BIOPROCESSING OF AGRO-WASTE AND ORGANIC DOMESTIC WASTE FOR BROILER FEEDS

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BIOPROCESSING OF AGRO-WASTE AND ORGANIC DOMESTIC WASTE FOR BROILER FEEDS

BY

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DEDICATION

This work is dedicated to:

My beloved husband, Ahmad Luthfi Bin Kassim, for his love, support and his endless pray for the betterment of my life.

My parents for their tender love and pray.

The diamonds of my life; Asiah, Abdullah, Aminah, Ali, Ahmad & Asmaa', who have given me strength to accomplish this work.

My beloved sister, Melati Khairudean, who was always be my side supporting me throughout my hard time.

My brothers and sisters for their love and support.

…..may the Mercies of Allah be with them.

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ABSTRAK

Kajian ini lebih kepada pemilihan pencilan berdaya tinggi untuk pencuraian sisa makanan, pembangunan inokulum serbuk, pembangunan prototaip sistem pencurai dan penilaian sisa makanan terproses sebagai bahan supplemen ayam pedaging. Sebanyak 23 jenis mikroorganisma telah berjaya dipencilkan daripada dua sumber iaitu kompos sisa pertanian dan sisa makanan tercurai. Keputusan kajian saringan menunjukkan 5.0 ml inokulum kultur campuran terdiri daripada pencilan H1, H4, C and E; dalam nisbah isipadu dan bilangan sel yang sama banyak, berupaya mencurai 100.00 g substrat sisa makanan dalam jangkamasa 10 hingga 11 hari dengan kandungan protein kasar tertinggi sekitar 72.97 ± 1.59 % dan lemak kasar 29.09 ± 1.67 % selepas 9 hari proses pencuraian. Pencilan H1, H4, C, dan E masing-masing telah dikenalpasti sebagai *Pseudomonas pseudoalcaligenes* H1, *Pseudomonas stuzerii* H4, *Serratia plymuthica* C, dan *Bacillus macerans* E.

Kajian menunjukkan 100.00 g substrat sisa makanan terkisar yang diinokulat dengan 5.0 ml inokulum kultur campuran yang berkepekatan 3.0 x 10^9 sel/ ml, 15 % (i/b) penambahan air, dan pengadukan pada kadar setiap 24 jam berupaya mencapai tahap 4 skala pencuraian dalam jangkamasa 3 hari dengan kandungan protein kasar 77.28 ± 1.71 % dan lemak kasar 28.02 ± 1.19 %. Proses penambahbaikan yang dilakukan ke atas media pertumbuhan menggunakan sistem kelalang goncang menunjukkan kepekatan biojisim sebanyak 2.58 ± 0.07 g/L telah diperolehi selepas 48 jam menggunakan komposisi media pertumbuhan yang terdiri daripada (b/i) 3.0 % sukrosa, 1.5 % ekstrak

yis, dan 0.15 % KH_2PO_4 dan nilai pH awal media tersebut pula ditetapkan pada 8.0. Sementara saiz inokulum, kadar pengadukan, dan suhu yang optima untuk pertumbuhan pula adalah masing-masing 10 % (i/i), 150 rpm, dan 28 ^{o}C ± 3 ^{o}C. Sistem fermenter tangki teraduk bersaiz 10 liter telah didapati berupaya mencapai kepekatan biojisim yang lebih tinggi iaitu 5.08 ± 0.03 g/ L selepas 24 jam proses pefermentasian dengan kadar pertumbuhan spesifik (µ) 0.254 jam^{-1}. Keputusan kajian juga menunjukkan bahawa inokulum kultur campuran bersaiz 10 % (i/i) memberikan nilai µ yang ketara lebih tinggi; 0.217 jam^{-1}, berbanding penggunaan inokulum bersaiz (i/i) 25 % and 50 % yang masing-masing memberi nilai µ pada tahap 0.078 dan 0.074 jam^{-1}.

Inokulum serbuk yang ditambah dengan susu tepung sebagai pembawa pada kadar 5 % (b/i) memberi kadar kemandirian terbaik iaitu 32.4 % ± 0.61 selepas 4 bulan penyimpanan. Kajian yang dijalankan juga menunjukkan bahawa 5.00 g inokulum serbuk berupaya mencurai 100.00 g substrat terkisar dalam jangkamasa 5 hingga 4 hari dengan penambahan air sebanyak 20 % (i/b), kandungan kasar protein substrat tercurai terbabit adalah 71.09 ± 1.69 %. Penggunaan inokulum serbuk pada kadar 7.00 g/ 100.00 g substrat terkisar tidak pula membantu meningkatkan kandungan kasar protein substrat tercurai terbabit. Kajian suapan berkelompok ke atas proses pencuraian sisa makanan di dalam prototaip sistem pencurai menunjukkan benih inokulum bersaiz 25 % dan 50 % (b/b) memberi kandungan protein kasar yang tidak ketara berbeza iaitu masing-masing 66.24 ± 2.32 % dan 67.00 ± 1.54 % selepas 2 hari proses pencuraian.

Kajian penilaian ke atas prestasi sisa makanan tercurai sebagai bahan makanan ayam pedaging menunjukkan bahawa kelompok ayam yang diberi diet yang mengandungi 50 % (b/b) sisa makanan tercurai mencatat prestasi tumbesaran yang ketara lebih baik dengan nilai kadar tumbesaran spesifik (SGR) dan kadar pertukaran pemakanan (FCR), masing-masing, adalah 9.79 ± 0.07 % and 1.27 ± 0.02, berbanding kelompok kawalan yang diberikan 100% (b/b) diet komersial yang memberikan nilai kadar tumbesaran spesifik dan kadar pertukaran pemakanan, masing-masing, 9.75 ± 0.08 % dan 1.45 ± 0.05. Kedua-dua kelompok, iaitu kelompok ayam yang diberi makanan yang mengandungi 50% (b/b) sisa makanan tercurai dan kelompok kawalan yang diberi makanan yang terdiri 100 % diet komersial, tidak menunjukkan indek hepatosomatik yang ketara berbeza iaitu masing-masing 2.74 ± 0.17 % dan 2.74 ± 0.12 %.

