Science of the Total Environment 613–614 (2018) 635–643

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Use of food waste, fish waste and food processing waste for China's aquaculture industry: Needs and challenge

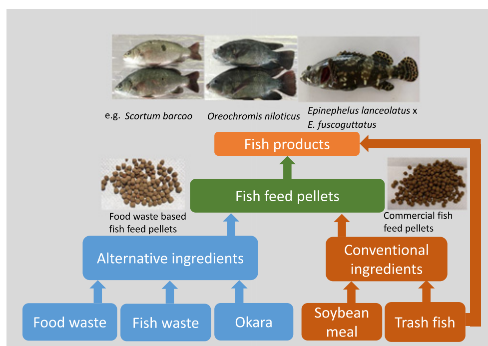
Wing Yin Mo [a], Yu Bon Man [a], Ming Hung Wong [a,b,c,*]

[a] Consortium on Health, Environment, Education and Research (CHEER), Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong, China
[b] School of Environment, Jinan University, Guangzhou, China
[c] Key Laboratory for Heavy Metal Pollution Control and Reutilization, School of Environment and Energy, Peking University Shenzhen Graduate School, Shenzhen, China

HIGHLIGHTS

- China's aquacultural industry dominates global aquaculture production
- Omnivorous and herbivorous fish are the major species cultured in China
- Conventional ingredients could be partially replaced by food waste
- Currently no laws or standards regulate the use of food waste in fish feed

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 February 2017
Received in revised form 31 August 2017
Accepted 31 August 2017
Available online 18 September 2017

Editor: D. Barcelo

Keywords:
Freshwater fish
Marine fish
Food waste
Processing by-product
Fish feed

ABSTRACT

China's aquaculture industry is growing dramatically in recent years and now accounts for 60.5% of global aquaculture production. Fish protein is expected to play an important role in China's food security. Formulated feed has become the main diet of farmed fish. The species farmed have been diversified, and a large amount of ‘trash fish’ is directly used as feed or is processed into fishmeal for fish feed. The use of locally available food waste as an alternative protein source for producing fish feed has been suggested as a means of tackling the problem of sourcing safe and sustainable feed. This paper reviews the feasibility of using locally available waste materials, including fish waste, okara and food waste. Although the fishmeal derived from fish waste, okara or food waste is less nutritious than fishmeal from whole fish or soybean meal, most fish species farmed in China, such as tilapia and various Chinese carp, grow well on diets with minimal amounts of fishmeal and 40% digestible carbohydrate. It can be concluded that food waste is suitable as a component of the diet of farmed fish. However, it will be necessary to revise regulations on feed and feed ingredients to facilitate the use of food waste in the manufacture of fish feed.

1. Current state of aquaculture in China

The latest available statistics indicate that China has been the world's largest producer and exporter of aquaculture products in 2015, accounting for 60.5% of global aquaculture production (FAO, 2017). The ratio of fishing to aquaculture production in China was 74:26 in 1978,

* Corresponding author at: Consortium on Health, Environment, Education and Research (CHEER), Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong, China.
E-mail address: minghwong@eduhk.hk (M.H. Wong).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.321
0048-9697/

increasing to 30.3:69.7 in 2008 (Fishery Bureau of Department of Agriculture, 2009). The amount of aquatic resources captured from the environment has plateaued in the past 20 years (FAO, 2016), and it could be expected that aquaculture production will account for a larger proportion of the total fish supply in the future, as domestic fisheries are over-exploited (FAO, 2016; Mallory, 2013; Villasante et al., 2013). Fish is an important protein source and aquaculture will play an increasingly important role in future food security.

Most freshwater fish ponds in China are polyculture ponds used for carp and tilapia. The species commonly reared in polyculture ponds include omnivorous fish such as common carp (*Cyprinus carpio*), crucian carp (*Carassius* spp.) and tilapia (*Oreochromis* spp.), herbivorous fish such as grass carp (*Ctenopharyngodon idella*) and filter-feeding fish such as silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*). Table 1 lists the species farmed and their production volumes in 2008 and 2015. China produced over 18 million tonnes of carp and around 1.27 million tonnes of tilapia in 2015, accounting for about 90% of global carp production and about 35% of global tilapia production (FAO, 2017). The data show that omnivorous and herbivorous Chinese carp are the major species produced by China's aquaculture industry. However, the farming practices of Chinese fish farmers have changed. Previously, dyke pond systems that used waste feed (various waste materials such as animal excreta, food waste or agricultural by-products) and grass (for culturing grass carp) were popular in China (Lau et al., 2003; Prein, 2002; Wong et al., 2004). Nowadays, more and more fish farmers have adopted intensive culture methods using formulated feed pellets (Chiu et al., 2013).

Another trend is that Chinese fish farmers have diversified the fish species farmed. For example, the production of non-native species in China increased from 780,000 t in 1998 to 2.5 million tonnes in 2006, representing 5.9% and 11.7% of the total inland aquaculture production, respectively (Liu and Li, 2010). A large quantity of tilapia (worth about US$ 1 billion) produced in China is exported to the United States, mainly as frozen fillets (Liu and Li, 2010). Moreover, because of the potential for higher selling prices, an increasing number of fish farmers culture various species of grouper, such as humpback grouper (*Cromileptes altivelis*), giant grouper (*Epinephelus lanceolatus*), orange-spotted grouper (*Epinephelus coioides*) and hybrid grouper (*Epinephelus lanceolatus* × *Epinephelus fuscoguttatus*) for export. Various species of grouper are frequently consumed in luxury restaurants in Hong Kong (WWF, 2013). Furthermore, a consumer preference shift from low-value freshwater fish to high-value seafood has also been observed in China, driven mainly by rapid urbanisation and higher overall levels of income in Chinese society (Fish Site, 2012; Mao, 2011, 2013).

2. Problems associated with current aquaculture production in China

The sustainability of China's aquaculture industry is being questioned. Fishmeal is commonly used as a protein source in the diet of farmed fish and is the most expensive ingredient in formulated fish feed. The protein digestibility of good-quality fishmeal is very high, as is the amino acid availability (Anderson et al., 1995). The crude protein content of fishmeal used as feed ranges from 60% to 68% and is a good source of essential fatty acids, minerals and trace elements (Heuzé et al., 2015). China's aquaculture industry consumed approximately 1.4 million tonnes of fishmeal in 2015 (Mundi, 2016), and China has always been the largest importer of fishmeal from the global market (Cao

Table 1
Fish species farmed by Chinese fish farmers and their production volume.

Fish	Species name	Production volume in 2009** (tonnes)	Production volume in 2015** (tonnes)	Percentage change (%)	Diet preference
Freshwater					
Grass carp	*Ctenopharyngodon idellus*	4,081,520	5,676,235	39.1	Herbivorous
Silver carp	*Hypophthalmichthys molitrix*	3,484,442	4,354,638	25	Filter feeder
Bighead carp	*Hypophthalmichthys nobilis*	2,434,555	3,359,440	38	Filter feeder
Common carp	*Cyprinus carpio*	2,462,346	3,357,962	36.4	Omnivorous
Carassius spp.	*Carassius* spp.	2,055,478	2,912,258	41.7	Omnivorous
Nile tilapia	*Oreochromis niloticus*	943,478	1,334,482	41.4	Omnivorous
Freshwater fishes nei	*Osteichthyes*	489,610	601,439	22.8	Not applicable
Wuchang bream	*Megalobrama amblycephala*	625,789	796,830	27.3	Herbivorous
Black carp	*Mylopharyngodon piceus*	387,623	596,102	53.8	Omnivorous
Snakehead	*Channa argus*	358,502	495,574	38.2	Carnivorous
Amur catfish	*Silurus asotus*	325,268	450,064	38.4	Omnivorous
Blue Nile tilapia, hybrid	*Oreochromis aureus* × *O. niloticus*	314,500 F	445,000 F	41.5	Omnivorous
Asian swamp eel	*Monopterus albus*	237,034	367,547	55.1	Carnivorous
Largemouth black bass	*Micropterus salmoides*	174,471	353,081	102.4	Carnivorous
Pond loach	*Misgurnus anguillicaudatus*	176,405	366,186	107.6	Omnivorous
Yellow catfish	*Pelteobagrus fulvidraco*	163,556	355,725	117.5	Omnivorous
Mandarin fish	*Siniperca chuatsi*	235,514	298,057	26.6	Carnivorous
Channel catfish	*Ictalurus punctatus*	223,233	264,965	18.7	Omnivorous
Pirapatinga	*Piaractus brachypomus*	85,706	108,874	27	Herbivorous
Obscure pufferfish	*Takifugu obscurus*	2210		5220	Carnivorous
Total		19,276,930	26,745,454	38.7	
Marine fish					
Marine fishes nei	Osteichthyes	264,851	794,685	200	Not applicable
Large yellow croaker	*Larimichthys croceus*	66,021	148,616	125.1	Carnivorous
Japanese seabass	*Lateolabrax japonicus*	101,971	122,542	20.2	Carnivorous
Snubnose pompano	*Trachinotus blochii*	66,000 F	110,000 F	66.7	Carnivorous
Groupers nei	*Epinephelus* spp	44,155	100,006	126.5	Carnivorous
Red drum	*Sciaenops ocellatus*	49,118	71,697	46	Carnivorous
Lefteye flounders nei	Bothidae	26,672	76,837	188.1	Carnivorous
Turbot	*Psetta maxima*	60,000 F	55,000 F	−8.3	Carnivorous
Porgies, Seabreams nei	Sparidae	40,253	69,795	73.4	Carnivorous
Cobia	*Rachycentron canadum*	29,104	36,867	26.7	Carnivorous
Amberjacks nei	*Seriola* spp	19,404	20,484	5.6	Carnivorous
Tiger pufferfish	*Takifugu rubripes*	18,868	23,372	23.9	Carnivorous
Righteye flounders nei	Pleuronectidae	11,521	8618	−25.2	Carnivorous
Total		800,148	1,643,754	105.4	

