AMERICAN UNIVERSITY OF BEIRUT

RECOVERING FOOD LOSSES AND WASTES AS FEED FOR FARM ANIMALS: A SYSTEMATIC REVIEW

by
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Caroline Rajeh

AN ABSTRACT OF THE THESIS OF

Caroline Nabil Rajeh for Master of Science
Major: Food Technology

Title: Recovering food losses and wastes as feed for farm animals: A systematic review

While society struggles to meet rising food demands and mitigate food security challenges, approximately one-third of the food produced globally is lost or wasted every year. Using food wastes as animal feed offers a solution that simultaneously addresses waste management and food security challenges while reducing the pressure to grow conventional feed, a resource, and environmental burden. The present review examines available literature discussing the feasibility of incorporating food wastes in feeds for fish (14 articles), pigs (28 articles), poultry (21 articles), rabbits (4 articles) and ruminants (14 articles) whilst assessing related safety and logistical concerns. Results suggested that various types of food losses and wastes are generally nutritious, can be converted into safe feeds by modern technologies and can be partially incorporated into animal diets. Animal growth performance in response to various food loss and/or waste substitution rates depended on tested feed sources, animal species, age, and length of the feeding trials. Animals fed waste-based feeds generally had comparable feed conversion ratios to those fed conventional feeds. More attention should be given to characterizing the nutrient variability of food losses and wastes and developing efficient and timely waste collection and transport processes. The present review suggests that partial incorporation of food wastes into animal feeds is a viable solution to mitigate food wastage without compromising animal growth nor health.

A GRAPHICAL ABSTRACT OF THE THESIS OF

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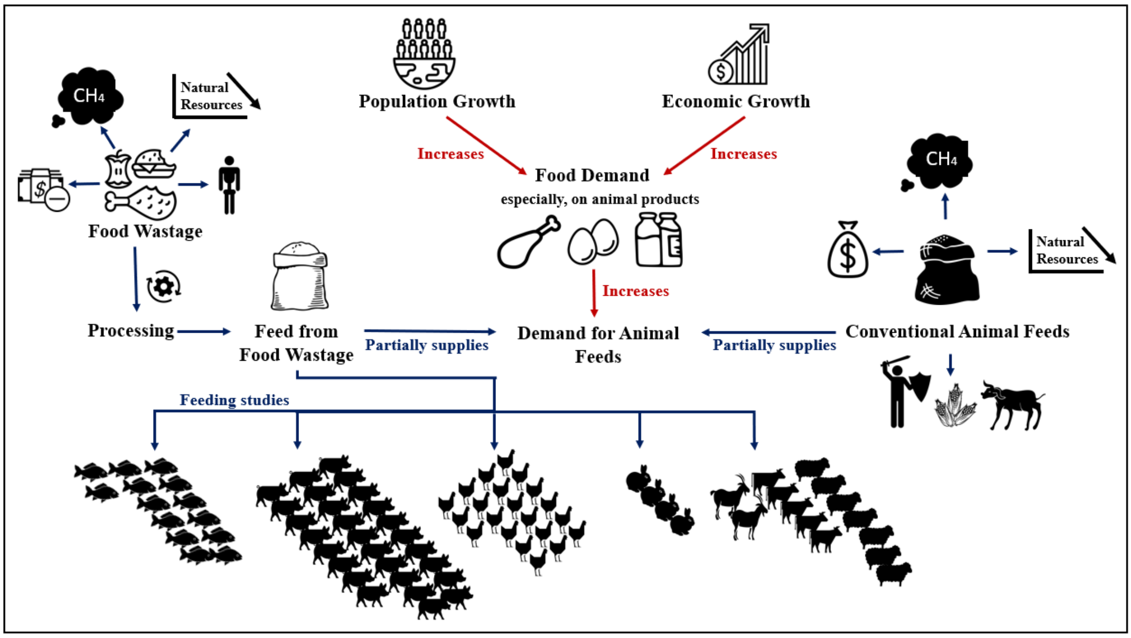