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ABSTRACT

This study has focused mainly on the selection of potential degrading isolates, development of powder inoculum for decomposition of food waste, development of home decomposing prototype system as well as the potential of decomposed material as poultry feed. A total of 23 types of microorganisms were successfully isolated from two sources; composted agro waste and fermented food waste. In the potential screening study, a mixed culture inoculum consisting of isolate H1, H4, C and E was able to degrade 100.00 g of substrate within 10 to 11 days with highest crude protein and crude lipid contents of 72.97 ± 1.59 % and 29.09 ± 1.67 %, respectively, after 9 days of bioprocessing. Isolate H1, H4, C and E were identified to be *Pseudomonas pseudoalcaligenes* H1, *Pseudomonas stuzerii* H4, *Serratia plymuthica* C, and *Bacillus macerans* E.

Improvement of process conditions showed that 100.00 g of ground substrate inoculated with 5.0 ml of 24-hour mixed culture inoculum at a concentration of 3.0 x 10^9 cells/ ml, 15 % (v/w) of water added, and mixing frequency of 24-hr interval was almost completely decomposed; reaching level 4 of degrading scale, within 3 days with crude protein and lipid contents of 77.28 ± 1.71 % and 28.02 ± 1.19 %, respectively. The improvement study of the medium composition and cultivation conditions in a shake flask system showed that a biomass concentration of 2.58 ± 0.07 g/ L was achieved after 48 hrs of fermentation process in a medium composition of (w/v) 3.0 % sucrose, 1.5 % yeast extract, and 0.15 % KH_2PO_4 with an initial medium pH of 8.0. The optimum cultivation conditions were 10 % (v/v) inoculum size, agitation rate of 150 rpm, and incubation temperature of 28 ^oC ± 3 ^oC. A 10-L stirred tank fermenter system was found out to give rise to a

higher biomass concentration of 5.08 ± 0.03 g/ L after 24 hr fermentation process with a maximum specific growth rate (μ_{max}) of 0.254 hr^{-1}. It was also found out that 10 % (v/v) of 24-hr mixed culture inoculum size gave rise to a higher biomass concentration with a μ of 0.217 hr^{-1} compared to inoculum size of (v/v) 25 % and 50 % which gave rise to μ values of 0.078 hr^{-1} and 0.074 hr^{-1}, respectively.

Powder inoculum, consisted of those four isolates, with an added carrier of 5 % (w/v) skim milk had the best viability rate of 32.4 % ± 0.61 after 4 months of storage. Study also showed that 5.00 g powder inoculum could degrade 100.00 g ground substrate with 20 % (v/w) added-water within 3 to 4 days with a crude protein content of 71.09 ± 1.69 %. A higher amount powder inoculum of 7.00 g did not enhance a further increase of crude protein content of decomposed product. Fed-batch study carried out on substrate decomposition process using a decomposing prototype system showed that seed inoculum size of 25 % (w/w) gave rise to a substrate crude protein content of 66.24 ± 2.32 % and a larger seed inoculum size of 50 % (w/w) did not promote a higher crude protein content of the decomposed waste. Feed evaluation study using broilers showed that inclusion of 50 % (w/w) fermented food waste in commercial diet recorded a significantly better growth performance with specific growth rate (SGR) and feed conversion rate (FCR) of 9.79 ± 0.07 % and 1.27 ± 0.02 compared to 9.75 ± 0.08 % and 1.45 ± 0.05, respectively, of 100% (w/w) commercial diet. Both groups had an insignificantly different hepatosomatic index of 2.74 ± 0.17 % and 2.74 ± 0.12 %, respectively (Table 4.18). In conclusion, these results suggested that inclusion of fermented food waste up to 50 % (w/w) in commercial diet does not give any deleterious effects on a chicken growth as far as SGR and FCR concerned.

CHAPTER 1: INTRODUCTION

1.1 Waste and environmental problems

Environmental pollution is related to the increase of waste production resulting from the economical and demographical developments. Development and improvement in life also result in negative effects on the environment and economy of many countries in the world. The waste generated increases along with the increase in world population. It was reported that 229 million tons of municipal solid waste (MSW) was produced in US alone in the year 2001(Hassan, 2005). Another 118 million tons were generated in China in 2000 and 4.5 million tons is generated in Morocco every year (Chofqi *et. al*., 2004). In fact, Malaysia generates around 23,000 tons of MSW daily consisted of 43 % food and agricultural-based residues, 15 % papers, 4 % wood and garden waste, 14 % plastics, 4 % metal, 3 % textile, 3 % glass and 10 % others (Goh, 2007).

There are two main sectors which contribute to the large production of solid waste; residential and agro-industrial sectors. Residential activities produced household and commercial establishment wastes which are referred to as MSW. Food waste is any left-over foods/meals or anything related to kitchen waste of residential units, restaurants, or hotels (OECD, 2001). Environmental pollution has prompted public awareness which has led to ‘go green’ activities such as recycling program. In 2003, Malaysia recycled only 6.0 % of the MSW whereas the rest of 94 % was dumped to landfills. However, in 2004 the amount disposed to landfills decreased to 41.1 % due to the introduction of the incinerator that resolved another 47.9 % of our solid waste problem (Chong *et. al*., 2005). With the fact that our current recycling rate of about 6 % and MSW generation of 23,000 tons per day (Goh, 2007), it is clearly shows that the recycling program which was introduced a decade ago has not shown much success yet.