**Production volume data from FAO (2017). F = FMO estimated values, nei = not elsewhere included.

Table 2
Estimated amount of protein required to grow Nile tilapia, common carp and grass carp to market size.

Fish species	Marketable size	Percent protein in diet	Estimated amount of protein required to produce 1 t of fish[a]	Estimated fishmeal consumption to produce 1 t of fish[b]	References
Nile tilapia	400–900 g	24–34%	480–680 kg	12–17 kg	Weimin (2004)
Common carp	250–500 g	28–30%	500–600 kg	42.5–51 kg	Peteri (2004), Flajšhans and Hulata (2006)
Grass carp	1.5–2.5 kg	28–30%	1120–1200 kg	95.2–102 kg	Rakocy (2005)

[a] Assuming feed conversion ratio = 2.
[b] Average fishmeal inclusion rate in China for carp = 8.5%; for Nile tilapia = 2.5% (Chiu et al., 2013).

et al., 2015). China also produces a large amount of fishmeal from 'trash fish' (De Silva and Turchini, 2009; Funge-Smith et al., 2005). Trash fish are the small fish that form the low-value component of commercial catches (Edwards et al., 2004). A large proportion of the trash fish available in China is composed of juveniles of commercially important species, small benthic and mesopelagic fish, crustaceans and cephalopods (Grainger et al., 2005). Unfortunately, China's capture fisheries have been fully or over-exploited (Funge-Smith et al., 2012). In addition to fishmeal, the production of fish feed pellets often requires various crop products, and soybean meal is another important protein source used in aquaculture feeds. However, the production of soybean meal requires considerable arable land that could be used to grow food crops for human consumption.

Formulated feeds have become the major diet of many important farmed species (Olsen and Hasan, 2012). As mentioned above, carp is the dominant group of fish cultivated in China and it has been noted that the average inclusion rates of fishmeal for culturing Chinese carp and Nile tilapia in China were 8.5% and 2.5%, respectively (Chiu et al., 2013). Table 2 shows the estimated amounts of protein required to produce Nile tilapia, common carp and grass carp. Chinese carp (excluding silver carp and bighead carp) and Nile tilapia are cultured in China in huge volumes (10.7 and 1.2 million tonnes, respectively, in 2014) (FAO, 2016a), so even low inclusion rates of fishmeal in fish feed can account for a substantial portion of global fishmeal demand (Chiu et al., 2013). Furthermore, the increasing popularity of carnivorous fish culture will inevitably increase the demand for fishmeal and/or trash fish. Carnivorous fish such as groupers require a much higher fishmeal inclusion rate in their diets, up to 50% (Tacon and Metian, 2008). The estimated production volume of various grouper species in China increased by 126.5% from about 45 thousand tonnes in 2009 to 82 thousand tonnes in 2015 (FAO, 2017). Trash fish are also used by some fish farmers as a supplement or directly used as feed for high-value species (Cao et al., 2015), such as marine carnivorous fish. The annual consumption of trash fish by China's mariculture industry is about 3 million tonnes (De Silva and Turchini, 2009; Funge-Smith et al., 2005). However, the use of trash fish as feed is an important cause of water quality depreciation. Chu (2000) revealed that the amount of unconsumed feed deposited in a group fed with pellets (24.1% ± 3.8%) was significantly lower than in the group fed with trash fish (37.8% ± 7.8%). It was also noted that only 8.1% of the dietary nitrogen was retained in the fish body when trash fish were fed to areolate grouper (*Epinephelus areolatus*), whereas 62% of the nitrogen was retained when moist pellets (50% protein and 20% lipid) were used as feed. Moreover, because raw fish contains a high amount of moisture, aquaculture with trash fish results in a relatively higher feed conversion ratio.

In addition to concerns about the sustainability of feed ingredients, there are concerns about the safety of fishmeal. Fishmeal is an important constituent in compound diets but also a major source of pollutants. Fishmeal may be accidentally or deliberately contaminated with heavy metals, persistent organic pollutants (POPs) and pesticides, and the contamination of fishmeal appears to be a global issue. A study showed that 55 samples of fish feed collected from the National Fish Hatcheries of the US Fish and Wildlife Service (from October 2001 to October 2003) contained various POPs: all samples contained polychlorinated biphenyl (PCBs), 39 contained chlorinated dibenzo-*p*-dioxin, 24 contained polychlorinated dibenzofuran and 24 contained DDT or its metabolites (Maule et al., 2007). These POPs were also found in several samples of salmon feed collected from fish hatcheries in Canada, as well as other contaminants, such as arsenic, lead, copper, zinc, fluorine and mercury (Kelly et al., 2008). It has been reported that the fishmeal available in China may contain high levels of various pollutants including dichlorodiphenyltrichloroethane (DDT) and mercury (Cheng et al., 2014; Dickman et al., 1998; Zhou and Wong, 2000). Poor-quality fish feeds appear to be a major source of mercury accumulated in fish (Cheng et al., 2011; Lacerda et al., 2011). Moreover, trash fish contain higher concentrations of organochlorine pesticides (OCPs), mainly DDT or its metabolites, PCBs (Guo et al., 2009) and total mercury and methyl mercury (Liang et al., 2011) than found in compound feeds.

China's per capita fish consumption had grown to 33.1 kg/year in 2010 (Msangi et al., 2013). It is expected that China's population will reach 1.41 billion by 2025 (Fu, 2015), and China is projected to account for 38% of global consumption of fish by 2030 and to become the largest fishmeal consumer in the coming decades (Msangi et al., 2013). It is expected that low trophic level fish such as carp and tilapia will remain the major fish species farmed in China. To prevent the depletion of valuable marine resources, alternatives to raw fishmeal protein sources should be explored to satisfy the huge demand for fish while reducing the current dependence on marine fish resources for aquaculture. Various waste materials, such as fish waste, okara and food waste, are produced in large quantities locally and they have potential as substitutes for conventional feed ingredients.

3. Using food processing waste and food waste as fish feed

3.1. Food processing waste

3.1.1. Fish waste

Fish waste is fish tissue that is not suitable for consumption, including bones, intestines, heads and tails, which can be used to produce fishmeal. It has been estimated that >50% of the total fish capture is not used as food (Kristinsson and Rasco, 2000). Fish and shrimp remains are currently used together with trash fish, anchovies and skinnycheek lanternfish (*Benthosema pterotum*) in the production of fishmeal in China (Chiu et al., 2013). Cao et al. (2015) estimated that the annual fish waste generated from fish processing in China could yield between 420,000 and 650,000 t of fishmeal, which is approximately 50% of the Chinese aquaculture industry's current total demand for fishmeal. Although the fishmeal derived from fish waste has a lower amount of crude protein (58%) (Esteban et al., 2007) than high-quality fishmeal (60% to 70%), the product is still nutritious and could be a potential source of fishmeal for low trophic level fish. Kotzamanis et al. (2001) noted that trout intestines leftover from from smoking fish could be a good source of fatty acids for gilthead bream. Fish waste is indeed a great source of minerals and fat (19% dry matter), with abundant monounsaturated, palmitic and oleic acids (Esteban et al., 2007).