CONTENTS

Appendix

ILLUSTRATIONS

TABLES

ABBREVIATIONS

ADG	Average Daily Growth Rate
BiW	Biscuit Waste
BSE	Bovine Spongiform Encephalopathy
BW	Bakery Waste
CF	Crude Fiber
CFW	Cafeteria Food Waste
CP	Crude Protein
DDS	Document Delivery Services
DM	Dry Matter
EE	Ether Extract
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organization
FCR	Feed Conversion Ratio
FrW	Fruit Waste
GHG	Greenhouse Gas
HFW	Hotel Food Waste
KFW	Household/Kitchen Food Waste
MENA	Middle East and North Africa
NFE	Nitrogen-Free Extract
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RFW	Restaurant Food Waste
RtFW	Retail Food Waste
UK	United Kingdom
UN	United Nations
VW	Vegetable Waste

CHAPTER I

INTRODUCTION

Along food supply chains, food moves from a primary producer to an end consumer progressing from harvesting, production, handling, processing, distribution and retailing to plate. During this progression, food is lost or wasted as a result of various technical, economic and/or societal reasons specific to each stage of the supply chain. Defining “food loss” and “food waste” has been a subject of debate among experts in the field. Based on definitions provided by the United Nations (UN) Food and Agriculture Organization (FAO), both food loss and food waste, together called food wastage, refer to the edible parts of a plant and/or animal products which are ultimately not consumed by people (FAO, 2016). Food loss is often the unintended outcome of managerial and technical limitations, such as improper handling, storage, infrastructure and/or packaging, in addition to inefficient marketing systems, and typically occurs at the early stages of the food supply chain (FAO, 2016). Examples include fruits bruised during picking, food degraded by pests during storage, food spills during processing and/or packaging, etc. Food waste, on the other hand, represents a deliberate decision to throw away food (FAO, 2016). It occurs primarily, but not exclusively, at the retail and consumption stages, and its scale is mostly influenced by consumer values and behaviors. Some examples include food not meeting atheistic standards and purchased or cooked food that is not eaten.

Approximately 32% by weight of global food production equivalent to 1.3 billion tons are lost or wasted every year (FAO, 2017). The scale of food wastage and its sources vary across regions. Food wastage is around 61 million tons/year in the United States, 92.4 million tons/year in China, 102.5 million tons/year across the

European Union and 4 million tons/year in Australia (Girotto et al., 2015). Cultural customs, income, industrialization and development status contribute to this variation. In the Arab world, cultural customs entail the preparation of excessive quantities of food in most social events to show generosity, wealth and social status; however, much of this food ends up wasted (Abiad and Meho, 2018). Developing countries lose 40% of their food during post-harvest operations mainly because of technological limitations and improper storage and handling (Girotto et al., 2015; Lipinski et al., 2013), whilst in developed countries 40% of food waste is generated at the retail and consumer stages because of overconsumption and unmet quality expectations (Girotto et al., 2015; Lipinski et al., 2013). However, it should be noted that almost all urban settings, whether located in developed or developing countries, experience significant levels of food waste. In fact, cities in developing countries may generate greater amounts of food waste than more advanced urban centers mainly because of poor infrastructure (Lipinski et al., 2013).

In 2007, the cost of global food wastage was roughly $750 billion. By 2012, that number became around $2.6 trillion (Papargyropoulou et al., 2014; FAO, 2014). These losses fall under three major categories: economic, environmental and social losses amounting to $1.1 trillion, $696 billion and $882 billion, respectively (FAO, 2014). Economically, food wastage represents the lost value of useful products which results in significant economic losses for actors in the food value chain. In Sub Saharan Africa for example, post-harvest losses reach $4 billion per year while average daily earnings are around $2 or less for many farmers (Lipinski et al., 2013). For a family of four in the United States, the cost of food waste is on average $1,600 per year (Lipinski et al., 2013). In the United Kingdom, the cost of food waste is £200 per year (around

$256 per year) for the average person and £700 per year (around $898 per year) for a family with children (Environment, Food & Rural Affairs Committee, 2017).

