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Current situation and development of kitchen waste treatment in China

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Abstract

More than 30 million tons of kitchen wastes (KW) are produced in China every year. Approximately 80% of the collected KW has been directly utilized as feedstuff in pig farms in China, which is facing strict restrictions by China's Ministry of Agriculture due to concerns of foot and mouth disease, and raw materials for illegal extraction of hogwash oil, which is unsanitary and can cause serious illness. In addition, the universal concern on environmental protection, resource utilization and food safety has brought increasing research on KW processing technology. According to the policy perspective on promoting the recycling application and resource saving of KW, developing resource-saving and environment-friendly society as well as circular economy and protecting the ecological environment in both China (FAGAIHUANZI [2010] No. 1020) and other countries, it is required especially in China that the construction of pilot projects should be conducted overall planning and combinational optimization to enhance resource-oriented utilization and harmless treatment of three phases in KW, including oil, solid and liquid phase (FAGAIHUANZI [2010] No. 1020). Because of policy encouragement, environmental concern and economic incentives by local and central governments in China, more diverse methods after thermal pretreatment should be developed as the amount of KW production increases rapidly. Besides, basing on the increasing universal concern on safety, energy and environmental preservation, finding proper disposal methods of KW for energy production, enhancing biogas production and reducing the amount of final residue is extremely important. In this regard, this paper aims at a comprehensive study on current treatment situations of KW in China and suggests several solutions to China's KW treatment.

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1. Introduction

The production of kitchen waste (KW) significantly increases along with the development of the restaurant industry as well as the increase in consumption in China. Approximately 80% of the collected KW has been utilized as feedstuff in pig farms. However, the direct use of KW as feedstuff is facing strict restrictions by China's Ministry of Agriculture due to concerns of foot and mouth disease[1]. Owning to their high moisture and salt content, there are two potential problems on the incineration of KW, including extra energy consumption, and generation and release of toxic pollutants to the environment, such as dioxins.

Three main reutilization methods for KW collected from formal channels include animal feed via sterilization, fertilizer via composting and bioenergy via anaerobic digestion (AD). KW could be applied to compost and anaerobic process due to their high organic matter content and comprehensive nutrition element. However, the high content of moisture, oil and salt in KW does not favour the compost process, thus restricts their application in fertilizer utilization. Anaerobic digestion, an effective technology that can convert KW to green energy, has been widely used for the treatment of municipal biomass waste in recent years. When KW is treated anaerobically, common problems would appear during conventional AD because of their high oil content and the presence of macromolecular compounds, including the accumulation of lactic acid at an early stage of the digestion process resulting in a sudden pH drop and inhibitory levels of ammonia, sulphide and long-chain fatty acids due to the high protein and fat content[2]. These factors usually impede digestion stability, thus restricting the application of anaerobic digestion. In addition, the lack of efficient technology for disposal of biogas residues, the secondary pollutant during anaerobic digestion, also limits the application of anaerobic digestion in the recycling of KW.

In addition, numerous pre-treatment methods, such as mechanical (e.g. sonication), chemical (e.g. alkali or acid), osmotic (e.g. NaCl treatment, freezing), oxidative (e.g. ozone), thermal and biological (e.g. enzyme) has been proposed to improve the physical and chemical properties of KW to enhance the solubilisation of organic particulates, sterilization effects and promote the subsequent reutilization, such as promote biogas production[3, 4].

Due to the concern on environmental protection, resource utilization and food safety, domestic and foreign governments have placed increasingly stringent restrictions on KW management, and since 2002, the European Union (EU) has enforced a ban on feeding these mixtures to animals due to the formation of harmful compounds during frying and their return back into the food chain through the animal meat. Recently, Chinese government has promulgated a series of laws and regulations for the disposal and recycling of KW to guarantee the effect of disinfection sterilization, avoid the premise of exogenous pollution and improve the recovery rate of useful resource such as nutrients and lipids.

Moreover, Chinese government has published the animal husbandry law for prohibiting the direct utilize of KW as feedstuff in pig farms, and three ministries in China including the Supreme People's Court, Ministry of Public Security and The Supreme People's Procuratorate co-issued the notification about severe punishment by the law on criminal activities of waste cooking oil. Meanwhile, since 2011, four ministries in China including National Development and Reform Commission, Ministry of Housing and Urban-Rural Development and Ministry of Environmental Protection and Ministry of Agriculture co-issued the notification of carrying out the pilot projects on resource utilization and innocuity treatment of KW. Till now, 100 pilot projects have been nominated and approximately 80% choose anaerobic digestion as the main disposal technique.