Because the production of Chinese carp and tilapia requires a minimal amount of fishmeal, fishmeal derived from fish waste could be a good source for culturing these species. It has been estimated that up to 25% of fishmeal is now obtained from fish processing waste (Chiu et al., 2013). Esteban et al. (2007) revealed that fish waste (mixed species) collected from fishmongers in Spain had no detectable concentrations of arsenic, lead, mercury or cadmium. Murthy et al. (2013) revealed that the concentrations of cadmium, lead and copper present in fish meal (derived from fish heads, skin, guts, fins, gills, livers, kidneys and scales) were 0.22 to 4.40 ppm, 4.60 to 18.20 ppm and 1.80 to 46.40 ppm, respectively, and mercury was not detected. Kinnunen et al. (2005) found that levels of chlordane, dieldrin, toxaphene, dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), DDT and mercury in salmon waste from Lake Michigan and Lake Huron were below the FDA's action levels for food fish, although the waste from fish caught in Lake Michigan exceeded the FDA's PCB level of 2.0 ppm for food fish. However, little is known about the concentrations of pollutants in fishmeal derived from fish processing waste from China. More information is needed to evaluate the appropriateness of using fish waste as feed in our region.

Heat sterilisation is required to inactivate microorganisms or pathogens present in fish waste before further processing. However, Esteban et al. (2007) observed that the digestibility of fish waste decreased with temperature, and hence treatment temperatures over 105 °C are not recommended to reduce moisture and avoid microbial growth in the waste. As an alternative to heat treatment, low-temperature storage can also lengthen the storage period of waste materials before processing. However, extra investment in building infrastructure and power consumption would be needed to utilise the waste more efficiently.

3.1.2. Okara

Okara (also called soybean dregs or bean curd residue) is the residue of soybean resulting from the production (soaking, blanching and boiling) of tofu or soymilk. About 1.1 kg of raw okara (about 80% moisture) is produced from processing 1 kg of soybean processed for tofu (Khare et al., 1995). It has been estimated that about 2.8 million tonnes of okara are produced annually by the tofu industry in China (Li et al., 2012). Raw okara is seldom consumed by humans and it is usually landfilled or used as animal feed. Dried okara is nutritious and it contains about 25% to 27% crude protein and 10% crude lipids (Mateos-Aparicio et al., 2010; O'Toole, 2016; Redondo-Cuenca et al., 2008). Okara protein has a good essential amino acid profile and in vitro digestibility (Chan and Ma, 1999; Ma et al., 1997). It also contains small amounts of starch, sugars and potassium and significant levels of B vitamins (Van der Riet et al., 1989).

Information regarding the use of okara in fish farming is limited. El-Saidy (2011) revealed that okara could replace up to 75% of fishmeal protein in practical diets of Nile tilapia mono-sex males without any adverse effects on growth performance, feed utilization or the body composition. Wong and Tang (1996) reported that common carp fed with papain-digested okara yielded significantly better growth in terms of weight and length gains than their counterparts without digestion. In Hong Kong, raw or semi-dried okara is frequently used as feed for carp, tilapia and grey mullet (*Mugil cephalus*) in polyculture ponds. Fish farmers can obtain fresh okara from domestic soybean milk producers for free or at a low cost. With its cheaper price, okara could partially replace fishmeal or soybean meal in the production of fish feeds (Li et al., 2012; Wong and Tang, 1996).

Because of its high moisture content (about 80%), raw okara can putrefy quickly if it is not preserved immediately (Taruna and Jindal, 2002; Wachiraphansakul and Devahastin, 2005); thus, a drying process is needed for prolonged storage. Moreover, as a derivative of soybean, okara contains anti-nutritional factors (ANF) such as trypsin inhibitor (Li et al., 2012). Unlike raw soybeans, however, the processes involved in soybean milk production (soaking, blanching and boiling) can reduce the trypsin inhibitor activity in okara by 81% when compared to raw soybean (Wickramarathna and Arampath, 2003).

3.2. Food waste

3.2.1. Food waste as fish feed ingredients

Food waste is food that is discarded or left uneaten. In developed countries, discarded food accounts for a relatively small amount of municipal solid waste (MSW). Yang et al. (2012) estimated that the annual food waste production of China is 195 million tonnes. Mian et al. (2016) reported that food waste accounts for 55.86% of MSW in China. It has been estimated that in total over 50 million tonnes of grain are wasted annually at the consumer stage in China (Zheng, 2011). Decomposition of food waste in landfills produces substantial quantities of methane – a potent greenhouse gas with 20 times the global warming potential of carbon dioxide (Ishigaki et al., 2002). This makes landfilling an unsuitable choice for disposal of food waste in China. Incineration is also not a suitable option because the high moisture content of food waste results in low net caloric value (Liu et al., 2006; Xiao et al., 2007; Yuan et al., 2006; Zhuang et al., 2008). Thus, instead of landfilling or incineration, food waste could be recycled. In fact, the use of food waste in animal production is not a new concept.

Table 3 lists the quantity of food waste and its share in the MSW in some Chinese cities. The data suggest that large cities in China produce large quantities of food waste daily, accounting for >50% of the MSW collected (except for Hong Kong, where it is about 36%). Therefore, turning food waste into fish feed at a larger scale should be encouraged.

Information regarding the use of food waste as fish feed is limited. Hsieh (2010) revealed that orange-spotted grouper (*Epinephelus coioides*) fed diets containing 10% or 20% food waste (consisting of a mixture of various foods, generated from a university cafeteria) showed no significant differences in growth performance compared to the group fed a diet with 0% food waste. Bake et al. (2013) used recycled food waste (including soy sauce waste, leftover food from convenience stores, food waste residues discharged during processing, hotel waste, restaurant cooking waste, tofu waste and bread production waste) to feed Nile tilapia and found that the groups fed diets with recycled food waste showed no significant differences in growth performance to the control group (fed a diet without food waste). Al-Ruqaie (2007) studied the effects of using food waste (leftover food from bakeries and fish markets, and hot water washed rice from restaurants) to feed

Table 3
Quantity of food waste and its share of municipal solid waste in some major China cities.

City	Year	Food waste (tonnes per day)[a]	Share of municipal solid waste (%)	Reference
Hong Kong	2012	3337	35.97	EPD, 2016
Beijing	2008	726	66.19	Tai et al., 2011
Shanghai	2008	588	71.14	Tai et al., 2011
Guangzhou	2008	269	52.00	Tai et al., 2011
Shenzhen	2008	300	51.10	Tai et al., 2011
Hangzhou	2010	130	53.00	HMSWDSC, 2010
Nanjing	2008	138	70.59	Tai et al., 2011
Xiamen	2008	74	74.63	Tai et al., 2011
Guilin	2008	15	61.31	Tai et al., 2011
Tianjin	2006	1417[b]	56.88	TCAEEDRI, 2007

[a] Figures rounded to the nearest whole number.
[b] Kitchen waste.

tilapia and found no significant differences in weight gain or specific growth rate between the group fed a commercial diet and those fed diets containing leftover food. Mo et al. (2014) revealed that food-waste-based diets (containing 70% w/w sorted food waste meal) contained satisfactory levels of essential amino acids, crude proteins, crude carbohydrates, crude lipids and phosphates; such diets were suitable for growing low-trophic level fish, including grass carp, grey mullet, bighead carp and tilapia. Furthermore, the fish fed food waste-based pellets had lower levels of contaminants (such as DDT and mercury) than those fed commercial feed pellets (Cheng et al., 2014; Cheng et al., 2015).

These studies all suggest that food waste could be used to make fish feed. However, these studies used food waste from specific sources and it was sorted before use. Due to the highly heterogeneous nature of food waste, it would be difficult to formulate feeds with acceptable nutritional values without proper source separation. For example, the optimal dietary crude protein levels for grass carp and Nile tilapia should be 22% to 30% and 30%, respectively (Cai et al., 2005; Wang et al., 1985). Mixed food waste generally contains around 20% crude proteins (Sayeki et al., 2001), and therefore its protein content would still be a bit low for low trophic level fish.