From an environmental perspective, food wastage represents a waste of resources, such as land, water, fertilizers, and energy, to produce food that will ultimately not be consumed. To grow this lost and wasted food, around 198 million hectares of cropland, 173 billion cubic meters of water and 28 million tons of fertilizers are exhausted annually (Lipinski et al., 2013). Food wastage is also responsible for significant quantities of greenhouse gas (GHG) emissions. In fact, if food wastage could be represented as a country, it would be the third-largest emitter of greenhouse gases after China and the United States (FAO, 2011).

Food wastage also has serious implications for food security. It is estimated that the total amount of food wastage generated every year is enough to feed more than four times the 800 million people who suffer from hunger (FAO, 2013). The social impact of food wastage is also linked to livelihood losses. For example, if food produced by a farmer gets degraded due to improper storage, weather conditions or pests, then it would have to be sold at lower prices or even discarded, thus adversely affecting the livelihood of said farmer. Food wastage also decreases the availability of food on the market, which may in turn cause food prices to rise and food-purchase capacity of low-income consumers to drop.

To mitigate food wastage along with its impacts, the United States Environmental Protection Agency (US EPA) proposed the food recovery hierarchy actions which include, from highest priority to lowest, source reduction, rediverting for human consumption, use as animal feed, industrial uses, composting and at the lowest priority landfill and incineration. The top levels of this hierarchy are the most preferred ways to prevent and divert wasted food since they are most beneficial for the environment, society and the economy with the conversion to animal feed ranking as the third-most preferred (US EPA, 2017). Not only does recovering food loss and food waste as animal feed address challenges of food wastage, it also provides means to meet growing food demands. By 2050, the demand for meat and milk, for example, is expected to reach 465 million tons and 1043 million tons; respectively (McMichael et al., 2007). However, urbanization, scarcity of natural resources and climate changes restrict agricultural growth. Moreover, commercial animal feeds made from grains are subject to price volatility, and their production reduces the availability of natural resources and accounts for around half of the GHG emissions associated with animal production (Sonesson et al., 2010, Steinfeld et al., 2006; Gardebroek et al., 2016).

Food losses and wastes represent an alternative, readily available and sustainable animal feed source that would simultaneously address both waste management and food security challenges. The present systematic review examines a collection of available literature found in Arabic, English, Japanese, Portuguese and Spanish to evaluate the feasibility of recovering food losses and wastes as feed for fish, pigs, poultry, rabbits, and ruminants while concurrently assessing related safety and logistical concerns. The work first identifies trends related to food wastage diversion into animal feed across various regions and supply chain stages, followed by an evaluation of nutritive attributes and treatment methods of food losses and wastes in addition to growth performance analysis of animals fed waste-based feeds. Finally, we provide an overview of some industrial practices and safety policies as practiced or recommended by a few global leaders in the field of recovered feeds.

CHAPTER II

METHODOLOGY

The present systematic review was performed according to applicable guidelines set by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement as well as by adapting methods described by Petticrew and Roberts (2008).

A. Search Strategy

The search, performed in fall 2018 and repeated in December 2019, was done using 10 bibliographic databases to ensure a broad coverage of available data on food loss and food waste diversion into animal feed. The databases include: Agricola (1900 – 2019), CAB Direct (1915 – 2019), Directory of Open Access Journals (1928 – 2019), Embase (1947 – 2019), Food Science and Technology Abstracts (1969 – 2019), Scopus (1823 – 2019), ISI Web of Science (1900 – 2019), Conference Proceedings Citation Index – Science (1900 – 2019), e-Marefa (1991 – 2019) and Iraqi Academic Scientific Journals (2005 – 2019). Other documents were located through citation tracking, following reference lists of key articles and online exploration using Google search engine. Search terms were identified through collaborative effort and centered around two key terms:

i. Food wastage: food waste(s), food wastage, food loss(es), kitchen waste(s), leftovers, plate waste(s), wasted food, organic waste(s), restaurant food waste(s), catering food waste(s), hospital food waste(s), vegetable waste(s) and fruit waste(s);

AND

ii. Animal feed: feed(s), animal feed(s), animal feeding and animal feeder(s)

Various permutations of the two key terms in all fields, excluding full-text, were used to maximize the extraction of relevant publications. “NOT” terms were also used to exclude irrelevant studies investigating food loss and food waste utilization in applications other than animal feed, such as methane production, ethanol production, fermentation products, biofuel, biogas, aerobic digestion, anaerobic digestion, composting and vermicomposting. Additionally, a complimentary search for gray literature was performed in Google Scholar for articles that included food wastage and animal feed, animal feeding or any mention of meat-producing animal species (cattle, sheep, goats, poultry, pigs, rabbits or fish) in the title field.