Among these treatment methods for KW, Each approach has its own characteristic including benefits and drawbacks. In this regard, this paper aims at a comprehensive study on the characteristics of treatment methods of KW in China. In addition, the performance and characteristics of the corresponding products of foreign countries are analyzed in detail. Some key techniques which are adopted in these products are discussed.

2. Materials and methods

KW characterization

Table 1 shows the chemical compositions of KW, and the main elements in KW consist of C, H, O, N, S and Cl. The characteristics of KW are closely related to local living standards, eating habits, etc. From table 2, it could be concluded that KW exists a significant spatial variation in composition and character as high moisture content, high lipid content, high organic content and high salinity. In particular, according to investigations carried out in certain cities in China, food waste and bones accounted for more than 90% of KW; the remaining proportions were mainly paper, plastic, etc (table 3).

Table 1. Chemical characteristics of KW (unit: %).

Parameter	C	H	O	N	S	Cl
KW	46.11	6.89	37.80	3.19	0.29	0.21

Table 2. Nutritional characteristics of KW in some Chinese cities (unit: %).

Cities	Moisture [a]	VS[1, b]	CP[2, b]	EE[3, b]	Oil[4, a]	Salinity[5, a]
Beijing	74.34	80.21	25.86	24.77	3.12	0.36
Tianjin	70.99	85.64	24.30	25.96	2.63	0.70
Chongqing	85.07	92.66	14.45	17.02	1.96	0.24
Suzhou	84.43	82.98	21.80	29.30	3.28	0.70
Hangzhou	74.94	91.50	16.46	24.31	2.09	1.32

a wet basis; b dry basis; 1 Volatile solid; 2 Crude protein; 3 Ether extract.

Table 3. Compositions of KW (unit: %).

Cities	Food waste	Paper	Metal	Bone	Wood	Fiber	Plastic
Guiyang	92.09	0.80	0.10	5.20	1.01	0.10	0.70
Shenyang	92.16	0.42	0.08	5.22	1.31	0.12	0.69
Chongqing	94.13	0.31	0	5.24	0.02	0.13	0.19
Wuhan	88.40	2.80	0.20	5.20	1.00	0.30	2.10

3. Results and Discussion

3.1 Potential utilization of KW in China

The high nutrition content of KW makes it a good candidate for three main utilization methods, animal feed, fertilizer and methane.

(1) Animal feed for KW

KW is rich in nutrient and the content is close to typical feed such as corn and soybean, thus, producing animal feed using KW could be an effective reutilization method. However, due to the characteristics of complex sources and complicated compositions for KW, using as raw feed materials usually brings potential security hazards, such as homologous problems, bacteria, heavy metals and toxic and harmful substances.

Table 4. Compound feed for piglets growing-finishing swine (GB/T 5915-2008).

Parameter	Limit value	Body Weight (kg)				
		3-10	10-20	20-40	40-70	70-120
CP(%)	Minimum	18	17	15	14	13
EE(%)	Minimum	2.5	2.5	1.5	1.5	1.5
CF(%)	Maximum	4.0	5.0	7.0	7.0	8.0
Crude ash(%)	Maximum	7.0	7.0	8.0	8.0	9.0
Lysine(%)	Minimum	1.35	1.15	0.90	0.75	0.60
Methionine(%)	Minimum	0.40	0.30	0.24	0.22	0.19
Threonine(%)	Minimum	0.86	0.75	0.58	0.50	0.45

Table 5. Compound feed for piglets growing-finishing swine (America).

