有餘有魚

Waste-to-wealth

香港教育大學
The Education University of Hong Kong

KNOWLEDGE TRANSFER SUB-OFFICE
知識轉移辦公室

科學與環境學系
Department of Science and Environmental Studies

Waste can be wealth misplaced!

A research team from

The Education University of Hong Kong

has successfully showcased

the concept of 'turning waste to wealth'

廢物，其實可以是放錯地方的財富！

香港教育大學的一支科研團隊

正為「轉廢為寶」的概念作了

成功實踐……

Professor Wong Ming Hung (upper right), Dr. Mo Wing Yin (lower right), Dr. Man Yu Bon (lower left), Mr. Zhang Feng (upper left)

黃銘洪教授（右上）與他的研究團隊。巫永然博士（右下），文裕邦博士（左下）及張峰先生（左上）。

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The magic touch of Professor Wong Ming Hung and his team

Professor Wong currently serves as the Advisor (Environmental Science) of the Department of Science and Environmental Studies of The Education University of Hong Kong, and as the Editor-in-Chief of Environmental Geochemistry and Health (Springer). He has published more than 750 SCI papers and 32 book chapters, edited 25 books or special issues of scientific journals, and filed 8 patents. According to information provided by Scopus, Professor Wong is ranked 24, and is also listed as the top Chinese scientist worldwide under Environmental Science, based on publications spanning 23 years (1996–2018). Professor Wong has been dedicated to the study of environmental toxicology and restoration. In recent decades, his research team has contributed an important milestone for the eco-fishery business in Hong Kong under his leadership.

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Treasures in landfills

Food waste has become a global problem with significant effects on society and the environment. The world produces an estimated 1.3 billion tonnes of food waste annually, which accounts for about one third of all food produced by humans. The annual direct economic loss from food waste worldwide is about US$1 trillion, leading to a social cost of US$900 billion and an environmental cost of US$700 billion.

The social and environmental problems caused by food waste are significant and serious in densely populated cites. For example, the daily food waste in Hong Kong is about 3600 tonnes, but only 1% of the food waste is recycled or reused, and the rest is sent to landfills. To solve its food waste problems, the Hong Kong government has launched a series of waste management pilot programmes and promotional activities, but food waste in Hong Kong has still increased from 3227 tonnes in 2004 to 3900 tonnes in 2017. According to the waste statistics provided by the Environmental Protection Department (EPD), the per capita municipal solid waste in Hong Kong reaches 1.5 kg per day!

The key to sustainable fishery development

The rapid growth of the fishery business has led to an increasing demand for compound fish feed, but fishery businessmen are facing challenges from the rising cost of fish feed, which directly affects the price of fish products. Small fish are the major protein raw materials in commercial compound fish feed, and small fish of various species also serve as important raw fish feeds used for fish farming by Hong Kong fishermen. For the sustainable development of fisheries, the Hong Kong government announced a ban on trawling in Hong Kong waters via legislation to restore the seabed and marine resources and ecology, which greatly increased the cost of Hong Kong fish farming. However, one critical factor for the sustainable development of Hong Kong fisheries is to solve the problem regarding the source of fish feed before any transformation of the fish farming industry can occur.

Another critical factor that affects the sustainability of fish farming is pollution. According to a report by the United Nations Environment Programme, mercury is among the most dangerous chemicals to human health, and due to increasing human industrial activity, the mercury level in the ocean is now 450% higher than natural levels. The result is a greater risk of contaminants poisoning fish, which can then be transmitted to humans. Professor Wong's research team once tested the mercury concentration of seafood from the Pearl River Delta and from the hair and blood of local residents and found that eating fish is one way for local residents to take in mercury. At the same time, the accumulation of pollutants from aquatic products came not only from polluted oceans and rivers, but also possibly from the fish feed used in fish farms.

At present, 47% of seafood sold in the market is farm-raised, so the quality of fish feed directly affects the quality of fish. Moreover, studies have clearly shown that fish feed used in commercial fish farms contains high concentrations of heavy metals (i.e. cadmium 0.07 to 0.4 μg/g dry weight and lead 0.12 to 2.05 μg/g dry weight) and organic pollutants (e.g. carcinogenic polycyclic aromatic hydrocarbon compounds [PAHs]).

The advantages of eco-fish feeds

> **'Turning food waste to fish feed immediately gives people doubts about the safety of the pellets', Professor Wong said. 'But the truth is, using this kind of fish feed for fish farming is even better.'**

The quality of the fish feed products can be guaranteed by quality control and selection of the food waste, and the food safety of the fish products can also be ensured. Professor Wong also stated that freshwater fish that are fed pellets made from food waste contain lower concentrations of heavy metals and organic pollutants than fish that are fed commercial feed, likely because the small fish used to supply protein for commercial feed are the main source of pollutants. Therefore, fish feed made from food waste is much lower in pollution.

Fish feed 廚餘飼料

How to change food waste to wealth?

> **'Food waste can be wealth misplaced! With biotechnologies, food waste can be turned to fish feed, meaning less landfill, cheaper feed and fewer contaminated fish', Professor Wong said. 'It can definitely bring a win-win-win result.'**

A decade ago, fish feed pellet made from food waste was just a concept. Professor Wong started a research project in 2011 with a research fund of HK$1.9 million granted by the Environmental and Conservation Fund (Integrated pond fish farming using food wastes: for quality fish production and habitat conservation ECF 2009-37), which thus turned the first page of the story of fish feed pellet production.

In that project, they partnered with Kowloon Environmental Development Limited, a pioneering company engaged in systematic food waste recycling services in Hong Kong, which took environmental protection as their core business philosophy, covering food waste collection, processing, recycling and sales. According to the needs of the research team, the company collected the required food waste (grains, vegetables, fruits, bones, meat, etc.) and produced powder via several processes of cutting, grinding and drum drying. The powder was then ready to make fish feed.

That research project had three main targets. First, food waste was recycled into the main ingredients of fish feed, based on cost-effectiveness analysis, to verify the ecological value of fish ponds, and also the feasibility of restoring their ecological functions. The second aim was to improve the ratio of conversion and digestibility of food waste-based fish feed (FWBF) by adding probiotics (yeast) and enzymes to raise the production volume of fish. Third, by farming fish of a lower trophic level (such as grass carp [*Ctenopharyngodon idellus*] and grey mullet [*Mugil cephalus*]), they were committed to producing safe and high-quality fish products and to avoiding accumulation of pollutants (such as pesticides and mercury) in the food chain.

After a 3½-year study, the research team led by Professor Wong accumulated a wealth of laboratory data, together with many encouraging and important discoveries!

First, two kinds of formula were used to produce FWBF. The first was 53% grain, 10% vegetables and fruits, 8% bone powder, 4% other food waste, 10% fish meal and 15% corn starch, and the second was 25% meat, 28% grain, 10% fruits and vegetables, 8% bone powder, 4% other food waste, 10% fish meal and 15% corn starch. Both formulas contain satisfactory nutrients and sufficient essential amino acids, crude protein, crude sugar, crude fat and phosphorus. They are suitable for farming fish of a lower trophic level, including grass carp, grey mullet, mud carp (*Cirrhinus molitorella*) and tilapia (*Oreochroms mossambcus*). Food waste can provide the necessary protein and amino acids for the growth of fish (Figure 1a), up to 75% of the fish feed come from kitchen waste. In general, the growth of the tested fish did not show any obvious difference from those that were fed commercial fish feed. However, the growth of grass carp and big head carp fed FWB and FWA, respectively, were even better than those fed commercial fish feed (Figure 1b).