Biotransformation of food waste by microorganisms is another possible approach to enhance the crude protein content and lower fibre content of food waste used as feed. Solid-state fermentation (SSF) is a process in which microorganisms are grown on solid substrates in the absence of free water (Lagemaat and Pyle, 2001). Lateef et al. (2008) reported that SSF with *Rhizopus stolonifer* LAU 07 could significantly increase the crude protein content of agro-wastes (the percentage increase in crude protein in the wastes due to the formation of fungal biomass ranged from 33.3% to 94.8%). Wang et al. (2010) also revealed that SSF fermented potato pulp had significantly increased crude protein (from 3% to 5% to >18%) and slightly increased lipid content (from 3% to 4% to 5% to 6%), whilst the crude fibre content significantly decreased from 40% to 50% to <12%. Fermentation with lactic acid bacteria can also enhance the nutritional composition of food waste. Yang et al. (2006) suggested that lactic acid fermentation of food waste could break down fibre and increase water-soluble carbohydrates in the fermentation product. Sotolu (2009) revealed that there was no significant difference between values of SGR, PER, FCR and protein intake between fish waste meal and fish meal based-diets at the same level of inclusion for juveniles of African catfish (*Clarias gariepinu*). Goddard et al. (2008) reported that the crude protein contents and the protein apparent digestibility coefficient of fish processing waste meal (from a commercial tuna and sardine cannery and fish meal plant) had no significant differences to anchovy meal.

Mixed food waste generally contains around 60% carbohydrates, 20% protein and 10% lipids (Sayeki et al., 2001). Liu (2014) revealed that carbohydrate-rich food items comprise a large proportion of food waste in China, making food waste particularly useful to China's aquaculture industry. When fed diets containing 40% digestible starch, omnivorous freshwater species such as tilapia and carp showed good growth performance with normal ranges of liver size and glycogen levels (Stone, 2003). As shown in Table 1, herbivorous and omnivorous fish account for the majority of fish cultured in China's aquaculture industry. The high carbohydrate content of food waste could be particularly useful for growing these fish. Nevertheless, information regarding different methods of processing food waste as feed is relatively limited, and more research is urgently needed.

3.2.2. Food waste-grown algae as fish feed

In addition to making pellet feeds for fish, food waste could also be used as a nutrient source to produce microalgae. Microalgae are widely used in fish hatcheries, either directly as a feedstuff for fish larvae or as prey to feed other live feed such as *Artemia* and rotifers (Muller-Feuga, 2000). Maintaining live microalgal cultures is expensive. It has been estimated that investment in culturing microalgae could represent 30% of a hatchery's operating cost (Coutteau and Sorgeloos, 1992), due to the expensive culture medium used to maintain the algal culture. However, the use of food waste hydrolysate could help to lower the cost. Pleissner et al. (2013) reported that the fungal hydrolysate of food waste (generated from a cafeteria) could be used as a culture medium for rearing *Schizochytrium mangrovei* and *Chlorella pyrenoidosa*, which contained higher concentrations of protein (*S. mangrovei*: 259.8 mg; *C. pyrenoidosa*: 130.6 mg) and lipids (*S. mangrovei*: 164.9 mg; *C. pyrenoidosa*: 209.9 mg) than those cultured with conventional medium (protein and lipids: *S. mangrovei*: 82.1 mg and 124.9 mg; *C. pyrenoidosa*: 69.4 mg and 48.6 mg, respectively). Lau et al. (2014) investigated the growth of *Chlorella vulgaris* and reported that food waste hydrolysate consisting of 17.9 g L^{-1} glucose, 0.1 g L^{-1} free amino nitrogen, 0.3 g L^{-1} phosphate and 4.8 mg L^{-1} nitrate resulted in the highest exponential growth rate in terms of biomass of 0.8 day^{-1}.

Freeze-dried *S. mangrovei* could be used to enrich the arachidonic acid (AA) and docosahexaenoic acid (DHA) contents of rotifers (Estudillo-del Castillo et al., 2009), and live *C. pyrenoidosa* could be co-fed live daphnia to larval loach (*Misgurnus anguillicaudatus*) to enhance fish growth and survival when compared to the groups fed microparticle diets or live daphina only (Wang et al., 2008).

Similar to fish waste and okara, pre-treatment of food waste to reduce moisture would be necessary before further processing because both fresh and cooked food usually contain a higher moisture content than uncooked food and thus favour microbial growth. Heat treatment of the food waste at 65 °C for 20 min would be adequate to eliminate most of the harmful microorganisms, including *Enterobacteria*, *Clostridium* and *Staphylococcus aureus*, with no loss of nutritional quality (Sancho et al., 2004).

4. Regulations on the usage of waste materials as animal feed

4.1. Current regulations of food waste as animal feed

As noted above, the use of waste materials for fish production has been practised for centuries. To the best of our knowledge, however, food waste is not widely used in the manufacture of feed pellets. Fish farmers in China tend to use compound pellet feeds (Chiu et al., 2013) to maximise fish growth. Currently, the most popular application of food waste is as swill for feeding pigs. In fact, the recycling of food waste as swill is actively promoted and regulated by various Asian countries, including Korea, Japan, Taiwan and Thailand (Menikpura et al., 2013), and thus far there have been no food safety issues related to the use of food waste for feeding pigs.

In Taiwan, which started recycling food waste in 2001, about 2000 t of food waste is recycled daily and steam-treated for use as pig swill (Taiwan, 2014). In 2011, Japan introduced the Promotion of Utilization of Recyclable Food Waste Act (Food Waste Recycling Law) to regulate the collection, transport and storage of food waste and the animal feed derived from food waste is known as 'Ecofeed' for growing pigs, poultry and ruminants (Ermgassen et al., 2016). Japan successfully recycled 52.5% food waste from manufacturing, retail and catering sectors as

Table 4
Treatment methods adopted by different countries using recycled food waste as feed.

Country	Treatment	Reference
Japan	Food waste containing meat must be heated for a minimum of 30 min at 70 °C or 3 min at 80 °C	Sugiura et al., 2009
Korea	Food waste must be heat-treated for 30 min to a core temperature of at least 80 °C	National Institute of Environmental Research, 2012
Taiwan	Food waste must be heated for at least 60 min to a core temperature of 90 °C	Taiwan, 2014
United States of America	Meat present in waste must be heated to 75 °C for 30 min	USDA, 2009

animal feed in 2006 (MAFF, 2011). However, because household food waste is vulnerable to contamination by foreign objects, it is not currently recycled in Japan (Sugiura et al., 2009). South Korea has also introduced laws to promote the recycling of food waste as swill for pigs (MOAFRA, 2010; MOE, 2008), and about 42.5% of food waste was recycled as animal feed in 2006 (Kim and Kim, 2010). Growing pigs with food waste is regulated by the Swine Health Protection Act in the United States of America, but only 28 of the 50 states permit the use of food waste as animal feed (USDA, 2016). Although the treatment methods vary among these countries, food waste used as animal feed must be heat-treated for sterilisation (EPA, 2013; National Institute of Environmental Research, 2012; USDA, 2016). Table 4 summarises the thermal treatment requirements of various countries.

The European Union has the most stringent regulations governing the use of waste as animal feed. To prevent the spread of prion diseases, the use of processed animal protein, also known as meat and bone meal, as animal feed has been banned in the European Union (Karapanagiotidis, 2014). Moreover, the use of waste to feed animals was banned due to the outbreak of foot-and-mouth disease in the UK in 2002 (Ermgassen et al., 2016). The European Union also forbids the use of farmed fish by-products in finfish feeds, but they can be used in crustacean diets and vice versa (Newton et al., 2014). Animal producers in the European Union have had to shift from using animal waste to using grains and/or formulated feeds. However, this has led to a large area of arable land being used to grow animal feed. A recent study indicated that using food waste as a primary source of swill to produce pork in Europe (which accounts for 20% of world production) could potentially save 1.8 million ha of agricultural land (Ermgassen et al., 2016).

4.2. Regulations of food waste as fish feed in China and its future development

China's aquaculture industry consumes a huge amount of fishmeal derived from wild fish and trash fish to produce fish feed or directly used as fish feed. It would be wise to make use of various waste materials to reduce reliance on precious marine resources and to save valuable agricultural land for food crops. However, there is an urgent need to modify the existing regulations on food waste recycling and the use of food waste as fish feed.

Currently there is no national law in China regarding management strategies to regulate food waste, and regulations on food waste recycling are at the city level only (Hu et al., 2012). Trial runs of food waste recycling (separated from other municipal waste) are being carried out in selected pilot cities in China (National Development and Reform Commission, 2014). Xining (the capital of Qinghai province), for example, was the first city to issue regulations on food waste recycling and management (Hu et al., 2012). Currently, recycled food waste is mainly used to produce compost, animal feed additives and biodiesel (Hu et al., 2012).