Studies have been carried out to reuse or to value-add the organic waste. Solid state fermentation technology has made extensive efforts to explore how value can be added to organic waste. Organic waste like agro-industrial residues; palm kernel cake, fruit waste, animal manures, cassava and sugarcane bagasses, coffee pulp and coffee husks and food waste have been studied intensively for value addition. There are many studies reporting on the reuse of organic waste as food or feeds such as palm kernel cake (Hutagalung *et. al*., 1982; Yeong, 1983; Abu *et. al*., 1984; Onwudike, 1986a,b,c; Hassan, 2004), fruit waste (Hulan *et. al*., 1982; El-Boushy and Van der Poel, 2000; Figuerola *et. al*., 2005) and food waste (Lee *et. al*., 1998; Myer *et. al*., 1999; Chae *et. al*., 2000; Chung, 2001; Kwak *et. al*., 2002; Ivanov *et. al*., 2004; Kwak and Kang, 2005). The inclusion of 50 % of processed food waste in the commercial diets for swine showed no deleterious effects. Data from this study suggests that processed food waste has a good potential as an animal feeding ingredient (Chae *et. al*., 2000; Kwak *et. al*., 2002; Kwak and Kang, 2005).

1.2 Rationale for selection of food waste

Food waste from households, restaurants and hotels is putricible waste that must be well managed to control vermin, odor, diseases and other sanitary issues related to its disposal (Yang *et. al*., 2005). Food waste is easily decomposed compared to lignocellulolytic residues. However, its disposal would usually give rise to environmental and hygienic problems since its decomposition process produces leachate, unpleasant odor and attract rats, flies, strayed cats and dogs which could eventually spread out related diseases. The amount of food waste generated is large enough. The Republic of Korea has reported generating 4.5 million metric tons of food waste annually (Yang *et. al*., 2005) while Singapore disposed about 1.1 million tons of food waste every year (Ivanov *et. al*., 2004). However, no official figure has been reported by the Malaysian local authorities on this matter and no efforts have been taken to collect or separate this potential waste from other components of municipal solid waste.

Food waste was proven to have high nutritional value, rich in protein and fat. So, it is suggested to be supplemented as animal feeds (Kwak *et. al*., 2002). Recycling this nutritionally rich waste would provide a nutritionally-valued protein for animal consumption and help to cut down the cost of feed production tremendously.

1.3 Scope of study

This study focused mainly on the bioprocessing of food waste into poultry feeding ingredient using selected decomposing microorganisms. Potential degrading microorganisms were isolated from two sources; composted agro waste and fermented food waste. These isolates were then screened for their degrading potential both in single and mixed culture systems. The degrading performance of the isolates was then evaluated based on the physical changes of the substrate and the contents of crude protein and lipid of the decomposed product. Potential isolates were identified based on the biochemical tests to eliminate the possibility of pathogenic or opportunistic microorganisms.

The rate of the substrate decomposition process was optimized by monitoring the physical parameters such as the amount of substrate/ container, size of inoculum, mixing frequency, water content and size of substrate particle. This study also involved the development of a home decomposing prototype which consists of three main components; a grinder, fermentation and drying compartment. The grinder (Whirlpool 782, Taiwan) which has a length of 20 cm and diameter of 16 cm is attached to the water outlet of the sink. The grinder has the capability to grind all types of food waste including bones and shells of the left-over meal. The fermentation container has a semi-circle shape with a length of 27cm and a diameter of 24 cm. The container has a working volume of 3.0 kg and would pour the content into the underneath drying tray automatically at a set time interval.

The drying tray with a diameter of 32 cm and height of 7 cm is located underneath the fermentation container and is attached to a heating source.

The biomass production for the powder inoculum development was carried out in a submerged fermentation process. The cultivation systems were optimized based on the basal medium composition consisting of sucrose, yeast extract and potassium hydrogen phosphate (K_2HPO_4). The optimized medium was then employed in various fermenter systems namely shake flask, stirred tank and airlifts (loop and tubular types). A kinetic study of the fermentation systems was carried out to evaluate the performance of the systems. Both batch and fed-batch modes were carried out using optimized medium composition and cultivation conditions.

A powder inoculum consisting of the selected potential isolates was developed. The viability and stability of the inoculum was studied. The application of the inoculum for maximum degradation rate was carried out both in the plastic container and home decomposing prototype system. Decomposition profiles of the food waste; both in batch and fed-batch modes, in decomposing prototype system was carried out using the optimum food waste degradation conditions in search of the optimum inoculum size.

Evaluation study on the efficiency and performance of processed food waste as poultry feed ingredient was conducted using Day-one old chicken (DOC) from species of COBB. The study was carried out for 5 weeks; the chickens were fed with commercial diets supplemented with 0 %, 25 %, 50 %, 75 % and 100 % (w/w) of processed food waste. Post-mortem, histological observation and clinical pathology measurements were carried out to ensure the feeding ingredient was free of deleterious effects. The Specific growth rate (SGR) and feed conversion rate (FCR) were calculated to measure the feeding performance.