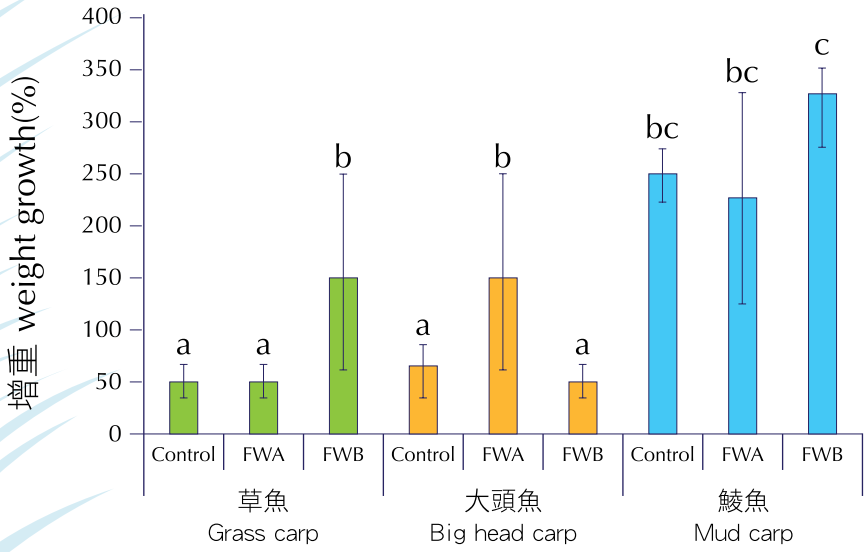
Second, the addition of bromelain and papain to the food waste can effectively improve the solubility of feed protein and help increase the use and conversion rate of food waste, thereby benefitting the growth of fish. In addition, it can offer a safer and healthier environment for fish growth than the commercial fish food sold in South China, and the farming cost is even lower. In addition, fewer contaminants are found in freshwater fish (such as dichloro-diphenyl-trichloroethane [DDT] and mercury), so people can enjoy it without food safety worries. The concentration of heavy metals (such as mercury) and organic pollutants (PAHs and DDT) detected in fish meat is not hazardous to health (Figure 2). The research data built a solid foundation for further research.

Figure 1（圖1）

a

	Food waste ingredients (75%) 廚餘飼料成分					Non-food waste ingredients (25%) 非廚餘飼料成分		Total (%) 總數	Protein (%) 蛋白質
	Fruit and vegetables 蔬果	Meat products 肉類	Cereals 穀物	Bone meal 骨粉	Others 其他	Fish meal 魚肉	Corn starch 玉米澱粉		
FWA 廚餘飼料 A	10	0	53	8	4	10	15	100	31.44 ± 0.44a
FWB 廚餘飼料 B	10	25	28	8	4	10	15	100	31.13 ± 3.36a
Control 商業飼料									30.16 ± 1.55a

b

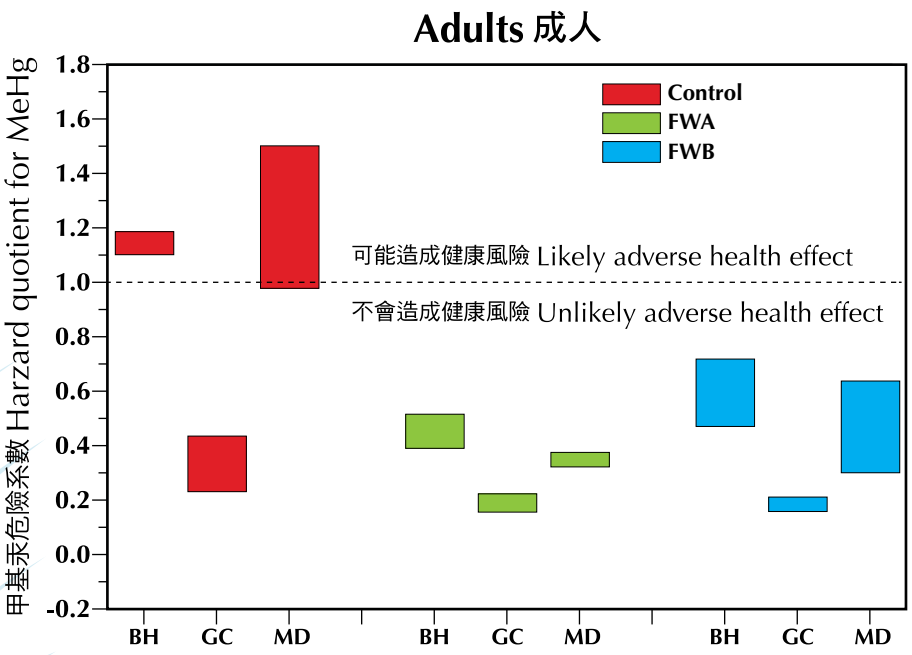


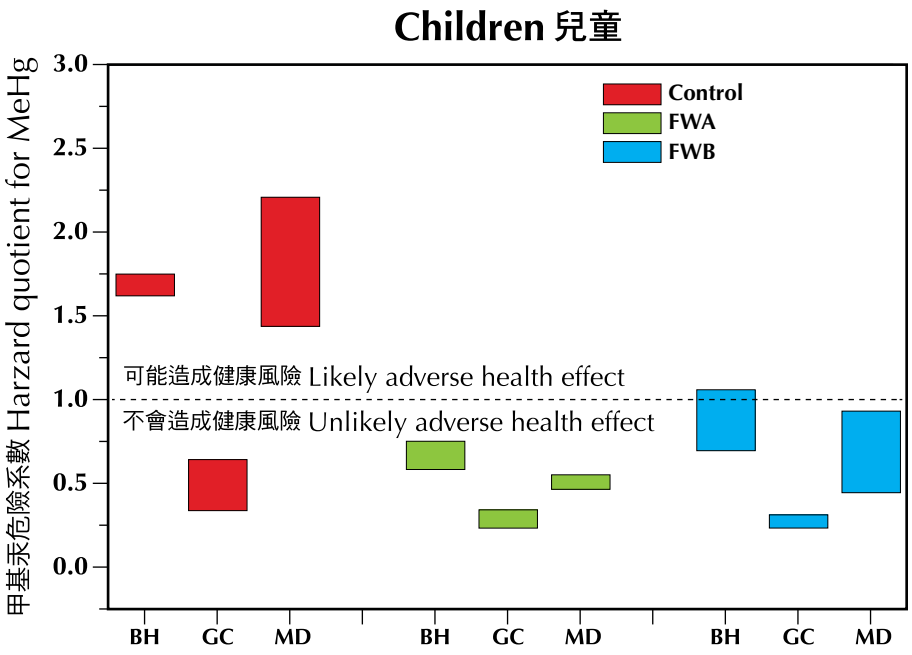
(a) The formula of food waste-based feed; (b) The growth performance of different fish fed food waste-based feed (75% of food waste) and commercial fish feed.

FWA: food waste-based feed A; FWB: food waste-based feed B; different letter (abc) means significant difference.