The majority of recycled food waste is used to produce compost. However, the number and the treatment capacity of composting plants in China decreased dramatically from 134 plants and 25,461 t per day (tpd) in 2001 to 11 plants and 5480 tpd in 2010, because the organic fraction of final compost product (about 20%) cannot meet the standard for organic fertiliser (>45%), which affects sales (Song et al., 2013). With the reduced number of treatment facilities, there is an urgent need to explore alternative methods for treating food waste other than landfilling. Fortunately, treatment facilities using other treatment methods (such as anaerobic digestion or fermentation to produce animal feed additives, biodiesel or biogas) are increasing (Hu et al., 2012), although the number of facilities does not appear to be sufficient to handle the massive amount of food waste produced in China.

Waste materials should be properly treated before their use as ingredients of formulated diets. The quality of raw food waste could be the most critical factor for manufacturing food waste–derived feeds because it is difficult to remove chemical contaminants (migrated from packing materials or cutlery) (Chen et al., 2015). However, because there is no strict rule or established system to collect recyclable waste materials, food waste is mixed with other waste such as plastics, papers and metals, and there is currently no strict regulation or system to collect recyclable waste (Mian et al., 2016). It has been reported that the MSW separation ratio is about 15% (Xiao et al., 2007). Food waste can only be used in animal feed if it is collected separately from other waste and is sufficiently fresh (Salemdeeb et al., 2017). Thus, with the low waste separation ratio, the amount of recyclable food waste in China could be very limited. Before processing, the materials should be properly inspected and handled because hazardous contaminants can migrate from printed paper bags or from the residues of cutlery or food processing apparatus (Xue et al., 2010; Yang and Zhao, 2009).

The safety of food waste–derived feed materials is always doubted by the general public. Currently in China there are laws and regulations relating to animal feed (including fish feed) quality and ingredients. Table 5 lists some important regulations on animal feed and feed additives. The regulations cover a wide range of guidelines on safety, hygiene requirements for the ingredients of feed and the corresponding management measures. It is illegal to feed ruminants bovine- or sheep-derived materials in China (MOA, 2001) and in regions such as the EU (EU Regulation (EC) No. 1069/2009, 2009), as feeding ruminants could transmit bovine spongiform encephalopathy (BSE). However, there are currently no regulations relating to turning food waste into fish feed pellets. In fact, BSE does not affect pigs, poultry or fish (Andreoletti et al., 2007). Similar to other feed products in China, feed derived from food waste should also comply with the Hygienic Standard for Feeds (GB 13078-2001). Chen et al. (2015) revealed that food waste treated by fermentation, dry heating or hydrothermal treatment coupled with fermentation can meet the strictest requirements of the Hygienic Standard for Feeds (GB 13078-2001), based on the microbial characteristics (total aerobic plate counts, total coliform, moulds and yeast, *Staphylococcus aureus*, *Salmonella* and *Listeria*) and concentrations of chemical contaminants (arsenic, cadmium, chromium, mercury, lead, aflatoxin B1, inorganic contaminant nitrites, DDT and HCH).

As noted above, regulations on food waste recycling exist at the city level only. However, unlike other countries that are recycling food waste as animal feed, China has no specialised laws to regulate the use of food waste. Table 5 also lists regulations regarding the use of food waste as animal feed (including fish feed) in other countries. The

Table 5
Regulations and guidelines on animal feed and feed additives: China and other countries and regions.

Regulations and guidelines	Year issued and amended (if applicable)	Reference
China		
Hygienical standard for feeds	2001	AQSIQ, 2001
Approved feed additives	2013	MOA, 2001
Regulation on the management of feeds and feed additives	2012	State Council, 2011
Regulation on feed and feed additive import registration	2014	MOA, 2014
Measures for the management of production licenses for feeds and feed additives	2012 amended 2013	MOA, 2013a, 2013b
Single feed products directory	2008	MOA, 2008
Other countries		
Food waste recycling law (Japan)	2001 amended 2007	MOE, 2008
Wastes control act (South Korea)	2008	MOE, 2008
Control of livestock and fish feed act (South Korea)	2008 amended 2010	MOE, 2008
Resource recycling and reuse program (Taiwan)	2003	EPA, 2013
Waste resource recycling promotion program (Taiwan)	2007	EPA, 2013
Swine health protection act garbage feeding final rules (USA)	2009	USDA, 2009

Chinese Government should revise existing regulations or enact new regulations/national standards/accreditation systems related to the use of waste derived materials, to provide clear guidelines for treatment facility operators to ensure that waste materials are properly handled and treated. For example, in South Korea, recycling food waste is regulated under the Control of Livestock and Fish Feed Act Article 8. Food waste can only be included in animal feed if it has been treated at registered feed production, of which there were 259 in 2010 (MOE, 2008). In the United States, food waste–derived feeds must meet the regulations and rules set by the Department of Agriculture. Meat present in waste must be heated to 75 °C for 30 min to inactivate pathogenic organisms (USDA, 2009) before any practical use. Despite these regulations, information related to the use of food waste as an ingredient in fish feed is very limited. There is an urgent need to devote more research effort to fill the knowledge gaps on the usage and processing methods of food waste, its economic viability and its possible negative impacts on the environment. Moreover, a substantial research effort is needed to ensure the safety of fish fed with food waste, to convince the general public and policymakers to accept food waste as fish feed.

5. Conclusions

A stable supply of fish feed is crucial to maintain food security. China contributes significantly to global aquaculture production. Although the fish species farmed in China are diverse, Chinese carp and tilapia will continue to be the major aquaculture production species. A large variety of waste materials could be utilised by the aquaculture industry to reduce the amount of conventional protein sources included in fish feed. Although food waste is mainly used as pig feed, the successful cases of using food waste as feed in South Korea, Japan and Taiwan suggest that the idea could also be applied to fish feed production. There is an urgent need for research to fill the knowledge gaps on the usage and processing methods of food waste. Renewing standards and regulations in a timely manner would also help the industry to move towards the use of waste materials in fish feed.

Acknowledgements

Financial support from Innovative Technology Fund (Innovative Technology Commission, Hong Kong): ITS/174/14FX, Sustainable Fisheries Development Fund (Agriculture, Fisheries and Conservation Department, Hong Kong): SFDF-0023, National Natural Science Foundation of China (41303083), Start-up Research Grant for Newly Recruited Assistant Professors (RG 55/2016-2017R), and The Education University of Hong Kong, is gratefully acknowledged.

References

Al-Ruqaie, I.M., 2007. Extruded leftover food as animal feed. I. Effect of extruded feeds on growth and feed utilization of tilapia, *Oreochromis niloticus* in Saudi Arabia. Pak. J. Biol. Sci. 10, 3248–3253.

Anderson, J.S., Lall, S.P., Anderson, D.M., McNiven, M.A., 1995. Availability of amino acids from various fish meals fed to Atlantic salmon (*Salmo salar*). Aquaculture 138, 291–301.

Andreoletti, O., Budka, H., Buncic, S., Colin, P., Collins, J.D., De Koeijer, A., Griffin, J., Havelaar, A., Hope, J., Klein, G., 2007. Opinion of the scientific panel on biological hazards on a request from the European Parliament on certain aspects related to the feeding of animal proteins to farm animals. EFSA J. 576, 1–41.

AQSIQ (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China), 2001. Hygienical Standard for Feeds. China GB 13078–2001. China Standard Press, Beijing.

Bake, G.G., Endo, M., Satoh, S., Sadiku, S.O.E., Takeuchi, T., 2013. Nitrogen and mineral budget of Nile tilapia fry fed recycled food wastes materials supplemented with lysine and methionine in a closed recirculating fish culture system. Cont. J. Fish. Aquat. Sci. 7, 18–31.

Cai, X., Luo, L., Xue, M., Wu, X., Zhan, W., 2005. Growth performance, body composition and phosphorus availability of juvenile grass carp (*Ctenopharyngodon idellus*) as affected by diet processing and replacement of fishmeal by detoxified castor bean meal. Aquac. Nutr. 11, 293–299.

Cao, L., Naylor, R., Henriksson, P., Leadbitter, D., Metian, M., Troell, M., Zhang, W., 2015. China's aquaculture and the world's wild fisheries. Science 347, 133–135.

Chan, W.M., Ma, C.Y., 1999. Modification of proteins from soymilk residue (okara) by trypsin. J. Food Sci. 64, 781–786.

Chen, T., Jin, Y., Shen, D., 2015. A safety analysis of food waste-derived animal feeds from three typical conversion techniques in China. Waste Manag. 45, 42–50.

Cheng, Z., Liang, P., Shao, D.D., SC, Wu, Nie, X.P., Chen, K.C., Li, K.B., Wong, M.H., 2011. Mercury biomagnification in the aquaculture pond ecosystem in the Pearl River Delta. Arch. Environ. Contam. Toxicol. 61, 491–499.