1.4 Study objectives

Based on the scope of the research, the objectives of this study were:

1. To screen and evaluate the degrading potential of locally isolated microbes from indigenous source for the decomposition of food waste.
2. To improve the biomass production of selected potential degrading isolates for the development of powder inoculum.
3. To improve the decomposition rate of food waste using the developed powder inoculum.
4. To evaluate the efficiency and performance of fermented food waste as poultry feed supplement.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview of source, production and management of solid waste

The increase of waste production has been closely related with economical and demographical developments. Besides a life improvement, such developments also gave rise to negative effects on the environment and economy for most part of the world. The demographical development and fast growth of economic activities in today life have been accompanied by the increase of solid waste production (Chofqi *et. al*., 2004). At the end of 2002, China produced 6.5 billion tons of municipal solid waste (MSW) occupying 55,000 hectares of land area (Dong *et. al*., 2001). Japan and Morocco currently generates around 15 million and 800,000 tons of MSW, respectively each year (Yasuhara and Katami, 2007; Chofqi *et. al*., 2004). Americans generated about 250 million tons of MSW in 2010 with a recycling and composting rate of 34.1 % (US EPA, 2012a) and Malaysians are currently producing approximately 23,000 metric tons of waste everyday with recycle rate of less than 5% and the amount generated is expected to reach 30,000 metric tons/day in 2020 (GEC, 2012).

There are two main sectors which contribute to a large production of solid waste, namely residential and agro-industrial activities. Residential activities produce household and commercial establishment waste which is also called MSW. Household waste contributes to 2/3 of MSW (OECD, 2001). Business dictionary (2012) defines household waste, or so called domestic/residential waste, as solid waste consists of garbage and rubbish (such as bottles, cans, clothing, compost, disposables, food packaging, food scraps, newspapers and magazines, and yard trimmings) that originates from private homes or apartments. It may also contain household hazardous waste which is chemical products such as cleaning solvents, paints, pesticides, and substances that can catch fire, react with other chemicals, explode, or are corrosive or toxic. Advanced countries with a better standard of living have been observed to generate more solid waste compared to developing countries (Hare, 1994). London produces 6707 tons of solid waste/ day compared to Calcutta, India which produces only 5646 tons/ day even the latter posses a much higher population. This figure could be contributed by the use of disposable items/products by those in higher living-standard countries.

The distribution of overall MSW in US was 28.2 % paper, 13.9 % food scraps, 13.4 % yard trimmings, 12.4 % plastics, 9 % metals, 8.4 % rubber, leather, and textiles, 6.4 % wood, 4.6 % glass and 3.4 % others (US EPA, 2012a). Whereas in Malaysia, its solid waste composition was generally consisted of 43 % food and agricultural-based residues, 15 % papers, 4 % wood and garden waste, 14 % plastics, 4 % metal, 3 % textile, 3 % glass and 10% others (Goh, 2007).

There are two main waste disposal methods that are widely used; landfill site and incineration. In the landfill, the waste are disposed in one area and compressed before being covered with a soil up to a depth of 1.5 – 2.5 meters and the processes are repeated until the area is full (Hadiwiyoto, 1983). Another waste disposal option is incineration. Incineration is a very effective process for MSW treatment since it ensures a substantial reduction of both volume and weight up to 90 % and 75 %, respectively after thermal processing coupled with energy recovery. However, the final residues of the process are still needed to be disposed to the landfills (Hassan, 2005). Incineration also produces residues namely ashes which are hazardous waste due to its high content of heavy metals (Cd, Pb, As, Se and Hg) and pollutants (Bagnoli *et. al*., 2005).

2.2 Source and production of food waste

The United States Environmental Protection Agency (US EPA) defines food waste as being: "Uneaten food and food preparation waste from residences and commercial establishments such as grocery stores, restaurants, and produce stands, institutional cafeterias and kitchens, and industrial sources like employee lunchrooms" (US EPA, 2012b). Food waste used to be characterized by high moisture contents, rich in carbon and protein sources (Kwon and Lee, 2004). Composition of food waste could be varied depending on the type of foods/meal; breakfast, lunch or dinner, generating places and also eating culture of the studied society. Seo *et. el*. (2004) in his study found out that food waste in South Korea, on a wet matter basis, are consisted of grain (5.9 – 23.6 %), fruits (17.7 – 29.7 %), vegetable (63.1 – 63.7 %), fish/meat (4.8 – 12.7 %) and others (2.39 – 12.7 %), whereas the composition of Malaysian food waste collected after breakfast meal are mainly consisted of 50 % grain and the rest were meat/fish, vegetable and others (How, 2002).

The magnitude of the food waste problems cannot be understated since the volume of its generation increases along with the growth of the world population and the impact on the environmental is really great. It was reported that USA wasted about 21.9 million tons of food in 1998 and the amount increased to 34 million tons in 2009 (Westendorf, 2000; US EPA, 2012b). There are approximately 45,000 and 11,155 tons of food waste produced every day in Taiwan and South Korea, respectively (Mao *et. al*., 2006; Kwon and Lee, 2004). While another 1.1 and 19.4 million tons of food waste are disposed to landfills or incinerated every year in Singapore and Japan, respectively (Ivanov *et. al*., 2004; Ohkouchi and Inoue, 2006). Waste and Resources Action Programme - WRAP of UK estimates that around 18 – 20 million tons of food wasted in UK alone in 2008 (DEFRA, 2010). Urban Malaysians are recently reported of generating around 1000 tons of food waste daily (Chai, 2010). Based on these figures, the amount of food wasted every year is large enough to be tackled wisely since most of them are disposed to landfills or incinerated with only a small amount is recycled. It is estimated that only 2.4 % of food waste generated in USA was recycled in 2005 (Westendorf, 2000; Hassan, 2005).