(a) 廚餘飼料配方（含有75%的廚餘成分）和 (b) 魚餵食不同飼料的生長表現。對照飼料為購買的商業飼料 (Jinfeng, 613 複合飼料)；FWA：廚餘飼料A；FWB：廚餘飼料；不同字母（a b c）表示具有顯著性差異。

Figure 2（圖 2）





Non-cancer risk assessment of MeHg in market fish and fish fed food waste based feed. BH-Big head fish; GC: Grass carp; MD: Mud carp; FWA: food waste-based feed A; FWB: food waste-based feed B; Control: commercial fish feed; MeHg: Methylmercury.

養殖魚的甲基汞非癌症(Non-Cancer Risk)風險評估結果。
BH：大頭魚；GC：草魚；MD：鯪魚；FWA：廚餘飼料A；FWB：廚餘飼料；control：商業飼料；MeHg：甲基汞。

'Recycling food waste to fish feed was just a concept a decade ago, but now, this concept has gradually been shaped and become a possible solution to many ecological and social problems at once.' said Professor Wong.

Based on the results of the above project (ECF, 2009-37), Professor Wong's research team successfully applied for another fund of HK$4.5 million from the Innovation and Technology Bureau for another project (ITS/174/14FX) in 2015, targeting an in-depth study of food waste recycling for fish farming. This time, they were partnered with South China Renewable Resources (Zhongshan) Co, Ltd, a well-established food waste recycling company that used automated equipment for food waste separation and fish feed production and developed advanced technology for upgrading (fermented) food waste into protein powder.

The food waste collected by that company was automatically sorted to remove solid waste, followed by deodorising and disinfecting procedures. Before fermentation by microorganisms, the sterilised food waste was dehydrated and crushed into tiny pellets. After passing a quality test, the fermented food waste (now in the form of protein powder) was dried and filtered; it was then ready to produce fish feed pellets (Figure 3).

South China Reborn Resources (Zhongshan) Co. Ltd.
華南再生資源（中山）有限公司

Figure 3（圖 3）

The procedure of producing food-based fish feed by South China Reborn Resources (Zhongshan) Co. Ltd.
華南再生資源（中山）有限公司廚餘回收及廚餘飼料再造流程

A. Recycle of food waste 廚餘回收

Capacity: 100 tonnes of kitchen waste per day, 4 collection trucks, 300 barrels of food waste (100 kg/barrel)/day
处理能力：每天100噸餐廚垃圾，4輛收集車，300桶收集物（100公斤/桶）/ 天

B. Selection 廚餘分揀

- food waste rich in protein (meat and fish)
  富含蛋白廚餘（肉類和魚類）
- food waste rich in fiber (vegetables and fruits)
  富含纖維廚餘(蔬菜和水果)
- food waste rich in carbon hydrates (noodles, rice and bread)
  富含碳水化合物廚餘(麵條、米飯和麵包)
- Useless food waste (Deliver to landfill)
  無用廚餘（運往堆填區）

C. Deodorization and sterilization 除臭和滅菌

The separated food waste components are deodorized and sterilized in a reaction chamber with ozone and ultraviolet rays, then become mushy after homogenization.
分離的廚餘成分在具有臭氧和紫外綫的反應室種進行除臭和滅菌處理，均質化成糊狀 。

D. Bacterial fermentation 細菌發酵

Fermentation (a variety of bacteria) for up to 6 days, the crude protein content of the selected food waste increased from 10% to 15-20%, then dried in a drum dryer and ground into finer particles.
發酵（多種細菌）長達6天，廚餘粗蛋白含量從10%增加到15-20%，隨後在鼓式乾燥機中乾燥並研磨成更細的顆粒。

E. Production of fish feed 廚餘飼料製作

Using QC passed protein powder as raw materials to produce fish feed pellets by adding other ingredients e.g. soybean meal, corn meal, fishmeal.
品質合格的廚餘粉為原料生產飼料顆粒，並添加豆粕，玉米粉，魚粉，維生素和多款物質等。

F. Testing of products 產品品質測試

檢測項目		單位	實測值
1	Crude protein 粗蛋白質	%	**34.72**
2	Lysine 賴氨酸	%	**2.14**
3	Ash 灰分	%	**7.98**
4	Crude Fat 粗脂肪	%	**3.92**
5	Calcium 鈣	%	**1.12**
6	Total phosphorus 總磷	%	**1.10**
7	Arsenic 砷	%	**0.366**
8	Lead 鉛	%	**2.3**
9	Chromium 鉻	%	**0.17**
10	Mercury 汞	%	**0.015**
11	Fluorine 氟	%	**94.8**

There were three aims of the project. First, it used food waste as the main raw material to develop efficient and practical ways to produce high-quality fish feed. Second, it lowered the cost of producing safer fish feed (e.g. containing lower levels of DDT and mercury). Furthermore, with the addition of Chinese herbal medicine ingredients, probiotics, microalgae and other active ingredients, the quality of FWBF was improved and upgraded, thereby improving the immunity and production of freshwater fish.

Seven formulas were designed for the research project (Table 1) to study how the content of food waste used, the proteases and important ingredients like wolfberry affect the growth of Nile tilapia and jade perch (*Scortum barcoo*). The research team first conducted a feeding experiment of Nile tilapia and jade perch on these seven feed formulas under laboratory conditions after comparing them with fish fed commercial fish feed. They chose the best performing formulas for further research: formulas A and F. They then moved to an outdoor fish pond for field-scale studies (Figure 4).

The studies showed that the performance of the two formulas of FWBF did not differ from the commercial fish feed used. Moreover, the concentrations of heavy metals and organic pollutants (PAHs) detected in the fish meat were classified as not hazardous to health and were safer than fish bought from markets (Table 2).

Professor Wong's research team has filed two patent applications for these two FWBF formulas. One is named 'Production process and user instructions for jade perch's fish feed' (CN201810474984.5), and the other is 'Production process and user instructions for Nile tilapia' (CN201810473652.5). At the same time, the related research achievements are also being translated into practice and promoted via cooperation with kitchen waste recycling companies.

Table 1 （表 1）

Seven formulas of food waste based fish feed 七種廚餘飼料配方

Diet codes 飼料編號	Protein meal from food waste (%) 廚餘蛋白	Soybean meal (%) 大豆粉	Peanut meal (%) 花生餅粉	Fish meal (%) 魚粉	Baker's yeast (%) 酵母	Starch (%) 澱粉	Vitamins and minerals (%) 維他命礦物複合物	Protease (%) 蛋白酶	Goji (%) 枸杞	Total (%) 總共
FWA	55	-	5	-	5	32	3	-	-	100
FWB	45	10	10	5	5	22	3	-	-	100
FWC	35	35	10	-	5	10	3	1	-	100
FWD	45	-	10	10	5	26.8	3	-	0.2	100
FWE	45	-	10	10	5	27	3	-	-	100
FWF	45	10	10	5	5	21.8	3	-	0.2	100
FWG	35	35	10	5	5	9.8	3	1	0.2	100

Note: FW: Food waste 注意：FW表示廚餘

Table 2 （表 2）

Non-cancer risk in human via consumption of market fish and fish fed food waste based diets.
不同飼料餵養的魚及街市魚的風險評估

Different fish fed by FW fish feeds and fish from market 不同飼料餵養的魚及街市魚	Hazard index (Adult) 危險指數 (成人)	Hazard index (Children) 危險指數 (小孩)
	Percentile 95th 百分位數	Percentile 95th 百分位數
Nile tilapia 羅非魚		
Commercial fish feed 商業飼料	0.365	0.421
Food waste based feed A 廚餘飼料 A	0.343	0.614
Market fish 街市魚	4.81	8.58
Jade Perch 寶石魚		
Commercial fish feed 商業飼料	0.583	0.673
Food waste based feed F 廚餘飼料 F	0.456	0.814
Market fish 街市魚	3.01	5.37

Notes:
Non-cancer risk assessment based on PAHs; all non-cancer risk are resented in units of 10^{-3}.