Cheng, Z., Mo, W.Y., Man, Y.B., Nie, X.P., Li, K.B., Wong, M.H., 2014. Replacing fishmeal by food waste in feed pellets to culture lower trophic level fish containing acceptable levels of organochlorine pesticides: health risk assessments. Environ. Int. 73, 22–27.

Cheng, Z., Mo, W.Y., Man, Y.B., Lam, C.L., Choi, W.M., Nie, X.P., Liu, Y.H., Wong, M.H., 2015. Environmental mercury concentrations in cultured low-trophic-level fish using food waste-based diets. Environ. Sci. Pollut. Res. 22, 495–507.

Chiu, A., Li, L., Guo, S., Bai, J., Fedor, C., Naylor, R.L., 2013. Feed and fishmeal use in the production of carp and tilapia in China. Aquaculture 414, 127–134.

Chu, J.C.W., 2000. Environmental Management of Mariculture: The Effect of Feed Types on Feed Waste. Regional Workshop on Sea Farming and Grouper Aquaculture. 17–20 April 2000, Medan, Indonesia.

Coutteau, P., Sorgeloos, P., 1992. The use of algal substitutes and the requirement for live algae in the hatchery and nursery rearing of bivalve molluscs: an international survey. J. Shellfish Res. 11, 467–476.

De Silva, S.S., Turchini, G.M., 2009. Use of Wild Fish and Other Aquatic Organisms as Feed in Aquaculture: A Review of Practices and Implications in the Asia-Pacific. In: Hasan, M.R., Halwart, M. (Eds.), Fish as Feed Inputs for Aquaculture: Practices, Sustainability and Implications. FAO Fisheries and Aquaculture Technical Paper. No. ss518. Rome, FAO, pp. 63–127.

Dickman, M.D., Leung, C.K., Leong, M.K., 1998. Hong Kong male subfertility links to mercury in human hair and fish. Sci. Total Environ. 214, 165–174.

Edwards, P., Tuan, L.A., Allan, G.L., 2004. A survey of marine trash fish and fish meal as aquaculture feed ingredients in Vietnam. ACIAR Working Paper 57. ACIAR, Canberra (56 pp).

El-Saidy, D.M.S.D., 2011. Effect of using okara meal, a by-product from soymilk production as a dietary protein source for Nile tilapia (*Oreochromis niloticus* L.) mono-sex males. Aquac. Nutr. 17, 380–386.

EPA (Environmental Protection Administration, China), 2013. The current status for kitchen waste recycling and reuse. http://web.epa.gov.tw/en/epashow.aspx?list=125&path=9105&guid=2d105564-911d-4536-ae70-798eb75b345c&lang=en-us, Accessed date: 9 June 2016.

EPD (Hong Kong Environmental Protection Department), 2016. Food waste: problems and solutions. Available at:. http://www.epd.gov.hk/epd/english/environmentinhk/waste/prob_solutions/food_waste_challenge.html, Accessed date: 26 May 2016.

Ermgassen, E.K., Phalan, B., Green, R.E., Balmford, A., 2016. Reducing the land use of EU pork production: where there's swill, there's a way. Food Policy 58, 35–48.

Esteban, M.B., García, A.J., Ramos, P., Marquez, M.C., 2007. Evaluation of fruit–vegetable and fish wastes as alternative feedstuffs in pig diets. Waste Manag. 27, 193–200.

Estudillo-del Castillo, C., Gapasin, R.S., Leaño, E.M., 2009. Enrichment potential of HUFA-rich thraustochytrid *Schizochytrium mangrovei* for the rotifer *Brachionus plicatilis*. Aquaculture 293, 57–61.

EU (The European Union), 2009. Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009, Animal By-products Regulation (EC) No. 1069/2009.

FAO, 2016. Nile tilapia: nutritional requirements. http://www.fao.org/fishery/affris/species-profiles/nile-tilapia/nutritional-requirements/en/, Accessed date: 28 April 2016.

FAO (Food and Agriculture Organization), 2017. FishStatJ: a tool for fishery statistics analysis, Version 2.12.5. http://www.fao.org/fishery/statistics/software/fishstatj/en, Accessed date: 24 April 2017.

Fishery Bureau of Department of Agriculture, 2009. Fishery Yearbook of China in 2008. Chinese Agriculture Press, Beijing (in Chinese).

Flajšhans, M., Hulata, G., 2006. Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations. Common carp, *Cyprinus carpio*. In: Svåsand, T., Crosetti, D., García-Vázquez, E., Verspoor, E. (Eds.), Evaluation of Genetic Impact of Aquaculture Activities on Native Populations: A European Network. GENIMPACT Final Report (EU contract n. RICA-CT-2005-022802), pp. 32–39.

Fu, J., 2015. Population to peak in 2025. China Daily. http://www.chinadaily.com.cn/china/2015-10/07/content_22119396.htm, Accessed date: 3 June 2016.

Funge-Smith, S., Lindebo, E., Staples, D., 2005. Asian Fisheries Today: The Production and Use of Low Value/Trash Fish from Marine Fisheries in the Asia-Pacific Region. RAP Publication 2005/16. Bangkok, FAORAP (38 pp).

Funge-Smith, S., Briggs, M., Miao, W., 2012. Regional Overview of Fisheries and Aquaculture in Asia and the Pacific 2012. Asia-Pacific Fishery Commission, FAO Regional Office for Asia and the Pacific. RAP Publication 2012/26 (139 pp).

Goddard, S., Al-Shagaa, G., Ali, A., 2008. Fisheries by-catch and processing waste meals as ingredients in diets for Nile tilapia, *Oreochromis niloticus*. Aquac. Res. 39, 518–525.

Grainger, R., Xie, Y., Li, S., Guo, Z., 2005. Production and Utilization of Trash Fish in Selected Chinese Ports. Asia-Pacific Fishery Commission FAO, Rome, Italy.

Guo, Y., HY, Yu, Zhang, B.Z., Zeng, E.Y., 2009. Persistent halogenated hydrocarbons in fish feeds manufactured in South China. J. Agric. Food Chem. 57, 3674–3680.

Heuzé, V., Tran, G., Kaushik, S., 2015. Fish meal. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://www.feedipedia.org/node/208, Accessed date: 3 June 2016.

HMSWDSC (Hangzhou Municipal Solid Waste Disposal Supervision Center), 2010. Hangzhou Municipal Solid Waste Physical Property Analysis and Disposal Method. Municipal Solid Waste Disposal Supervision Center, Hangzhou (in Chinese).

Hsieh, M.J., 2010. Effects of Fish Meal Replacement by Kitchen Waste on the Growth and Body Composition of Tilapia (*Oreochromis nilotica* × *Oreochromis aurea*), Giant Grouper (*Epinephelus lanceolatus*) and Orange-Spotted Grouper (*Epinephelus coioides*). Master's Thesis. National Taiwan Ocean University.