2.3 The need for management of waste at source

Like other waste, food waste can be dumped, but food waste can also be fed to animals; typically swine or it can be biodegraded by composting or anaerobic digestion, and reused to enrich soil. Food waste easily degrades once it is disposed; however, its degradation process could lead to health and environmental problems. Degradation process of food waste is known to produce odor detrimental to environmental quality and its direct disposal to landfill creates various problems such as putrid smells and leachate that would obviously cause pollution to ground and surface waters (Tsai *et. al*., 2006). Its anaerobic degradation process also becomes a significant source of methane, a potent greenhouse gas with 21 times the global warming potential of carbon dioxide (US EPA, 2012b). Sending the waste to incinerators has also caused several problems such as lost of combustion energy due to its high moisture content and formation of undesirable by-products such as dioxin-related compounds (Sakai *et. al*., 2001). Due to these reasons, several states in the USA and a number of European and Asian countries tried to collect, process and reuse the food waste in order to reduce the amount of organic matter reaching disposal sites (Westendorf, 2000; Seo *et. al.*, 2004; Mao *et. al.*, 2006). The US and Australia governments have made an enforcement on residential units to operate food waste processor system. In this system, the in-sink food waste processor/grinder is used to macerate organic waste generated in the kitchen and dispose it to sewage system using water as a transport medium. This system performed well in term of separating food waste from other components of MSW which is used to be disposed to landfills or incinerated (Lundie and Peters, 2005). In South Korea, the Ministry of Environment has recommended of recycling food waste into animal feeds, fertilizers and energy recovery. Since there are problem arise due to the wide distribution of generating sources, transportation and storage, large restaurants and corporate cafeterias have been enforced to operate facilities for recycling the food waste on site (Kwon and Lee, 2004).

Several efforts have been explored in an attempt to develop suitable composting methods that could operate at generating sources. Yun *et. al*. (2000) has studied the feasibility of using a slurry-phase bioreactor system which was adopted from the solid substrate fermentation system. In this system, water was added into the substrates to form a slurry medium and mixing rate was improved using impeller to enhance oxygen transfer and speed up the decomposition rate. This composting system was found out to be able to degrade 82 % of carbonaceous compounds within 5-day operation. A slurry-phase was believed to be a more favourable environment for aerobic microorganisms compared to normal solid phase. There are also several small-to-medium size composting bioreactors for in-site applications have been developed in Europe and Japan. This system is generally known as in-vessel composting system and most of them have a composting time maturity of 14 days to one month (Chang *et. al*., 2006). One type of in-vessel composting system with a better operational efficiency has been tested in South Korea. This in-vessel composting system was operated using a fed-batch mode in which the food waste was added into the system periodically and treated without discharging the by-products for a specified period (Kwon and Lee, 2004). These systems; both the slurry phase and in-vessel systems, were considered as efficient enough to be operated in restaurants, hospitals and corporate cafeterias in which the fresh food waste would be added into the systems on a daily basis.

In Taiwan, the government policy encourages composting as another option toward food waste management as quality compost is valuable in agriculture application. A few composting plants has been built in Taiwan for this purpose. Taiwan also legislated mandatory recycling of household food waste to be composted and processed it as a swine feeding ingredient in 2005 (Mao *et. al*., 2006). This policy has its own goodness in recycling this useful rich garbage and minimizing environmental pollutions related to its disposal. However, there is still a deep caveat in the system if it is not handled carefully. Mao *et. al*. (2006) in his study evaluating the performance of three food waste composting plants in Taiwan found out that composting food waste have presented malodor problems into the surrounding environment and affected the quality life of the nearby society. Samples of ambient air inside the plants, at exhaust outlets and plant boundaries revealed a high concentration of six compounds; ammonia, amines, acetic acid, ethyl benzene, dimethyl sulfide and *p*-Cymene, which exceeded human olfactory thresholds. Odour concentration (OC) of samples collected at plant boundaries had a range of 74 – 115 OC which is exceeded Taiwan's EPA (1994) standard of 50 OC in industrial and agricultural regions and 10 OC in residential areas. This study suggested a more extensive evaluation to be carried out on the operational and management procedures of the system in order to tackle the related problems.

Attempts have also been underway in Korea and Japan to promote home composting which could be carried out in a small bin. If handled properly, home composting would control the generation of wet food waste at generating sources (Seo *et. al*., 2004). Furthermore, according to life cycle assessment conducted by the Centre for Water and Waste Technology, University of New South Wales, home composting, if operated aerobically, has the least environmental impact compared to centralized composting and co disposal of food waste with municipal waste (Lundie and Peters, 2005).

Collection of residential food waste is extensively taking effect in parts of the U.S. Survey conducted by BioCycle's in 2009 revealed that more than 90 communities/ counties are now involved in residential food waste collection for recycle program compared to only 42 communities reported in 2007. The number was doubled with the effort and support of the waste management authorities and non government organizations. The residents are provided with green carts/ bins for food waste collection besides blue carts/ bins for normal garbage disposal. The food waste is collected daily and sent to nearby composting facilities. In June 2009, the mayor of San Francisco County, Gavin Newsome, passed a mandatory source separation ordinance which came into effect in October, 2009. The ordinance requires residents and businesses to separate organics and recyclables from the garbage (Yepsen, 2009).

The UK consumers generate over 80 million tonnes of waste including 7 million tonnes of food waste per year and around 40% of waste from households is currently recycled as compared to 11 % in 2000/ 01. As intensive effort toward a better food waste management, Biffa; the UK based integrated waste management company, has opened the country's largest Anaerobic Digestion (AD) facility in June 2011 located in Poplars, Staffordshire which is also marks the country's first 'super' AD plant dealing with food waste. This 120,000-tonne capacity plant is expected to generate 6 MW of electricity through the combustion of biogas in three 2-MW gas engine once running at full capacity in July 2011(Thorpe, 2011).

Here in Penang, the state government recently mulled over the idea of placing food processing machines at hotels, restaurants, high-rise buildings and factories to convert food waste to feed mill. Penang Health, Welfare, Caring Society and Environment Committee were reported collecting data from the relevant parties and would come up with a proper mechanism hopefully by the end of the year 2010. This afford would help the state conduct a proper food waste management program under the Green Penang project (Kasturi, 2010).