注意：
非癌症風險評估基於PAHs；所有的數值以10^{-3}表示）

Figure 4（圖 4）

Field scale feeding trial (Fanling) 戶外魚塘養殖實景圖（粉嶺）

Create greater economic value

'At first, we only targeted some freshwater fish species at the lower level of the food chain, for example, Nile tilapia, jade perch and grey mullet, whose market price is relatively low. Because their nutritional needs are rather low, they're easier to farm, but of course, their selling price is not as high as carnivorous marine fish', Professor Wong said. 'If we can recycle food waste to feed carnivorous marine fish, it will not only satisfy market needs, it can also create greater economic value.'

Professor Wong's research team applied for more than HK$8.5 million (Safe and Quality Fish Production: Development of High Grade Pellets Using Food Wastes for Three Popular Marine Fish; SFDF-0023) from the Sustainable Fisheries Development Fund for research work in 2017 in an attempt to develop an FWBF and enhance fish farming technology for marine fish.

The research content of this project included a number of items. The first was to design a variety of FWBF formulas and to evaluate the growth performance of various formulas for three kinds of carnivorous marine fish: Sabah giant grouper (*Epinephelus fuscoguttatus x Epinephelus lanceolatus*), pomfret (*Trachinotus blochii*) and star snapper (*Lutjanus stellatus*). Second, based on the results of laboratory testing, the scientists moved to outdoor experiments to verify the efficacy of FWBF. The third aim was to test the major environmental pollutants in the tested fish and develop a potential health risk assessment.

Recalling the difficulties encountered, Professor Wong said, 'It wasn't an easy and smooth one, because most of the experiments were conducted outdoors, and ever changing weather conditions had destructive impacts. I remember that in the year of typhoon Mangkhut, many fish died, which wasted us half a year of hard work!'

In addition to the weather, the team encountered numerous other difficulties. For example, because the nutritional needs of freshwater fish and carnivorous marine fish differ completely, the latter require a higher ratio of protein in their food. The protein content in fish feed must be increased to 40% or above to satisfy the growth of the Sabah giant grouper, but it only needs to be 20% for freshwater fish. Their partner, South China Renewable Resources (Zhongshan) Co, Ltd, could provide large quantities of food waste for use; however, because most of the food waste collected was carbohydrates (rice and noodles), the fish feed produced via automation was not satisfactory for the experimental requirements due to its low protein content. To solve this tough problem, they finally returned to their first partner, Kowloon

Figure 5（圖 5）

The procedure of producing food-based fish feed by Kowloon Environmental Development Ltd.
九龍環境處理發展有限公司廚餘回收及廚餘飼料再造流程

Salmon waste: bones and some meat left after cutting meat for making sushi and sashimi
三文魚廢棄物--切下肉做壽司和生魚片後留下的骨頭和一些肉

Food waste processing equipment
廚餘處理設備

Salmon powder from food waste
廚餘三文魚粉

Food waste: e.g. fish, bread, food waste from restaurants and food processing plants
廚餘：例如魚，麵包，餐館和食品加工廠的食物廢料

Low temperature storage (4°C)
低溫儲存(4°C)

Cutting and grinding
切割和研磨

Melting pot
熔爐

Drum drying
轉鼓乾燥

Powdered food waste
廚餘乾粉

Other nutrients: such as peanut flour, soybean meal, vitamins and minerals
其它營養成分：例如花生粉、豆粕、維生素和礦物質

Fish feed
廚餘魚飼料

Ordinary powder from food waste
普通廚餘粉

Environmental Development Limited, which helped by asking workers to sort food waste manually to obtain enough salmon meat and bones for further production of pellets (Figure 5). This eventually satisfied the high protein needs for farming carnivorous marine fish.

More fruits of research

The project has reached its closing chapter and has made many meaningful achievements. Among them, the research team has designed an optimal marine fish feed formula after comprehensive considerations of production cost and fish growth performance (Table 3); this formula can save up to 30% of the total production cost (Table 4). They also found that the FWBF is well suited for farming Sabah giant grouper, as the growth data show no difference from that of fish fed commercial feed. Third, they launched a triangle taste test to compare the Sabah giant grouper and pomfret they farmed with FWBF against the same species purchased from markets; the results showed that the volunteers who tried pomfrets were unable to tell the difference between fish fed FWBF and those bought from markets (Figure 6a). For Sabah giant grouper, although volunteers were able to tell the difference between fish fed FWBF and those bought from markets, they did not detect any obvious difference in color, taste and texture (softness and elasticity) of the fish meat (Figure 6b).

Figure 6（圖 6）

Taste test result of Sabah Giant Grouper and Pomfret. a: Number and percent of assessors that correctly identified the grouper fed food waste feed; b: Preferences between Sabah Giant Grouper fed food waste feed and commercial feed by attributes.

沙巴龍躉和鯧魚的試吃三角測試結果。
a：辨別廚餘飼料養殖的沙巴龍躉的統計結果；
b：根據色澤、口感、肉質滑感和肉質彈性對魚進行評分的統計結果。

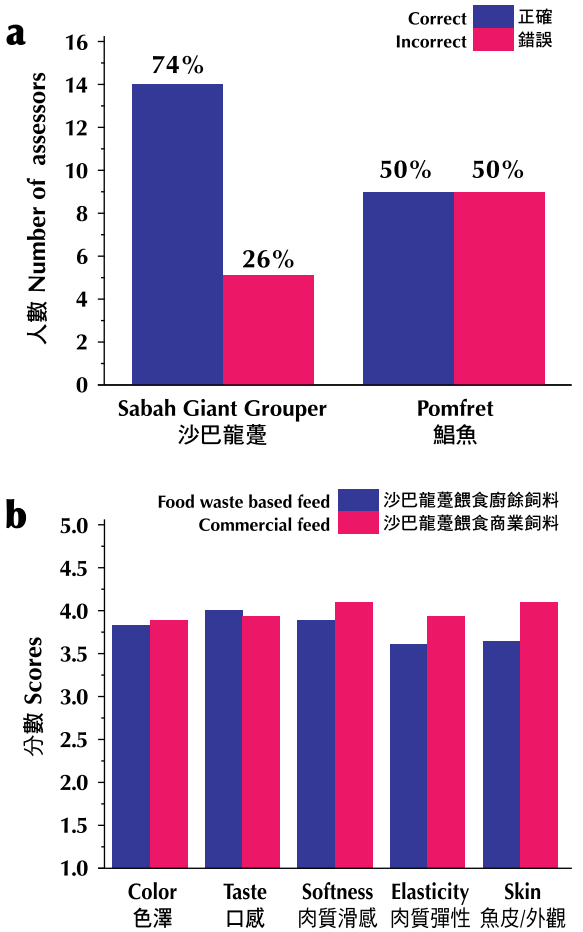


Table 3 （表 3）

Three formulas of food waste based fish feeds for marine fish
海水魚三種廚餘配方

ingredients (g/100g) 成分	Food waste feed 1 廚餘1號飼料	Food waste feed 2 廚餘2號飼料	Food waste feed 3 廚餘3號飼料
Commercial fish meal 商業魚粉	22	22	27
Fish powder (waste from cod and salmon) 魚粉 (鱈魚和三文魚廢料)	35	20	35
Soybean dregs 豆渣	0	0	10
Meat (expired meat) 肉 (過期肉)	25	40	10
Flour 麵粉	10	10	10
Yeast 酵母	5	5	5
Vitamin and minerals complex 維生素和礦物質複合物	3	3	3
Total (%) 總共	**100**	**100**	**100**
Production cost (HK$) 生產成本	**8000**	**7400**	**8550**