Parameter	Limit value	Body Weight (kg)						Standard
		3-5	5-10	10-20	20-50	50-80	80-120	
DE(kcal/kg)	Minimum	3400	3400	3400	3400	3400	3400	NRC-1998
ME(kcal/kg)	Minimum	3265	3265	3265	3265	3265	3265	
CP/%	Minimum	26.0	23.7	20.9	18.0	15.5	13.2	
Lysine (%)	Minimum	1.34	1.19	1.01	0.83	0.66	0.52	
Methionine (%)	Minimum	0.36	0.32	0.27	0.22	0.18	0.14	
Threonine (%)	Minimum	0.84	0.74	0.63	0.52	0.43	0.34	
EE/%	Minimum	4.0	4.0	4.0	4.0	4.0	4.0	NIH-2004
CF/%	Maximum	6.0	6.0	6.0	6.0	6.0	6.0	

The requirements (listed in table 4 and table 5) are both China and USA committees' best estimates of minimum and maximum requirements of young weanling pigs (from 3 to 20 kg body weight), and of growing- finishing pigs (from 20 to 120 kg body weight). It is obvious that the standards performed in China are less strict than those in the United States, such as lower limitation values and more control index. Moreover, taking dietary amino acid requirements for example, 12 kinds of amino acids are required to be constrained in NRC (1998) compared unfortunately with just 3 respectively Lysine, Methionine and Threonine in Chinese standard GB/T 5915-2008 for a complete and balanced diet.

Pretreatment section includes removal of oil, water and salinity.

Advantages: good sterilization effect;

Disadvantages: low efficiency of killing the bacteria such as bacillus; heat-sensitive nutrients under high temperature is easy damaged; short storage time in order to avoid the rot of KW;

Domestic technology application: Shanghai minhang, Tianjin, Hohhot, Urumqi, Xining

(2) Bioenergy for KW

The high biodegradability and water content of KW makes it a good candidate for anaerobic digestion with the concomitant benefit of biogas production. However, due to the high organic particulate matter content, accumulation of intermediary compounds occurs easily, giving rise to an unbalanced fermentation, and consequently, diminishing the stability of the process. On the other hand, the soluble organics are converted rapidly to volatile fatty acids (VFAs) at an early stage of the digestion process, resulting in a drastic pH drop if no sufficient buffering capacity is present. In addition, KW has a high protein and fat content which can lead to inhibitory levels of ammonia, sulphide and long chain fatty acids[5].

Numerous pretreatment methods, such as mechanical (e.g. sonication), chemical (e.g. alkali or acid), osmotic (e.g. NaCl treatment, freezing), oxidative (e.g. ozone), thermal and biological (e.g. enzyme), and new process techniques, for example co-digestion with substrates containing high levels of ammonium nitrogen and alkalinity have been proposed to improve the properties of organic waste to enhance the solubilisation of organic particulates and promote biogas production. Among these methods, thermal treatment has been demonstrated to be an effective method to provide better phase separation, higher hydrolysis rate of complex particulate organic substrates and apparent sterilisation effects, thus improving the subsequent disposal, such as enhancing the efficiency of anaerobic digestion process[6,7].

Pretreatment section includes screening, broken and water regulation.

Advantages: could recycle methane gas; well for resource recycle;

Disadvantages: large engineering investment; covering an area of large; difficult for equipment installation and debugging; complicated process; large amount of biogas slurry and difficulty renewal and processing; high operating costs;

Domestic technology application situation: Ningbo, Chongqing, Lanzhou, Kunming and Fujian KW plant

(3) Fertilizer for KW

There is an alternative method of aerobic treatment of KW, known as composting, which converts organics in KW into a hygienic, humus-rich, relatively stable product that conditions soils and nourishes plants[8]. KW contains a high amount of organic matter and is a very suitable raw material for composting. In order to produce a good composting product from KW, the carbon to nitrogen ratio needs to be adjusted to around 30 by the addition of carbon-enriched materials such as sawdust, straw etc. With the addition of oxygen and water, a good biodegradation process can be achieved. The compost derived from KW contains a good balance of nutrients for plant growth and the high organic content can improve the physical properties, especially for degraded agricultural soils under the continuous application of inorganic fertiliser.

Composting also leads to reduction in odour and removal of pathogens. The application of composts from KW could improve the physical properties of the soil and the yields of crops. The optimal conditions for composting of KW are: moisture content of the composting material must be at least 65%; pH near neutral; the C/N ratio of the material must be between 25 : 1 and 35 : 1. Additional aeration can improve the process; a temperature of 60 ^{o}C must be kept for optimal thermophilic composting[9].