Hu, X.J., Zhang, M., JF, Yu, Zhang, G.R., 2012. Food waste management in China: status, problems and solutions. Acta Ecol. Sin. 32, 4575–4584.
Ishigaki, T., Inanc, B., Okhouchi, Y., Mohri, S., Yamada, M., Inoue, Y., Kazakai, T., Nagamori, M., Ono, Y., 2002. Relationship between gas flux and ground temperature on a surface of a waste landfill site. Proceedings of the Second Asia Pacific Landfill Symposium, September 25–28. Seoul, Korea, pp. 477–481.
Karapanagiotidis, I.T., 2014. The re-authorization of non-ruminant processed animal proteins in European aqua feeds. Fish. Aquac. J. 5, 1–3.
Kelly, B.C., Ikonomou, M.G., Blair, J.D., Gobas, F.A., 2008. Bioaccumulation behaviour of polybrominated diphenyl ethers (PBDEs) in a Canadian Arctic marine food web. Sci. Total Environ. 401, 60–72.
Khare, S.K., Jha, K., Gandhi, A.P., 1995. Citric acid production from okara (soy-residue) by solid-state fermentation. Bioresour. Technol. 54, 323–325.
Kim, M.H., Kim, J.W., 2010. Comparison through a LCA evaluation analysis of food waste disposal options from the perspective of global warming and resource recovery. Sci. Total Environ. 408, 3998–4006.
Kinnunen, R.E., Gould, M.C., Cambier, P., 2005. Composting Commercial Fish Processing Waste from Fish Caught in the Michigan Waters of the Great Lakes. Michigan State University Extension, USA.
Kotzamanis, Y.P., Alexis, M.N., Andriopoulou, A., Castritsi-Cathariou, I., Fotis, G., 2001. Utilization of waste material resulting from trout processing in gilthead bream (*Sparus aurata* L.) diets. Aquac. Res. 32, 288–295.
Kristinsson, H.G., Rasco, B.A., 2000. Fish protein hydrolysates: production, biochemical, and functional properties. Crit. Rev. Food Sci. Nutr. 40, 43–81.
Lacerda, L.D., Soares, T.M., Costa, B.G.B., Godoy, M.D.P., 2011. Mercury emission factors from intensive shrimp aquaculture and their relative importance to the Jaguaribe River Estuary, NE Brazil. Bull. Environ. Contam. Toxicol. 87, 657–661.
Lagemaat, J.V., Pyle, D.L., 2001. Solid state fermentation and bioremediation: development of a continuous process for the production of fungal tannase. Chem. Eng. J. 84, 115–123.
Lateef, A., Oloke, J.K., Kana, E.G., Oyeniyi, S.O., Onifade, O.R., Oyeleye, A.O., Oladosu, O.C., Oyelami, A.O., 2008. Improving the quality of agro-wastes by solid-state fermentation: enhanced antioxidant activities and nutritional qualities. World J. Microbiol. Biotechnol. 24, 2369–2374.
Lau, T.S.K., Lee, J.C.W., Young, L., 2003. Pilot Project to Raise Awareness of the Ecological Importance of Pond-fish Farming in the Mai Po Inner Deep Bay Ramsar Site. World Wide Fund for Nature Hong Kong.
Lau, K.Y., Pleissner, D., Lin, C.S.K., 2014. Recycling of food waste as nutrients in *Chlorella vulgaris* cultivation. Bioresour. Technol. 170, 144–151.
Li, B., Qiao, M., Lu, F., 2012. Composition, nutrition, and utilization of okara (soybean residue). Food Rev. Int. 28, 231–252.
Liang, P., Shao, D.D., Wu, S.C., Shi, J.B., Sun, X.L., Wu, F.Y., Lo, S.C.L., Wang, W.X., Wong, M.H., 2011. The influence of mariculture on mercury distribution in sediments and fish around Hong Kong and adjacent mainland China waters. Chemosphere 82, 1038–1043.
Liu, G., 2014. Food Losses and Food Waste in China: A First Estimate. OECD Food, Agriculture and Fisheries Papers, No. 66. OECD Publishing.
Liu, J., Li, Z., 2010. The role of exotics in Chinese inland aquaculture. In SS De Silva and FB Davy (eds.) Success Stories in Asian Aquaculture. Springer Science + Business Media B.V, Dordrecht, p. 230.
Liu, Z.Q., Liu, Z.H., Li, X.L., 2006. Status and prospect of the application of municipal solid waste incineration in China. Appl. Therm. Eng. 26, 1193–1197.
Ma, C.Y., Liu, W.S., Kwok, F., 1997. Isolation and characterization of proteins from soymilk residue (okara). Food Res. Int. 29, 799–805.
MAFF (Ministry of Agriculture, Forestry, and Fisheries), 2011. Circumstances Surrounding the Ecofeed. Tokyo, Japan.
Mallory, T.G., 2013. China's distant water fishing industry: evolving policies and implications. Mar. Policy 38, 99–108.
Mao, G.F., 2011. Change is afoot in China. http://www.seafoodsource.com/news/supply-trade/change-is-afoot-in-china, Accessed date: 3 June 2016.
Mao, G.F., 2013. China eating more seafood than it produces. http://www.seafoodsource.com/news/supply-trade/china-eating-more-seafood-than-it-produces, Accessed date: 3 June 2016.
Mateos-Aparicio, I., Redondo-Cuenca, A., Villanueva-Suárez, M.J., Zapata-Revilla, M., Tenorio-Sanz, M., 2010. Pea pod, broad bean pod and okara, potential sources of functional compounds. LWT Food Sci. Technol. 43, 1467–1470.
Maule, A.G., Gannam, A.L., Davis, J.W., 2007. Chemical contaminants in fish feeds used in federal salmonid hatcheries in the USA. Chemosphere 67, 1308–1315.
Menikpura, S.N.M., Sang-Arun, J., Bengtsson, M., 2013. Integrated solid waste management: an approach for enhancing climate co-benefits through resource recovery. J. Clean. Prod. 58, 34–42.
Mian, M.M., Zeng, X., Nasry, A.A.N.B., Al-Hamadani, S.M., 2016. Municipal solid waste management in China: a comparative analysis. J. Mater. Cycles Waste 19, 1127–1135.
Mo, W.Y., Cheng, Z., Choi, W.M., Man, Y.B., Liu, Y., Wong, M.H., 2014. Application of food waste based diets in polyculture of low trophic level fish: effects on fish growth, water quality and plankton density. Mar. Pollut. Bull. 85, 803–809.
MOA (Ministry of Agriculture of the People's Republic of China), 2008. Single feed products directory.Available at. http://www.xmys.moa.gov.cn/slgz/201006/t20100606_1535077.htm, Accessed date: 11 June 2016 (In Chinese.).
MOA (Ministry of Agriculture of the People's Republic of China), 2013a. Approved feed additives.Available at. http://www.moa.gov.cn/fwllm/zxbs/xzxk/bszl/201104/t20110415_1969961.htm, Accessed date: 11 June 2016 (In Chinese.).
MOA (Ministry of Agriculture of the People's Republic of China), 2013b. Measures for the management of production licenses for feeds and feed additives.Available at. http://www.moa.gov.cn/zwllm/zcfg/nybgz/201401/t20140120_3743551.htm, Accessed date: 11 June 2016 (In Chinese.).
MOA (Ministry of Agriculture of the People's Republic of China), 2014. Regulation on feed and feed additive import registration.Available at. http://www.moa.gov.cn/fwllm/zxbs/xzxk/bszl/201403/t20140305_3805022.htm, Accessed date: 11 June 2016 (In Chinese.).
MOA (People's Republic of China Ministry of Agriculture), 2001. Notice on Prohibition on Adding the Animal Feed in Ruminant Animal Feed. People's Republic of China.
MOAFRA (South Korea Ministry of Agriculture, Food, and Rural Affairs), 2010. Control of livestock and fish feed act. South Korea. Available at. http://elaw.klri.re.kr/eng_mobile/viewer.do?hseq=18513&type=sogan&key=7, Accessed date: 11 June 2016.
MOE (South Korea Ministry of Environment), 2008. Wastes Control Act. South Korea. Available at. http://www.moleg.go.kr/english/korLawEng?pstSeq=47552, Accessed date: 11 June 2016.
Msangi, S., Kobayashi, M., Batka, M., Vannuccini, S., Dey, M.M., Anderson, J.L., 2013. Fish to 2030: Prospects for Fisheries and Aquaculture. World Bank Report, (83177-GLB).
Muller-Feuga, A., 2000. The role of microalgae in aquaculture: situation and trends. J. Appl. Phycol. 12, 527–534.
Mundi, Index, 2016. China fish meal domestic consumption by year. http://www.indexmundi.com/agriculture/?country=cn&commodity=fish-meal&graph=domestic-consumption, Accessed date: 11 June 2016.
Murthy, L.N., Mohan, C.O., Ravishankar, C.N., Badonia, R., 2013. Biochemical quality and heavy metal content of fish meal and squid meal produced in Veraval, Gujarat. Ind. J. Fish. 60, 113–117.
National Development and Reform Commission, 2014. Notice on the fourth instalment of the recommending pilot cities for kitchen waste recycling and safe disposal options. from. http://www.sdpc.gov.cn/gzdt/201405/t20140506_610067.html, Accessed date: 5 June 2016 (In Chinese.).
National Institute of Environmental Research, 2012. Management Technologies of Organic Waste. Ministry of Environment, Seoul, South Korea.
Newton, R., Telfer, T., Little, D., 2014. Perspectives on the utilization of aquaculture coproduct in Europe and Asia: prospects for value addition and improved resource efficiency. Crit. Rev. Food Sci. Nutr. 54, 495–510.
Olsen, R.L., Hasan, M.R., 2012. A limited supply of fishmeal: impact on future increases in global aquaculture production. Trends Food Sci. Technol. 27, 120–128.
O'Toole, D.K., 2016. Soybean: soymilk, tofu, and okara. In: Wrigley, C., Corke, H., Seetharaman, K., Faubion, J. (Eds.), Encyclopedia of Food Grains (Second Edition) Volume 3: Grain-based Products and their Processing. Elsevier, Oxford, UK, pp. 134–143.
Peteri, A., 2004. Cultured Aquatic Species Information Programme: *Cyprinus carpio*. FAO Fisheries and Aquaculture Department, Rome Available at. http://www.fao.org/fishery/culturedspecies/Cyprinus_carpio/en, Accessed date: 15 January 2017.
Pleissner, D., Lam, W.C., Sun, Z., Lin, C.S.K., 2013. Food waste as nutrient source in heterotrophic microalgae cultivation. Bioresour. Technol. 137, 139–146.
Prein, M., 2002. Integration of aquaculture into crop–animal systems in Asia. Agric. Syst. 71, 127–146.
Rakocy, J.E., 2005. Cultured aquatic species information programme: *Oreochromis* niloticus. FAO Fish. Aquac. Department, Rome. Available at. http://www.fao.org/fishery/culturedspecies/Oreochromis_niloticus/en, Accessed date: 15 January 2017.
Redondo-Cuenca, A., Villanueva-Suárez, M.J., Mateos-Aparicio, I., 2008. Soybean seeds and its byproduct okara as sources of dietary fibre: measurement by AOAC and Nglyst methods. Food Chem. 108, 1099–1105.
Salemdeeb, R., Ermgassen, E.K., Kim, M.H., Balmford, A., Al-Tabbaa, A., 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. J. Clean. Prod. 140, 871–880.
Sancho, P., Pinacho, A., Ramos, P., Tejedor, C., 2004. Microbiological characterization of food residues for animal feeding. Waste Manag. 24, 919–926.
Sayeki, M., Kitagawa, T., Matsumoto, M., Nishiyama, A., Miyoshi, K., Mochizuki, M., Takasu, A., Abe, A., 2001. Chemical composition and energy value of dried meal from food waste as feedstuff in swine and cattle. Anim. Sci. J. 72, 34–40.
Site, Fish, 2012. Demand for high-end US seafood in South China remains. http://www.thefishsite.com/fishnews/19045/demand-for-highend-us-seafoodin-south-china-remains, Accessed date: 3 June 2016.
Song, L., Chen, S., Bi, Z., Tao, Q., 2013. Study on the current situation of municipal solid waste composting in china and development trend. http://www.nswaienvis.nic.in/Waste_Portal/wasteportalpdf/Current%20Situation%20of%20Municipal%20Solid%20Waste%20Composting%20in%20China.pdf, Accessed date: 12 June 2016.
Sotolu, A.O., 2009. Comparative utilizations of fish waste meal with imported fishmeal by African Catfish (Clarias gariepinus). Am.-Eur. J. Sci. Res. 4, 285–289.
State Council (The People's Republic of China), 2011. The feed and feed additive regulation. Available at. http://www.gov.cn/zhengce/content/2011-11/15/content_2810.htm, Accessed date: 11 June 2016.
Stone, D.A.J., 2003. Dietary carbohydrate utilization by fish. Rev. Fish. Sci. 11, 337–369.
Sugiura, K., Yamatani, S., Watahara, M., Onodera, T., 2009. Ecofeed, animal feed produced from recycled food waste. Veterinaria Italiana 45, 397–404.
Tacon, A.G., Metian, M., 2008. Global overview on the use of fishmeal and fish oil in industrially compounded aquafeeds: trends and future prospects. Aquaculture 285, 146–158.
Tai, J., Zhang, W., Che, Y., Feng, D., 2011. Municipal solid waste source-separated collection in China: a comparative analysis. Waste Manag. 31, 1673–1682.
Taiwan, E.P.A., 2014. Recycling food waste for feeding pigs. http://www.epa.gov.tw/ct.asp?xItem=9130&ctNode=31520&mp=epa, Accessed date: 25 May 2016.
Taruna, I., Jindal, V.K., 2002. Drying of soy pulp (okara) in a bed of inert particles. Drying Technol. 20, 1035–1051.
TCAEEDRI (Tianjin City Appearance Environmental Engineering Design and Research Institute), 2007. Investigation on Municipal Solid Waste in Tianjin 2006. Tianjin (in Chinese).
USDA (United States Department of Agriculture), 2009. Swine health protection act garbage feeding final rule. Available at. https://www.aphis.usda.gov/animal_health/animal_dis_spec/swine/downloads/shp_garbage_feeding_final_rule.pdf, Accessed date: 9 September 2016.