Table 4 （表 4）

Production cost comparison between fish fed food waste based feed and commercial fish feed
廚餘飼料與商業飼料用於不同魚類養殖的生產成本對比

* Price of the year 2014 , 30% protein content; **price of the year 2017, 30% protein content; ***price of the year 2019, 42% protein content

* 2014年的價格，30% 蛋白含量；**2017年的價格，30% 蛋白含量；***2019年的價格，42%蛋白含量

Fish 魚類	Commercial fish feed 商業魚飼料			廚餘魚飼料 FW fish feed			Production cost saved 節省生產成本
	Cost of fish feed (HKD/tonne) 飼料價格 (港幣/噸)	Feed conversion ratio 換肉率	Production cost per tonne of fish (HKD/tonne) 每噸魚生產成本 (港幣/噸)	Cost of fish feed (HKD/tonne) 飼料價格 (港幣/噸)	Feed conversion ratio 換肉率	Production cost per tonne of fish (HKD/tonne) 每噸魚生產成本 (港幣/噸)	
Grass carp 草魚	8500*	2.41	20485	6000	2.02	12120	**40.8%**
Nile tilapia 羅非魚	9000**	1.12	10080	6800	1.06	7208	**28.5%**
Jade Perch 寶石魚	9000**	1.28	11520	7500	1.16	8700	**24.5%**
Sabah giant Grouper 沙巴龍躉	16000***	1.88	32900	12500	1.95	24375	**22.0%**

Figure 7（圖7）

Taste test guest: Professor Wong, Dr. Chu Chun Wah, Senior Fisheries Director, Agriculture Fisheries and Conservation Department, Mr. Wong Yuk Chun, Founder of Kowloon Environmental Development Limited, Dr. Yau Wing Kwong, Chief Executive, Environmental Association, Dr. Man Yu Bon and Mr. Law Chun Choi, Vice Chairman, Hong Kong Fishermen Consortium.

各界代表參加廚餘養殖魚的試吃活動。代表有：黃銘洪教授、漁農自然護理署的高級漁業主任朱振華博士、九龍環境處理發展有限公司創辦人黃旭進先生、環保協進會總幹事丘榮光博士、文裕邦博士及香港漁民團體聯會副主席羅廣財先生等。

Marketing preparation

To promote this innovative and environmentally friendly fish feed, the Agriculture, Fisheries and Conservation Department plans to launch some workshops for fish farmers and potential recyclers who could provide raw materials for production. Dr Man Yu Bon said, 'It's not easy to change the habits of fish farmers when it comes to choosing fish feed. We hope a concessionary scheme from the government can entice the fish farmers to accept this kind of eco-fish feed. The fact is, the price of the FW fish feed is 20% lower than commercial fish feed, and the benefits for fish farming are obviously satisfactory!'

The eco-fish feed is now ready to enter the market. The production partner and distributor of the FWBF, Mr Li Kwok Sing, the manager of South China Renewable Resources (Zhongshan) Co, Ltd, claimed that the production process requires strict control; although it is made from food waste, the development of this product shows great marketing potential.

The sales of FWBF would be more competitive in the future, said the research team. Fish farm owner Mr Raymond Ng Wai-man agreed and added that the appearance of the fish is better than that fed on commercial feed. 'If you

cut open the fish, you will see that the meat is juicer and fresher with a nice sheen on it', he said.

The team launched a taste test event for fish farmed with FWBF (Figure 7). To isolate the real taste, they steamed the fish with no ginger, green onion or soy sauce; they just wanted the guests to try its fresh taste. They prepared 50 'experimental fish' for taste testing, from appearance to taste, and the fish fed FWBF received a great response, which gave the research team confidence and joy.

Figure 8（圖 8）

Silver Medal in the International Exhibition of Inventions of Geneva. From left to right: Dr. Man Yu Bon, Professor Wong Ming Hung, Dr. Chow Kai Lai, Dr. Mo Wing Yin.

項目榮獲日內瓦國際發明展銀獎。
（左起）文裕邦博士、黃銘洪教授、周嘉麗博士及巫永然博士

Benefitting society by knowledge transfer

'Knowledge transfer is a two-way process to apply university research to society. Partnership is key', said Dr Stephen Chow, Director of Knowledge Transfer at The EdUHK. This also means building awareness, finding appropriate manufacturers and distributors, and obtaining intellectual property protection. The University's Knowledge Transfer Sub-office has promoted the project on various occasions, including public events, innovation exhibitions and trade fairs in Hong Kong, the Chinese mainland and overseas. The project won a Silver Medal at the International Exhibition of Inventions in Geneva, 2019 (Figure 8). 'We also need all of the stakeholders to agree on patent ownership. This is always a complicated but vital issue', added Dr Chow.

The University's Knowledge Transfer Sub-office is still actively promoting the project in various ways. On campus, they have established a showcase platform with brochures to promote the concept of food waste recycling and the importance of environmental protection to university students and visitors to enhance the popularisation of sustainable aquaculture concepts in the Greater Bay Area, and to plant seeds for future cultivation of talents in related fields. The demonstration platform was initially built by the research team (Figure 9).

Figure 9（圖 9）

Demonstration platform for culturing marine and freshwater fish with food waste based fish feed

廚餘用於魚類養殖技術的展示平台

Advancement

However, the team didn't stop there. Commercialising the product is the next big step; at the same time, they are aiming for better quality and functions of the product.

> **Professor Wong said, 'This time, we will make full use of the principles of Chinese herbal medicine, extracting the active ingredients through fermentation technology, so as to upgrade the functions of the food waste-based fish feed.'**

Traditional Chinese medicine (TCM) has been used for thousands of years, and the active ingredients in various herbs are used to prevent and treat diseases. A considerable portion of those herbs have immunomodulatory effects and contain anti-tumour bioactive substances, with few adverse effects. Professor Wong was inspired by the achievements of his previous projects (supported by the Innovation Technology Fund and the Sustainable Fisheries Development Fund) to increase the growth rate of the fish with the addition of supplements to FWBF (such as yeast, probiotic enzymes and some Chinese herbal extracts). Lower levels of contaminants (DDT and mercury) were found than in fish fed commercial fish feed, which resulted in a more valuable product. The major innovative idea of this proposal is the use of bacteria (such as *Aspergillus oryzae* and *Trichoderma reesei*) for fermentation of TCM residues, allowing the polysaccharides and active compounds in TCM residues to be fully released, and then adding them to the fish feed for farming of freshwater fishes, such as grass carp.