Aerobic systems of solid composting can be open systems (aerated pile process and windrow process) and in vessel or container systems. The main advantages of invessel systems are the high speed of the process (10–14 days), low land requirement, minimization of any odour problems and complete process control[10]. Fresh compost is an intermediate product of the thermophilic stage, but a certain stage of maturation is needed to obtain a stabilized product. Composting of KW is not suitable in countries with limited land resources.

Advantage: the processing method is simple and the cost is low;

Disadvantages: covers large area; long processing cycle, difficult to control the odour, un-complete sterilization; poor fertilizer effect; Soil salinization easily;

Domestic technology application situation: the Nangong composting plant

(4) Thermal hydrolysis of KW

Thermal pretreatment of KW could meet these requirements and could also enhance the production of waste edible oils, which could not only be used as the raw oil for biodiesel production, but also effectively alleviate biological inhibiting reactions induced by the high concentrations of oil and grease in KW.

Advantages: disinfection completely; beneficial for oil recovery; relatively high product quality;

Disadvantages: high investment; large energy consumption; small handling capacity for single equipment; longer agricultural production industry chain during the backend application;

Domestic technology application situation: Suzhou, Shenzhen, Shanghai chongming KW plant.

(5) Biological protein feed of KW

Feed Protein from KW is used for material of producing poultry, livestock feed and aquatic product feed. Its economic benefits are shown as following:

- Enhance animal appetite and feed digestion and absorption ratio accelerate growth of animal and decrease feed conversion ratio.
- Stimulate immune system and enhance immunity
- Decrease bacteria in animal excreta and improve breeding environment
- Adjust microbial flora balance in intestines and stomach, accelerate beneficial bacteria reproduction, and decrease bacterial diarrhea.

- It is insensitive to antibiotic, producing no tolerance after feeding it to animals, and has no side effects in long-term application.
- It can replace a large proportion of fishmeal under the nutritionist's instructions.

3.2 Potential utilization of KW in America

The food waste recovery hierarchy is that prioritizes actions organizations can take to prevent and divert wasted food. And actions divert food waste from landfills include following methods[11]:

a) Source Reduction/Prevention: Preventing food waste before it is created;
b) Feeding People: Donating fresh, wholesome food to those in need;
c) Feeding Animals: Feeding safe, fresh food scraps to animals like pig farms;
d) Industrial Uses: Rendering fats, oils, and grease and turning it into products or biofuel;
e) Composting: Turning food waste into a valuable soil amendment;
f) Anaerobic Digestion: Turning food waste into renewable energy and a valuable soil amendment.

Why divert food waste from landfills in the USA? Because it could reduce the amount of food wasted which has significant economic, social & environmental benefits.

A. Environmental benefits
- Reduce methane from landfills
- Reduce resource use associated with food production
- Create a valuable soil amendment
- Improve sanitation, public safety, and health

B. Economic benefits
- Lower disposal costs
- Reduce over-purchasing and labor costs
- Receive tax benefits by donating food

C. Social Benefits

Feed People, Not Landfills: An estimated 50 million Americans do not have access to enough food. Organizations can donate safe and healthy food to a food bank or food rescue organization and both reduce food sent to landfills and feed those in need.

3.3 Potential utilization of KW in Korea

Starting in 2014, the Ministry of Korea is actively pursuing a project to create Eco-friendly Energy Towns, which are designed to return profits to the residents by combining the production of new and renewable energy such as waste energy and solar photovoltaic energy. The ministry developed a project model aimed at improving the welfare and income of local residents by using waste resources such as food waste, and livestock manure and biomass to produce energy, including heat and electricity, or by providing or selling the gas and heat generated from landfills or incineration facilities to the surrounding areas, and is conducting a pilot project in Hongcheon-gun, Gangwon-do. Also, it plans to establish three Eco-friendly Energy Towns each year in the future[12, 13].