Conclusively, proper management is very crucial to prevent further environmental destruction and to promote sustainable development. Recycling and value-adding this waste seem to be the best option to bring the value back to our food chain and contribute for sustainable environment.

2.4 Bioprocessing of organic waste

Decomposition of organic waste produces both useful gaseous products; a mixture of carbon dioxide (CO_2) and methane (CH_4), and a solid fibrous "compostable" material. Natural decomposition of organic waste such as food or agro-industrial waste is normally carried out by natural readily-exist microorganisms such as bacteria, fungi and yeast (Figure 2.1 and 2.2). Small insects such as fruit flies, maggots or worms usually speed up the process. Organic waste is usually made up of carbohydrates; starch or cellulose, as the main build-up materials besides proteins and lipids. In natural decomposition process, microorganisms would use the organic waste as substrates or sources of their nutrients for growth. These microorganisms would synthesis or secrete related enzymes to breakdown the substrate compositions into simpler compounds that later on would be used up for their growth. Amylase hydrolyzes the α-glycosidic bonds of polysaccharides like starch or glycogen into simpler form of disaccharide; maltose. Maltose would be broken down into glucose molecule which is the simplest form of carbon source that is normally used in the cellular level. β-glycosidic bond of cellulose is broken down by cellulase. Cellulolytic materials could also be broken down by a type of snail; *Achatina sp*., which is able to secrete β-glycosidase to hydrolyze cellulose. Peptide bonds of the protein are broken down by several hydrolyses that would cleave the specific peptide bonding based on their location in the polypeptide chain. The cleavage would result in a simpler form of free amino acids. Digestion of lipids is catalyzed by esterase especially lipase into simpler end-products like glycerol, free fatty acids and triglycerides.

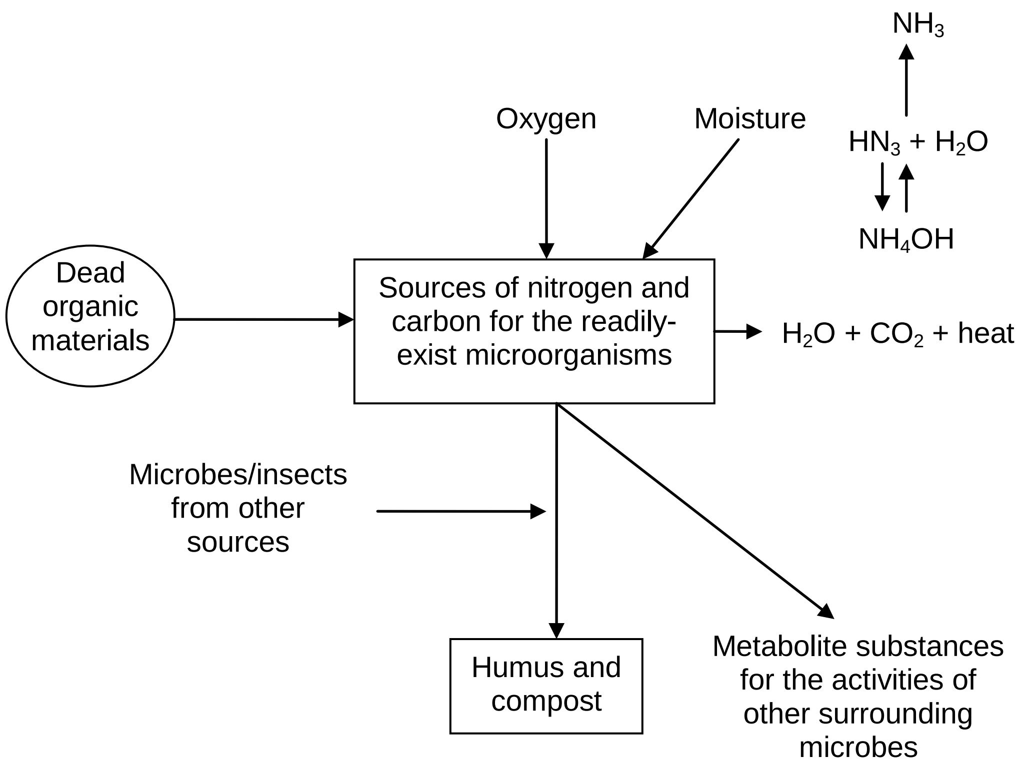

Figure 2.1: Decomposition process carried out naturally by readily-exist microbes in soils resulting in formation of stable humus.
**Modified from: Ibrahim, C. O. (2002).*

Anaerobic decomposition of organic waste resulting in the production of biogas as showed in Figure 2.2. There are three groups of bacteria involved in this process. First group of fermentative and hydrolysis bacteria consisted of anaerobic and facultative ones that break down the complex components of the waste; polysaccharides, proteins, lipids, celluloses, into simpler forms; propionate, butyrate, long-chain fatty acids, hydrogen, carbon dioxide, formate and acetate. Acetogens which is the second group that break down butyrate and propionate into hydrogen and acetate. This group of bacteria is also known as hydrogen producer and common species of this group are *Syntrophobacter wolfei* and *Syntrophobacter wolinii*. Other groups of hydrogen producing microorganisms; *Thermoanaerobacterium, thermosaccharolytium* and *Desulfotomaculum geothermicum,* were used to be detected from the thermophilic acidogenic culture and *Thermotogales* strain and *Bacillus* species were detected from the mesophilic acidogenic culture. The third group, which is called methanogen, is an absolute anaerobe that uses hydrogen and carbon dioxide to convert acetate into methane.