Coptis chinensis
黃連

Sophora flavescens
苦參

Scutellaria baicalensis
黃芩

Andrographis paniculata
穿心蓮

Professor Wong expects that the active compounds will have positive effects on fish by modulating the fish

gut microbiota, thus resulting in enhanced immunity. Fermented TCM residues as feed supplements would serve as 'natural antibiotics' to relieve the abuse and overuse of antibiotics in aquaculture. This is extremely important for food safety and environmental protection. The team feels confident in its ability to turn the TCM residue into a high value-added product and to produce safer fish products with high quality at lower cost. This research has great marketing potential, not only locally, but also regionally and even internationally, and it could make a significant contribution to the sustainable development of the aquaculture industry.

Moreover, the team will soon begin studying the effects of plant-based biochar on the growth of juvenile grass carp (RGC Ref No. 28300619). Dr Man Yu Bon is in charge of that project. He said, 'The adsorption of biochar may reduce the accumulation of pollutants in fish meat, and it also reduces the bioavailability of contaminants in fish intestines, at the same time improving fish immunity.'

In this study, various types of vegetable food waste, such as coffee grounds and tea grounds, will go through the process of pyrolysis to produce biochar. The researchers will study the adsorption mechanism (adsorption and desorption) of various sizes of biochar particles against persistent toxic substances. In addition, in laboratory-scale experiments, the effects of biochar formula fish feed and commercial formula fish feed on fish farming will be compared, and the best formula will then be used in an outdoor fish pond for further observation and testing. Most importantly, this study aims to determine the immune parameters of fish, the composition of the microbial communities in fish intestines, the bioavailability of pollutants, and data on the total pollutant content in fish, which will be used to assess the health of the fish and the health risks that may result from human consumption of these fish. The study will compensate for the deficiencies of previous related studies of the relationship between biochar in fish pollutant intake, the fish immune system and the fish intestinal microbial community.

Aspiring to a win-win-win result

The sales network in the fish feed market is a traditional one. It is not an easy task for Professor Wong's research team to enter that market. However, this project's leaders do not seek to make a profit; they have a bigger aspiration: building a broader network.

> **'There are a lot of people in the Greater Bay area leaving a lot of unconsumed food', says Professor Wong. 'If each city in the area were to recycle its food waste, there'd be less landfill, cheaper feed and fewer contaminated fish. What a win-win-win situation!'**

黃銘洪教授團隊化腐朽為神奇

黃銘洪教授是一位著名的環境學專家，一直致力於環境污染的追溯和修復方面的研究，在過去的十數年間，他帶領著科研團隊，為環保漁業寫下了重要的一頁！黃教授現為香港教育大學科學與環境學系顧問（環境科學），兼任Environmental Geochemistry and Health (Springer) 期刊的總編輯，曾發表逾750篇科學論文，以及32本書籍的章節，編輯25本書籍及科學期刊，並成功申請多項專利（6項獲批，2專案正在審查）。根據1996至2018年所發文章，在全球環境生態學學者名列24，華人首位(Scopus)。作為一位環境學的專家，黃教授致力於環境污染的生態毒理和修復。

堆填區有寶

廚餘已是一個全球性的問題，對社會和環境都造成了巨大的影響。全球每年估計產生13億噸廚餘，大約佔人類生產的所有食物總量的三分之一，而全球每年因食物浪費所造成的直接經濟損失，大約為10,000億美元，造成的社會成本約為9,000億美元，造成的環境成本約為7,000億美元……

廚餘所造成的社會和環境問題在人口密集的城市尤其嚴重。例如，香港每天產生超過3,600噸廚餘，然而，僅有1%的廚餘被回收利用，其他則丟棄於堆填區。為了減少食物浪費，香港政府已發起一系列廢物管理試點計劃和宣傳活動，儘管如此，香港每天的廚餘產生量，已從2004年的3,227噸，增至2017年的3,900噸。

根據統計資料，香港人的都市固體廢物人均棄置量，竟多達每日1.5公斤！

漁業可持續發展的關鍵

作為人類的食糧，魚類產品是人類消費的主要蛋白質來源之一，據統計，魚類佔動物蛋白質總消費量的16%，而且比例還在不斷攀升，因此，漁業在過去的幾十年中迅速發展，才能滿足人們對魚類產品不斷增長的需求。

漁業既快速發展，導致對專用複合魚類飼料的需求不斷增加。然而，漁業面臨著養魚飼料成本上漲的挑戰，更成為影響魚產品價格的主要因素。其中，雜魚，主要是幼魚，是商業複合養魚飼料主要的蛋白質原料，曾經也是香港漁民養殖經濟

魚類的重要天然飼料。為了推動漁業的可持續發展，香港於2010年10月13日宣佈禁止在香港水域拖網捕魚，因此，香港漁業的養殖成本也大幅度增加。然而，香港漁業的可持續發展，首先要解決的還是養魚飼料來源的問題，方能談論海魚養殖業的轉型。

此外，環境污染已成為影響漁業可持續發展的另外一個主要因素。據聯合國環境署的數字顯示，人類工業活動已令海洋水銀（汞）的含量嚴重超標，高出自然水平達百份之四百五十。這不但增加了魚類受污染的機會，亦增加了通過食物鏈傳遞給人類的風險。黃銘洪教授的研究團隊曾對珠江三角洲的水產品和當地居民的頭髮及血液進行了汞濃度檢測，發現食用魚類是當地居民攝入汞的主要途徑之一。水產品中污染物的積累，不僅來自於受污染的海洋和河流，亦可能來自於養魚場所用的魚糧！

目前，我們食用的海產中有47%來自於人工養殖。魚糧品質的好壞，直接決定了水產質素的高低。同時，已有研究表明，商業魚糧中的魚粉含有相當高濃度的重金屬（包括鎘：0.07-0.4微克/克乾重；鉛：0.12-2.05微克/克乾重），以及有機污染物（例如具有致癌性的多環芳烴化合物）。

環保飼料的優勢

「將廚餘轉變為魚飼料，給人的第一反應是質疑廚餘飼料的安全性。但事實恰好相反，廚餘養殖魚更安全!」黃教授說。

通過對廚餘的質量把控，既可控制魚飼料的品質，從而保證魚類產品的食用安全。黃教授續指出，用廚餘製成飼料養殖的淡水魚，比起以商業飼料餵養的魚類，所含有的重金屬和有機污染物的濃度較低，這主要可能是因為商業飼料的蛋白質原料來自於雜魚，而雜魚恰恰就是污染物的主要來源。故以廚餘製成的環保飼料取代雜魚，無疑可以降低魚飼料的污染。

廚餘如何變寶

「廚餘是放錯了地方的財富，通過生物技術將廚餘轉變為魚類飼料，可同時解決香港的廚餘堆填問題、

漁業飼料的來源問題和水產品安全問題，可說是一石三鳥。」黃教授說。

從十多年前開始，黃教授便致力於「廚餘變寶」的研究項目。於2011年時，研究團隊獲得環保署資助一百九十餘萬，用於環境保育項目（利用廚餘進行池塘魚類綜合養殖：用於優質魚類生產和生境保護；ECF 2009-37）的研究，開始了廚餘改造魚飼料的篇章。