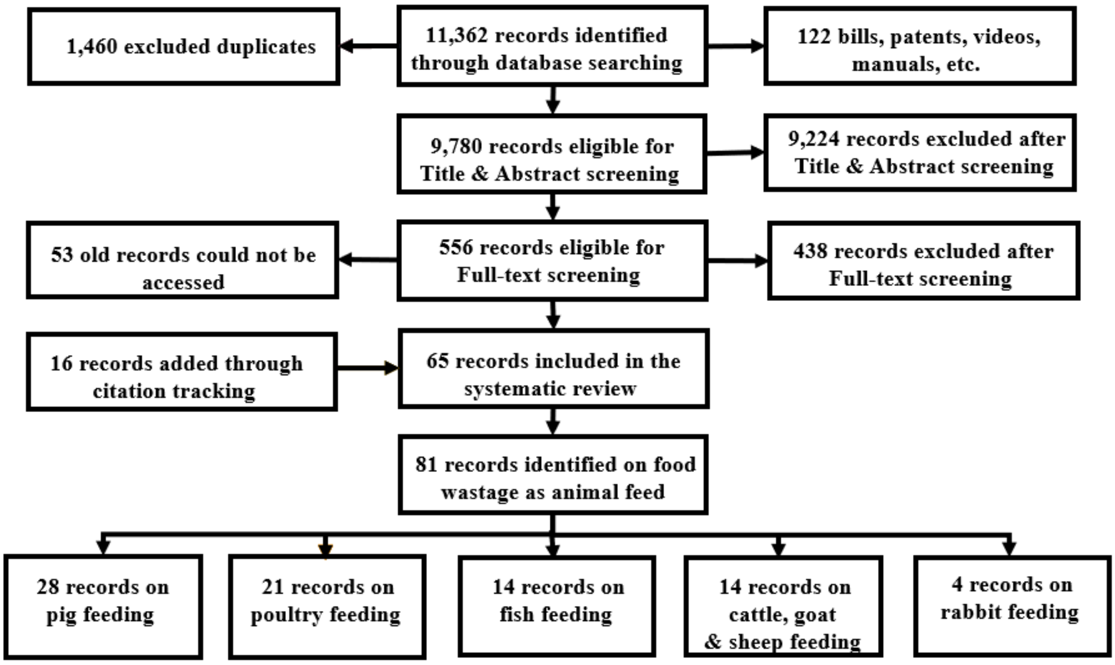
The search was not limited to a specific time frame but included all years starting from the establishment year of each database up to 2019. There was no restriction on the publication language. Retrieved studies written in Arabic, English, Japanese, Portuguese, Spanish and other foreign languages were all assessed. Language assistance was referred to when needed. The search targeted journal articles, books, theses and dissertations, and gray literature. Both indexed and non-indexed journals were included in the present review to ensure that important literature was not overlooked. However, bills, patents, videos, manuals, book reviews, announcements, notes, editorials, and commentaries were excluded.

B. Inclusion Criteria and Selection Process

Studies selected for inclusion in the present review were those involving: (a) animal feed incorporating food waste and/or food loss, (b) animal feeding experiments reporting on growth performance and feed conversion ratio (FCR) and (c) meat-producing animals, including: cattle, sheep, goats, poultry, pigs, rabbits or fish.