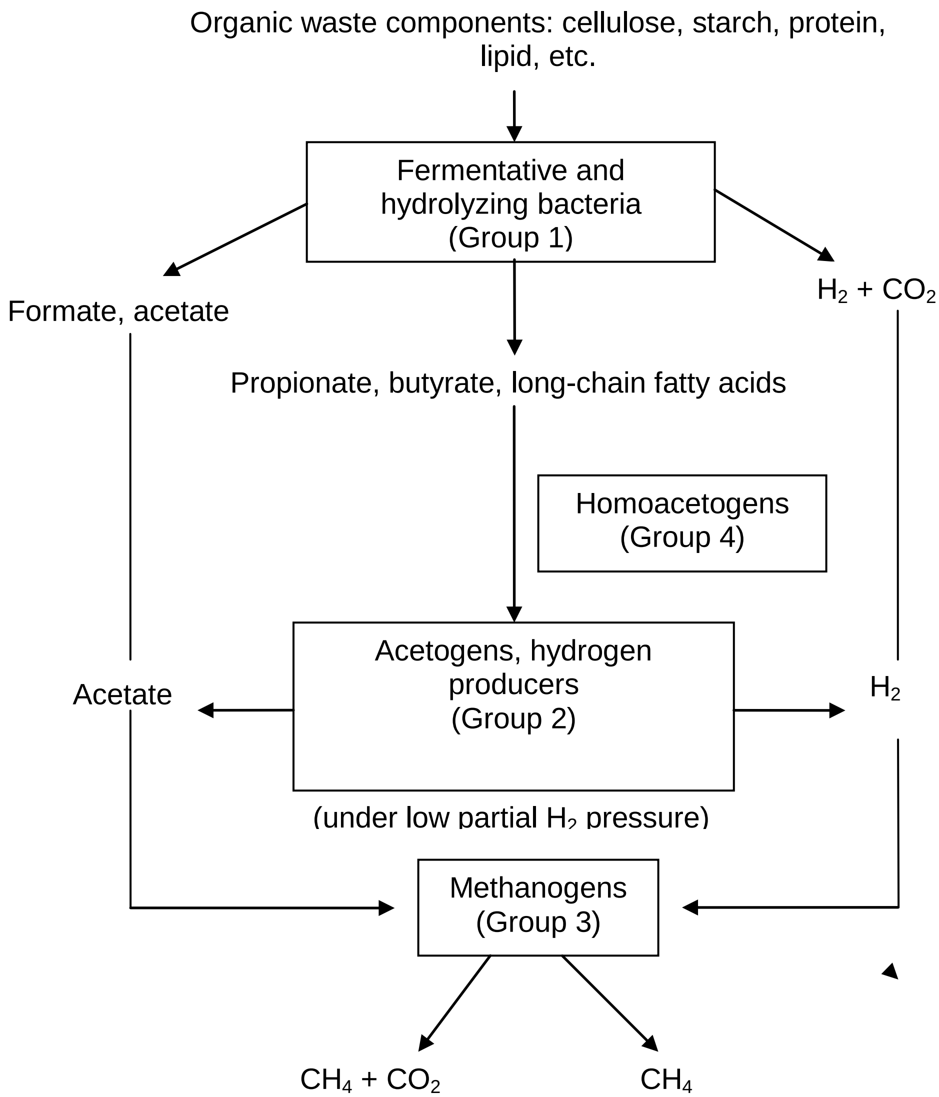

Figure 2.2: Anaerobic decomposition process of organic waste carried out naturally by readily-exist microbes in soils leading to a production of biogas.

**Source: Ibrahim Che Omar (1994)*

2.5 Feasible applications of processed food waste

There have been intensive researches carried out on the value addition of food waste and problems related to it. The degradable components of MSW should be fundamentally oriented towards reduction, followed by reuse and recycling. Only in case of necessity these garbage should be utilized for energy needs (Sancho *et. al.*, 2004).

2.5.1 Use of processed food waste for animal feed

2.5.1.1 Malaysia's poultry industries in overview

Broiler industry has been a primary source of poultry meat in nowadays life throughout the world. Chicken has changed from being a holiday or Sunday dinner treat to a daily menu items. Within 20 years time; 1940 – 1960, the broiler has changed from being a bird marketed at 16 weeks of age to 8 weeks with an average weight of 3.0 to 3.5 lbs (1.40 to 1.60 kg) and currently it is marketed at 6 weeks of age and expected to be marketed at 4 weeks in the future (Moreng and Avens, 1985). This resulted from extensive scientific studies on breeding and diet formula.

In Malaysia, the livestock industry is dominated by the poultry industry which was reported to be 83% of industry sales of RM1232.4 million in 2005 (AGR, 2009). The poultry industry includes large integrated corporate farms producing both poultry meat and eggs. Some of these businesses are large sized public companies that are listed on Malaysia's stock exchange. Examples of these companies include Leong Hup, Chareon Pokphand and Dindings Poultry. The production of poultry meat has reported to be increasing tremendously within 20 years period from 221.4 x 10^3 matrix tan in 1985 to 558.2 x 10^3 matrix tan in 2003 and this figure is expected of going up to 1033.04 x 10^3 matrix tan in 2010 (Department of Veterinary Service, 2003; Table 2.1). Malaysia is the third largest producer of poultry meat in the Asia Pacific region and considered as self sufficient in poultry, pork and eggs, but imports about 80% of its beef requirements (MIDA, 2011). Instead of being self sufficient in the above-mentioned products, we in fact suffer from a severe shortage of animal feed ingredients so such products have to be imported to keep our livestock industry fully operational (AGR, 2009). The feed production is considered as the biggest investment in the industry which comprises 70% of the production cost (Abdurrahman and Shanmugavelu, 1999). Malaysia has a number of large multinational, international and local animal feed suppliers; Cargill Feed, Chareon Pokphand Feed Mills, the Malayan Flour Mills group feed companies, Federal Flour Mills group, Gold Coin Malaysia, Sabah Flour and Feedmills, Sin Heng Chan, Sinmah Multifeed and the Soon Soon Group, which produces poultry (mainly), pig, cattle and other livestock feeds (AGR, 2009). For the last few years, Malaysia uses more than 3 million tones of feeding materials per year, including locally available agricultural products and related waste materials, with estimated import of the feeding ingredients amounted to RM1309.2 million in 2007, up from RM677.9 million in 2003. The industry produced 2.2 million tones of poultry feed alone in 2007. The Chart below (Figure

2.3) provides an overview of feeding ingredients used in feed production (AGR, 2009).