此次合作夥伴為九龍環境處理發展有限公司，該公司是一家在香港最早從事系統性廚餘回收服務的公司，以環境保護為核心經營理念，從事廚餘的回收、處理、再造及銷售。根據研究團隊提供的飼料配方，九龍環境處理發展有限公司收集相關廚餘成分（穀物、蔬果、肉骨、肉類等），經過切割、研磨和轉鼓乾燥等流程，生產出廚餘乾粉，隨後用於廚餘飼料的製備。

此項研究項目的主要目的有三，第一，是以廚餘作為魚類飼料的主要成分，根據成本效益分析，驗證魚塘的生態價值，以及恢復水產養殖池塘的生態功能的可行性。其二，是通過加入益生菌（酵母）和酶，來提高廚餘飼料的轉化和消化率，以增加魚類的整體產量；第三，是通過養殖低營養級魚類（例如草魚和烏頭），生產安全優質的魚類產品，從而避免污染物（例如農藥和汞）在食物鏈中的富集。

經過歷時三年半的研究，黃教授帶領的研究團隊積累了豐富的實驗資料，而從研究結果顯示，團隊獲得了多項令人鼓舞的重要發現！

首先，兩種用廚餘飼料配方（A：53%穀物，10%蔬果，8%骨粉，4%其他廚餘，10%魚粉和15%玉米粉，B：25%肉類，28%穀物，10%蔬果，8%骨粉，4%其他廚餘，10%魚粉和15%玉米粉）都含有令人滿意的養份和足夠的必需氨基酸、粗蛋白、粗糖、粗脂肪、磷。這兩種飼料都適合低營養級魚類的生長，包括草魚 (*Ctenopharyngodon idella*)，烏頭 (*Mugil cephalus*)，鯪魚 (*Cirrhinus molitorella*) 和羅非魚 (*Oreochroms mossambcus*)。廚餘能夠為魚類的生長提供必需的蛋白質和氨基酸。如圖1a所示，廚餘在魚糧中的比例高達75%。儘管如此，餵食廚餘飼料的魚的生長表現並不遜于餵食商業魚糧的對照組。餵食廚餘飼料B的草魚和餵食廚餘飼料A的大頭魚的生長表現，甚至比其餵食商業飼料的對照組更好 (如圖1b所示)。

其二，在廚餘殘渣中加入鳳梨蛋白酶和木瓜蛋白酶，可以有效地提高飼料蛋白的溶解度，以及飼料利用率和轉化率，從而促進魚的生長。此外，所研製的廚餘魚糧相比於華南地區的商業魚糧而言，魚類的生長環境比較安全與健康，而且成本較低，餵養的淡水魚體內污染物也較少（例如滴滴涕 (DDT) 和汞），人們可以放心食用。至於從魚肉中的所檢測出的重金屬（例如汞）和有機污染物（多環芳香烴 (PAHs) 和 (DDT)）的濃度，也不會造成健康風險（圖2）。同時，這些研究數據更為後續的研究打下了扎實的基礎。

「十多年前，把廚餘轉化為魚糧，只是一個概念。時至今日，這個概念已漸次成型，成為了可能一舉解決多項問題的出路。」黃教授說。

基於上述項 (ECF, 2009-37) 的研究成果，黃教授的研究團隊於2015年，再次向創新及科技局申請了另一筆共450萬資助的研究專案 (ITS /174 /14FX)，用於廚餘再造魚糧及養魚技術提升的深入研究工作上。那時候，為研究團隊提供廚餘回收和飼料製備的合作夥伴是一家大型的廚餘回收公司（華南再生資源（中山）有限公司），他們採用自動化設備分離廚餘和製備魚飼料，並研發了將廚餘升級（發酵）成蛋白粉的技術。

由這家公司收集的廚餘會通過分類去除固體廚餘，然後進行除臭和消毒。在由微生物發酵前，消毒過後的廚餘將會脫水並碾碎成小顆粒。一旦通過品質檢測，發酵過後的廚餘（現已變成蛋白粉）即會被烘乾和篩選，這樣處理過後的蛋白粉已經可來準備生產顆粒魚飼料了（圖3）。

此專案的研究目的有三，首先，是以廚餘為主要原材料，開發高效以及實用的方法，生產高品質魚飼料；其二，是以更低的成本，生產更安全的魚飼料（例如含有更低的DDT和汞）；再者，是通過加入中草藥成分、益生菌、微藻及其他活性成分，將廚餘飼料進行改良升級，從而提高淡水魚的免疫力以及產量。

此次研究共設計了7種不同配方的魚飼料（表1），用於研究飼料中廚餘的含量、蛋白酶和重要成分（枸杞）對羅非魚和寶石鱸 (*Scortum barcoo*) 生長的影響。研究團隊首先在實驗室的條件下對這7種飼料配方進行了羅非魚和寶石鱸的餵食實驗，通過與商業飼料進行對比，分別為兩種魚類篩選出了表現最優的飼料（配方A和配方F）。隨後，這兩種配方的飼料在戶外池塘種進行了進一步的驗證。

研究結果表明，這兩種廚餘飼料的餵食表現與商業飼料無異。魚肉中的所檢測出的重金屬和有機污染物 (PAHs) 的濃度，不僅不會造成健康風險，而且比從街市購買的魚更加安全（表2）。

目前，黃教授的研究團隊已對這兩種廚餘飼料配方進行了專利申請。這兩項專利分別為一種寶石魚飼料及其製備方法和使用方法(CN201810474984.5)和一種羅非魚飼料及其製備方法和使用方法(CN201810473652.5)。同時，相關的研究成果也同時通過與廚餘回收公司合作的方式，進行成果轉換和推廣。

創造更大經濟價值

「起初我們只針對食物鏈中較低層的淡水魚類品種，例如：羅非魚、寶石魚和烏頭等經濟魚類，因為牠們的營養需要較低，比較容易飼養，當然經濟價值沒有海水魚高。」黃教授說：「將廚餘轉變為海水魚的飼料，不僅有更大的市場需求，而且也會創造更大的經濟價值。」

黃教授的研究團隊於2017年，向漁業持續發展基金申請了一筆共八百五十餘萬的研究經費(SFDF-0023)，用於開發海水魚廚餘飼料及養魚技術提升的研究工作。此專案的具體研究內容包括多項，其一，是設計多種廚餘飼料配方，並評估不同配方對三種海水魚的生長表現，包括沙巴龍躉(*Epinephelus fuscoguttatus x Epinephelus lanceolatus*)、鯧魚 (*Trachinotus blochii*) 和石蚌 (*Lutjanus stellatus*)。其二，是以實驗室規模研究結果為依據，開展戶外大規模實驗，驗證廚餘飼料功效；第三，是對廚餘養殖魚中的主要環境污染物進行檢測，開展潛在健康風險評估。

回顧團隊遇上過的困難，黃教授說：「項目的開展並不是一帆風順，由於大部分實驗是在戶外進行，突發天氣狀況對實驗影響往往是毀滅性的。記得山竹颱風那一年，死了不少研究中的魚類，足足耗費了半年的心血啊！」

除了天氣因素，研究的開展也遇到其他棘手的問題。例如，由於海水魚的食性與淡水魚截然不同，故對飼料中蛋白的含量要求很高。其中，沙巴龍躉飼料中的蛋白含量便需要到達40%以上，而淡水魚只需要20%即可以滿足。與研究團隊再次合作的華南再生資源（中山）有限公司）儘管可以生產大量的廚餘飼料，但由於回收的廚餘大多以碳水化合物（米飯）為主，自動化生產出的魚類飼料的蛋白含量並不能滿足實驗需求。為了解決問題，研究團隊遂轉向另外一家環保公司（九龍環境處理發展有限公司），得以用人工分揀的方式，例如專