USDA (United States Department of Agriculture), 2016. Swine disease information. Available at. https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/swine-disease-information, Accessed date: 9 September 2016.
Van der Riet, W.B., Wight, A.W., Cilliers, J.J.L., Datel, J.M., 1989. Food chemical investigation of tofu and its byproduct okara. Food Chem. 34, 193–202.
Villasante, S., Rodríguez-González, D., Antelo, M., Rivero-Rodríguez, S., de Santiago, J.A., Macho, G., 2013. All fish for China? Ambio 42, 923–936.
Wachiraphansakul, S., Devahastin, S., 2005. Drying kinetics and quality of soy residue (okara) dried in a jet spouted bed dryer. Drying Technol. 23, 1229–1242.
Wang, K., Takeuchi, T., Watanabe, T., 1985. Effect of dietary protein levels on growth of Tilapia nilotica. Bull. Jpn. Soc. Sci. Fish. 51, 133–140.
Wang, Y., Hu, M., Cao, L., Yang, Y., Wang, W., 2008. Effects of daphnia (*Moina micrura*) plus chlorella (*Chlorella pyrenoidosa*) or microparticle diets on growth and survival of larval loach (*Misgurnus anguillicaudatus*). Aquac. Int. 16, 361–368.
Wang, T.Y., Wu, Y.H., Jiang, C.Y., Liu, Y., 2010. Solid state fermented potato pulp can be used as poultry feed. Brit. Poult. Sci. 51, 229–234.
Weimin, M., 2004. Cultured aquatic species information programme: *Ctenopharyngodon idellus*. FAO Fish. Aquac. Department, Rome. Available at. http://www.fao.org/fishery/culturedspecies/Ctenopharyngodon_idellus/en, Accessed date: 15 January 2017.
Wickramarathna, G.L., Arampath, P.C., 2003. Utilization of okara in bread making. J. Biosci. 31, 29–33.
Wong, M.H., Tang, L.Y., 1996. The use of enzyme-digested soybean residue for feeding common carp. Biomed. Environ. Sci. 9, 418–423.
Wong, M.H., Cheung, K.C., Yediler, A., Wong, C.K.C., 2004. The dyke-pond systems in South China: past, present and future. Wong MH (ed), Wetlands Ecosystems in Asia: Function and Management. Elsevier, Amsterdam, pp. 47–68.
WWF, 2013. HKU- led research finds at least 20 popular grouper species facing extinction. Available at. http://www.wwf.org.hk/en/whatwedo/oceans/seafoodupdates.cfm?9922/HKU–led-research-finds-at-least-20-popular-grouper-species-facing-extinction, Accessed date: 6 November 2016.
Xiao, Y., Bai, X., Ouyang, Z., 2007. The composition, trend and impact of urban solid waste in Beijing. Environ. Monit. Assess. 135, 21–30.
Xue, M.Q., Wang, S.F., Huang, Z.X., 2010. Determination of heavy metals (Pb, Cd, Cr and Hg) in printed paper as food packaging materials and analysis of their sources. CIESC J. 12, 3258–3265.
Yang, S.Y., Ji, K.S., Baik, Y.H., Kwak, W.S., McCaskey, T.A., 2006. Lactic acid fermentation of food waste for swine feed. Bioresour. Technol. 97, 1858–1864.
Yang, C., Yang, M., Yu, Q., 2012. An analytical study on the resource recycling potentials of urban and rural domestic waste in China. Proceedings of the 7th International Conference on Waste Management and Technology, pp. 25–33 (Beijing; China).
Yang, L.N., Zhao, H., 2009. Survey of dishwashing detergent residue in boarding school. J. Environ. Health 26, 575.
Yuan, H., Wang, L., Su, F., Hu, G., 2006. Urban solid waste management in Chongqing: challenge and opportunities. Waste Manag. 26, 1052–1062.
Zheng, C., 2011. Serious food waste found in the catering sector in China.Available at. www.chinadaily.com.cn/hqgj/jryw/2011-03-08/content_1957714.html, Accessed date: 6 November 2016 (In Chinese).
Zhou, H.Y., Wong, M.H., 2000. Mercury accumulation in freshwater fish with emphasis on the dietary influence. Water Res. 34, 4234–4242.
Zhuang, Y., Wu, S.W., Wang, Y.L., Wu, W.X., Chen, Y.X., 2008. Source separation of household waste: a case study in China. Waste Manag. 28, 2022–2030.