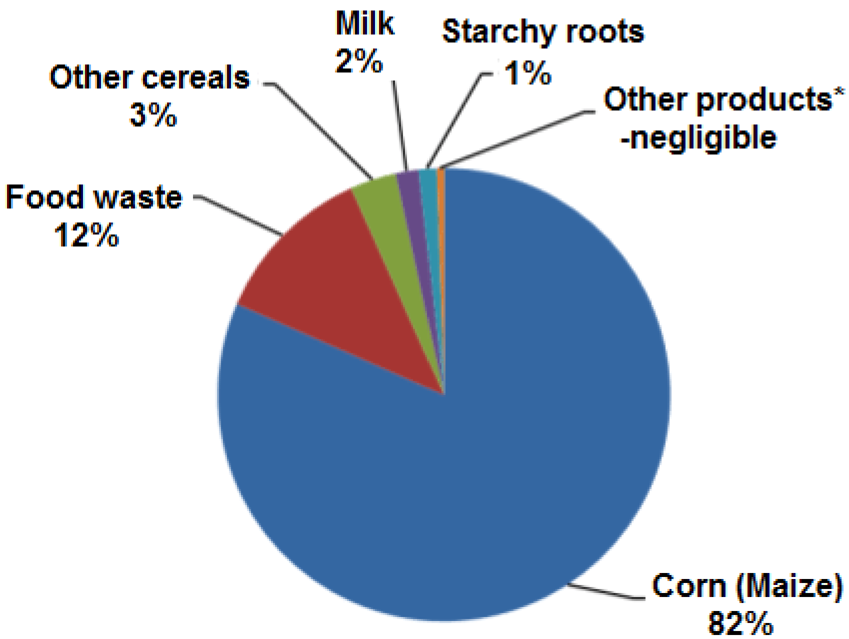

Figure 2.3: Animal feed ingredients in Malaysia

**: Includes fish meal.*
Source: Agriculture and Agri-Food Canada (AGR), 2009.
Data includes imported corn.

Corn, mainly imported, is the main feed ingredient for carbohydrate source. There was 2.7 million tons of corn valued at RM2063.8 million imported mainly from Argentina in 2007 (AGR, 2009). So far, studies on local agro-industrial waste like palm kernel cake (PKC), palm oil mill effluent (POME) cocoa and pineapple pulps have been carried out to replace commercial imported feed ingredients for our poultry industry. However, the results were not well successful yet and the efforts are still carried on to support our local industries. Recycling of food and other organic waste for animal feed would clearly reduce the cost of feed production and also import of feeding ingredients substantially.

Table 2.1: National target on poultry production 2001 – 2010.

Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2010**
Production (x 10^3 tan matrix)	821.59	840.49	859.82	879.59	899.82	1033.05
Demand x 10^3 tan matrix	663.86	680.46	697.47	714.91	732.78	825.04
Consumption per capita (kg/year)	35.4	35.5	35.6	35.7	35.9	36.8

*Source: Department of Veterinary Service, Malaysia.

2.5.1.2 Use of processed food waste as animal feeds

Among available organic waste, food waste are considered of having a very good potential to be processed into animal feed due to its high protein content. However, besides of its large generated amount as mentioned earlier, not much attention has been given to utilize this waste either for value-addition or other bioprocessing products. In Malaysia, there is no reported study related to bioprocessing of food waste except the one carried out for this thesis. This could be due to the reason that its huge volume is actually available in wide distribution sources; restaurants, hospitals, hotels, cafeterias and household units. So far, not much attempt has been made to collect and separate them from other MSW except in a few countries such as Taiwan (Mao *et. al*., 2006), Korea (Kwon and Lee, 2004) and Norway (Rundberget *et. al.*, 2004).

There have been several studies carried out in Rep. of Korea to utilize food waste as swine feed (Lee *et. al.*, 1998; Myer *et. al*., 1999; Chae *et. al*., 2000; Chung, 2001; Kwak *et. al.*, 2002). Kwak *et. al*. (2002) and Chae *et. al*. (2000) found out that restaurant food waste has a higher nutritional value than household food waste. It is rich in protein and fat, but low in metabolized energy than a typical corn-soy diet for finishing pigs. Results of Kwak and Kang (2005) showed that inclusion of Food waste mixed with bakery by-products up to 50% of dry mass basis into the diets during finishing phase of swine growth did not give any deleterious effect on pig production, carcass characteristic and meat quality, except a reduced feed efficiency and paler-color meat. These results generally imply that the feed value of processed food waste and bakery by-products mixture was comparable with commercial corn-soy diet. Most authors suggested supplementing food waste with grain, grain by-products, or commercial corn-soy diet to improve its feeding value especially in term of metabolized energy supply (Westendorf *et. al*., 1998; Myer *et. al.*, 1999; Chae *et. al*., 2000). Yang *et. al*. (2005) studied the potential of lactic acid fermentation process, which was adopted from the silage technique that typically applied to forage, to preserve food waste for swine feed. The results showed that anaerobic treatment and 0.2% (v/w) inoculation of LAB improved the fermentative characteristics of mixed food waste