiod: 14:10 h (light:dark) 30% of the water in each system was changed weekly to maintain optimal water quality Water aeration: by regenerative blower and submerged air diffusers Temperature: 27 ± 1°C (maintained by submerged heating elements) **1st experiment:** 15 fibreglass tanks of 180-L connected to a biological filter and settling tank. 5 feeding regimens in which commercial food was substituted by waste-based feed (at 0, 25, 50, 75 and 100%) of daily offering **2nd experiment:** A recirculating system consisting of 21 indoor glass aquaria, 52-L (58 × 30 × 30 cm; L × W × H), connected to a biological filter and settling tank 7 feeding treatments in which daily offerings of commercial food were alternated with waste-based feed in 6-d cycles	• 100% survival in all treatments • Significant difference in growth (weight and length) among treatments • No significant effect on survival, growth, feed conversion, hepatosomatic, viscerosomatic indices, haemoglobin, haematocrit and total plasma protein by 25% replacement of the commercial food with waste-based feed • Feasible replacement of feed between 25% and 33% without significantly affecting survival or growth in terms of the same abovementioned parameters • Restaurant waste-based feed can be utilized in the culture of *O. niloticus* for the improvement of farmers' financial returns and parallel reduce of food waste and harmful environmental impacts	Nasser et al. (2018)
• *Hypophthalmichthys nobilis* (Bighead carb, filter feeders) • *Ctenopharyngodon idellus* (Grass carp, herbivores) • *Cirrhina molitorella* (Mud carp, bottom feeders of omnivorous chain) (All imported from mainland China)	Food processing waste and partially post-consumption waste collected from local hotels and restaurants of China. Classification into 4 major categories: 1. vegetables and fruits, 2. cereals, 3. meat products, and 4. bones	**Pellets:** **FW A:** fruit and vegetables 10%; cereal 53%, bone meal 8%, other 4%, fish meal 10% and corn starch 15% **FW B:** fruit and vegetables 10%; meat products 25%; cereal 28%, bone meal 8%, other 4%, fish meal 10% and corn starch 15% Food waste made up for 75% weight of the final fish feed pellets	3 farmed ponds (20 × 10 × 4 m; L × W × H) filled up with spring water (pH: 6.84, dissolve O_2: 3.99 mg/l, temperature: 21.8 °C). 3 fed treatments: FW A, FW B, and control Control diet: commercial feed Jinfeng®, 613 formulated pellets	• Food wastes can serve as an alternative source of protein for culturing grass carp • The fish fed with food waste feeds achieved better or similar growth performance and feed conversion ratio • Among the 3 different treatments the fed with FW A containing the maximum cereal content as the major protein source the values of length, weight, feed conversion ratio, specific growth rate, and protein efficiency ratio in grass carp were significantly higher than those with fed FW B indicating that cereals could be easily digested by grass carp (herbivores), and similar to those fed with control diet • Grass carp and bighead carp fed with food waste feeds were relatively free of PAHs	Z. Cheng et al. (2015)

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