Recently, Ministry of Environment has been shifting its policy direction to restrict the generation of food waste and has implemented a volume-based food waste fee system that imposes fees in proportion to the amount of food waste generated. This program has been implemented nationwide by expanding targets to include multi-unit housing starting in 2013. A volume-based fee system has been implemented for residential waste with an aim to reduce the amount of waste generated and promote recycling since 1994, but recycling products separately discharged and food waste have been excluded from imposing the fees charged in the proportion of the amount of waste generated. However, as the amount of food waste generated has been increasing since the direct landfill of food waste was banned in 2005, people’s living standards have improved, and the number of one- or two-person households now accounts for 48% of the total households, there is an increasing need to reduce the amount of food waste generated. In 2012, the daily generated amount of food waste was about 13,209 tons, which makes up about 27% of the total amount of generated residential waste (48,990 tons/day). Subsequently, the relevant ministries jointly adopted the “Comprehensive Measures for Food Waste Reduction” in 2010 and are promoting various measures fit for the characteristics of food waste by the stage and source of generation. As part of the implementation measures, the volume-based food waste fee system was implemented.

Although the Ministry of Environment put a priority on reducing the generation of food waste as its basic direction of food waste management policy, it is also actively promoting recycling of food waste inevitably generated as organic resources despite the reduction efforts. Food waste can be turned into valuable resources such as feed and fertilizer since they contain organic substances and nutritive components.

Table 6. Food waste generation and treatment in Korea (Unit: ton/day) [12].

	2007	2008	2009	2010	2011	2012
Generation	11,452	15,142	14,118	13,671	13,537	13,209
Generation per person (kg/person/day)	0.29	0.30	0.28	0.27	0.26	0.26
Landfill	451	565	281	194	167	153
	(3.1%)	(3.7%)	(2.0%)	(1.4%)	(1.2%)	(1.1%)
Incineration	674	867	459	422	465	381
	(4.7%)	(5.7%)	(3.3%)	(3.1%)	(3.4%)	(2.9%)
Recycling	13,327	13,710	13,378	13,055	12,905	12,675
	(92.2%)	(90.5%)	(94.7%)	(95.5%)	(95.3%)	(96.0%)

To that end, the developer of a housing and tourist complex was made to mandatorily install a facility to convert food wastes into resources in December 1997. According to the “Fundamental Plan on Food Waste Recycling” established in 1998, the reduction target and implementation measures are to reduce the total amount of generated food waste by more than 10% and recycle the total amount of food waste by more than 60% by 2002. In 2004, Comprehensive Measure for Reducing Food Wastes was established. As a result, 96% of the total amount of generated food waste (13,209 tons/day) is used as recycling materials, such as feed and compost, as of 2012.

As of the end of 2013, a total of 185.1 billion won has been used to fund the installation of public facilities to convert food wastes into resources, and vehicle purchases for 130 businesses and 926 billion won was loaned to a total of 2,227 private businesses from the Recycling Industry Promotion Fund to assist related technology development and facility installation in the private sector.

3.4 Potential utilization of KW in Japan

In Japan, a revised Food Recycling Law went into effect in 2007 to promote a “recycling loop” that requires food industries to purchase farm products that are grown using food waste-derived compost/animal feed (Table 8). The law requires that food waste emitters recycle their food waste into compost, animal feed/bio-gas or into effective use of heat from incineration, known as heat recovery [14, 15]. The primary recycling method in Japan is composting, however, the demand for recycled compost was low, due to competition from chemical fertilizer [16, 17] and safety issues [18, 19]. The leftover compost is discharged, rather than using it for farms [20, 21]; therefore, this shows that the sales destination of recycled products was a critical issue.

Table 7. Food waste recycling in Japan (Unit; %).

	Prevention	Reduction	Recycling	Fertilizer	Feed	Biogas	Oil
Manufacturer	5	3	73	(48)	(48)	(1)	(3)
Wholesaler	4	1	56	(44)	(47)	(1)	(8)
Retailer	4	2	25	(51)	(35)	(2)	(12)
Food service	4	4	13	(53)	(25)	(2)	(20)

3.5Current policies and regulations on food waste management in some countries

To date, most developing countries have not widely practiced food waste recycling and the regulations for food waste management are quite incomplete. As a result, most food waste is mixed with municipal solid waste (MSW) and landfilled. The recent policies, regulations, and official plans addressing food waste in some countries are shown in Table 8.

Table 8. Recent policies, regulations and official plans addressing food waste in some countries.