挑三文魚骨和廢棄魚肉，從而獲得足夠的廚餘蛋白質（圖5）。

研究成果再進一步

目前，該項目已進入尾聲，獲得了一些很有意義的研究成果，其中，在經過綜合考慮飼料成本和魚的生長表現，科研團隊設計了一種最優海水魚廚餘飼料配方（表3），可節省30%的生產成本（表4）。

此外，廚餘飼料比較適合沙巴龍躉的生長，與商業飼料相比無異。第三，廚餘飼料養殖的沙巴龍躉和鯧魚與街市上購買的魚進行了試吃對比，試吃結果表明，試食者無法辨別出廚餘飼料養殖鯧魚與街市鯧魚和商業飼料養殖鯧魚之間的差異（圖6a）。對於沙巴龍躉而言，儘管試吃者可以辨別出廚餘飼料養殖的沙巴龍躉，但是整體評分，包括色澤、口感、肉質滑感和肉質彈性等，都沒有顯著性的差異（圖6b）。

為打入市場作好準備

政府漁農自然護理署正為養魚戶、有機會提供生產原材料的回收商等安排工作坊，向他們推廣這款創新環保魚糧。文博士說：「要改變養魚戶一向使用魚糧的習慣，是有一定難度的。我們希望藉著優惠計劃，說服他們接納環保魚糧，因為，環保魚糧的價格始終較一般商業魚糧產品低兩成，效果也甚顯著！」

目前，環保魚糧正在計劃推出市場。生產及經銷商華南再生資源（中山）有限公司的李國聲先生表示：「雖然以廚餘作為原材料生產魚糧，但生產的過程有著很高的規管要求，而以目前市場來看，的確有發展這類魚糧的潛力。」

研究團隊指出，魚糧的未來的銷售會比較有競爭力。養魚戶伍偉文先生亦深表認同，他更指出食用環保魚糧的魚，較食用商業魚糧的賣相更佳：「如果將魚剖開，你會看到魚肉更新鮮、多汁，還有一層漂亮的光澤呢！」

研究團隊曾舉行廚餘養殖魚的試吃活動（圖7），由於要試出真味，蒸好的魚不放醬油不放薑葱，務必要試食者嘗出魚的真味。這次試食會共有50條 「實驗魚」供享用，無論在魚的外型，還是食味，都獲得了一致好評，令研發團隊平添了信心和喜悅。

知識轉移惠及社會

教育大學知識轉移辦公室總監周卓輝博士表示：「知識轉移是一個互動過程，將大學研究成果應用於社會；箇中關鍵，當然是要找到合作夥伴。」這意味著建立意識、尋找合適的生產商和分銷商，以及取得知識產權保護。

教大知識轉移辦公室已在不同場合，包括香港、內地及海外各類型公開活動、創新展覽及貿易展覽會中協助推廣。該項目亦於2019年日內瓦國際發明展上榮獲銀獎（圖8）。周博士續稱：「我們需要所有持分者認同一個專利持有人。這個過程向來都相當複雜，但極為重要。」

除此之外，教大知識轉移辦公室還在校園內支援廚餘用於魚類養殖技術的推廣，以建立展示平台和撰寫宣傳小冊的方式，向該校的學生和其它參觀人士宣傳廚餘回收的理念以及環境保護的重要性，以促進大灣區可持續水產養殖概念的普及，為未來相關領域人才的培養埋下種子。目前研究團隊已初步建立了展示平台（圖9）。

再接再厲的研究

然而，教大團隊並未就此滿足而停步。接下來的工作，除了要推動廚餘飼料的商品化外，還要進一步升級它的功能和質量。

黃教授說：「這次，我們將會充分利用中藥殘渣，通過生物發酵技術提取裏面的活性成分，用於提升廚餘飼料的性能。」

中藥已經使用了數千年，利用各種草藥中的有效成分可預防和治療疾病。眾所周知，這些草藥中有相當一部分具有免疫調節和抗腫瘤生物活性，幾乎沒有副作用。中藥通常通過熱水提取後使用，香港每年產生了大量的中藥殘留物，其中可能仍含有活性成分未被充分利用。黃教授的靈感來自早前項目的積極成果（由創新技術基金 (ITF) 和可持續漁業發展基金 (SFDF) 支持），研究結果證明，通過在廚餘魚飼料中添加飼料補充劑（如酵母，酶益生菌以及某些中藥提取物的混合物），的確可以提高魚類的生長速率，與商業飼料和雜魚養殖的魚相比時，魚肉中所含污染物（滴滴涕和汞）濃度更低，成本也更低。此提案的主要創新思想是通過使用細菌（例如米麴黴和里氏木黴）發酵中藥殘渣，以充分釋放藥物殘渣中的多醣和活性化合物，然後將其添加到廚餘飼料中，飼養重要的淡水魚類，例如鯇魚。

黃教授預計釋放出的活性化合物具有免疫調節和抗腫瘤生物活性，可以調節魚腸菌群，從而提高了魚類的生長速度，增加了魚的免疫力。將發酵的中藥殘留物用作飼料添加劑，它將作為「天然抗生素」來替代水產養殖中應用的抗生素，對食品安全和環境保護至關重要。團隊有信心通過將藥物殘渣轉化為作為高附加值產品，以較低的成本生產安全優質的魚產品。

這項研究將具有巨大的潛力，不僅對本地，而且對區域，甚至在國際上，都將對水產養殖業的可持續發展作出重大貢獻。

除此之外，研究團隊正準備開始研究植物性生物碳對鯇魚幼魚生長的影響 (RGC Ref No. 28300619)。文裕邦博士是該項目的負責人，他認為：「生物炭的吸附作用，可能會減少污染物在魚肉中的累積，降低魚類腸道中污染物的生物可給性，同時改善魚類的免疫力。」

在此項研究中，不同的植物性廚餘，例如咖啡渣和茶葉渣等，將會通過熱解生成生物炭，並會研究不同大小的生物炭顆粒，對持久性有毒物質的吸附作用（吸附和脫附）機制。另外，在實驗室規模實驗中，將會比較生物炭配方魚飼料和商業配方魚飼料對魚類生殖的影響，而最佳效果之配方飼料將應用於戶外規模實驗中。更重要的是，這項研究將會收集有關魚類的免疫力參數、魚腸道中微生物群落的組成、污染物的生物可給性，以及魚類體內總污染物含量的數據，並用於評估魚類的健康和人類食用這些魚類後的健康風險。本研究更可以填補過去相關研究的不足，了解生物炭於魚類污染物攝入、魚類免疫系統、及魚類腸道微生物群落之間的關係。

三贏的宏願

在魚糧市場內，滿是扎根深厚的傳統營銷網絡。黃教授的團隊要打入這個市場，殊不容易。不過，這個項目並非以謀利為目標，反而是基於一個宏願：建立一個更廣大的網絡。

黃教授指出：「在大灣區內，不時有人留下大量未經食用的食物。如果此區域內的每個城市，都能夠將廚餘循環再造，不僅能夠減少堆填，亦可生產更便宜的飼料，減少魚類受污染，改善我們賴以生存的環境，這絕對是一個三贏的結果！」

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