Regulations, policies, and plans	Main content	Issuing date	Issuing division
Brazil			
National Policy on Solid Waste (Law 12.305/2010)	Closuring of all open dumps by 2014. Separation and collection recyclable waste and wet organic waste are aimed at 36%, 53%, respectively, by 2031.	2010/8/2	Brazilian government
Costa Rica			
Law for an Integrated Management of Residues	The law is to provide the necessary legislation to regulate and organize a comprehensive national plan for the management of solid waste.	May-10	Costa Rican government
China			
The food safety law of the People's Republic of China	Regulations on safety issues of FW treatment.	2009/2/28	Chinese government
State council circular to further enhance grain saving and FW reduction	Detailed countermeasures on organizing, educating, supervising, and inspecting the work on food waste reduction in China.	2010/1/18	State Council
China's 12th Five-Year Plan (2011–2015) for Environmental Protection	Detailed plan for household waste collection and treatment (a safe treatment rate of 80% in urban areas by 2015).	2011/12/15	Ministry of Environmental Protection
Malaysia			
Solid waste Management Act and Public Cleansing 2007	Segregating household waste at home by separated bins include organic bin and recyclable waste material bin.	Gazetted on 2007/08/30 and enforced on 2011/09/01	Malaysian government
Thailand			
National 3Rs Strategy and the 3Rs Act	The 3Rs Strategy aims to increase organic waste utilization by 50% before 2026.	Draft (be issued soon)	Pollution Control Department
Turkey			
The by-law on Landfill of waste (No:27533 2012/03)	The law aimed to decrease the amount of landfilled FW by operating composting facilities and facilities for electricity production from methane gas.	2010/3/26	Turkish government
The EU Landfill Directive (99/31/EC) will be carried out by 2025	The EU Landfill Directive will be carried out by 2025 for reducing of biodegradable waste amounts.	1999/4/26	European Parliament
European			
Directive 2008/98/EC	The directive sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery.	2008/11/19	European Parliament and of the Council
Technical Standards and Regulations Directive 98/34/EC	The Directive seeks to prevent the creation of new technical barriers to trade and lays down a procedure for the provision of information in the field of technical standards and regulations. It applies to all member States, the European Economic Area (Norway, Iceland and Liechtenstein), EFTA (Switzerland) and Turkey.	2013/10/1	Department for Business Innovation & Skills

America			
Federal Swine Health Protection Act (PL 96 468)	In cases where food contains meat or animal materials, or food that has come into contact with meat or animal products, converting food into feed for hogs is regulated by the Federal Swine Health Protection Act (PL 96 468). This Act requires that all such food must be boiled before being fed to hogs and that facilities conducting the boiling be registered with either the USDA or the chief agricultural or animal health official in the state in which the facility is located.		
British			
Technical Standards and Regulations Directive 98/34/EC	The Directive seeks to prevent the creation of new technical barriers to trade and lays down a procedure for the provision of information in the field of technical standards and regulations. It applies to all member States, the European Economic Area (Norway, Iceland and Liechtenstein), EFTA (Switzerland) and Turkey.	2013/10/1	Department for Business Innovation & Skills
Compost Certification (to PAS 100 and the Compost Quality Protocol)	Inspection and certification services to PAS 100 and the Compost Quality Protocol on behalf of The Association for Organics Recycling (AfOR).		
Anaerobic Digestion Certification (to PAS 110 and the Anaerobic Digestion Quality Protocol)	Inspection and certification of anaerobic digestion plants under the Biofertiliser Certification Scheme (BCS), on behalf of Renewable Energy Assurance Ltd.		

Generally, more and more countries have paid attention to food waste management, but in a few countries, detailed stipulations by law remain incomplete, or some of these forms of draft legislation have not yet been approved or have not yet entered into force. Most budgets for recycling activities and projects come from overseas aid budgets, such as NGOs and the World Bank, while developing countries set a low budget for segregating activities and establishing FW treatment facilities [25, 26]. The main problems of properly managing food waste in many developing countries are inadequate administrative measures and poor budget allocations to enhance recycling activities. Moreover, the experiences from developed countries have shown that a country could not solve its food waste issue if a government does not establish the specified objectives for reducing FW and implement comprehensive legislative regulations [26].

4. Conclusions

This study has investigated the current situation of KW treatment methods in both China and other countries. The results show that various disposal techniques of KW were carried on in different countries. In addition, current policies and regulations on food waste management in both developing and developed countries have been discussed. It could be concluded that in developing countries, KW management is seriously lacking in whole management systems and among legislative measures.

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