After removing duplicates, bills, patents, manuals, and other excluded publication types, a two-tier screening approach based on the above inclusion criteria was used to assess the relevance of the remaining 9,780 studies (Figure 1). To convey additional rigor to the systematic review process, two researchers examined each title, abstract and the full-text. A title and abstract screening was first performed through which 9,224 irrelevant studies were identified and removed. This was followed by a full-text screening of the remaining 556 studies. However, 53 studies that may have been relevant could not be accessed because they were unavailable through the Document Delivery Services (DDS) and the Interlibrary loan at the American University of Beirut. Accordingly, 503 manuscripts were examined whereby 438 irrelevant studies were excluded leaving only 65 relevant studies to be included in the present review in addition to 16 studies retrieved through citation tracking. Out of these 81 studies, 28 discussed pig feed, 21 discussed poultry feed, 14 fish feed, 14 ruminant feed, and four rabbit feed.

Figure 1 Flow chart of the search and selection process of studies on food wastage recovery as animal feed



C. Data Extraction

After performing a pilot test extraction, a data extraction sheet was designed whereby the following variables were identified: (a) language, (b) country, (c) year of publication, (d) type of publication, (d) animal-related information, including species and age, (e) food waste-related information, including type of food waste, nutritive attributes, processing method, levels of inclusion and optimum inclusion level, (f) experimental information, including sample size, replicates and duration of the experiment, (g) average daily growth (ADG) and (h) FCR.

CHAPTER III

RESULTS AND DISCUSSION

A. Trends

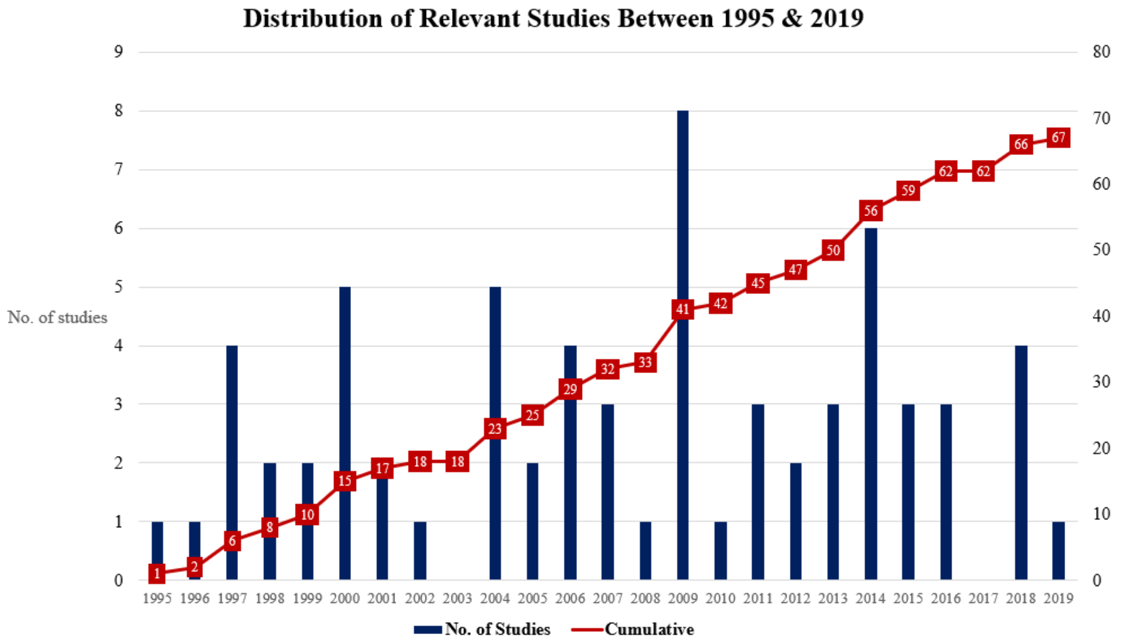
Relevant studies investigating food wastage recovery as animal feed were mainly in English (70 studies). Four relevant studies were found in Portuguese, four in Spanish, two in Japanese and one in Arabic. High impact research is often published in the new *lingua franca* which is English, which may explain the ample number of identified articles in English compared to those in other languages.

Relevant articles dating back to 1956 were found. Using food waste as animal feed has long been practiced in many parts of the world (Westendorf, 2000). However, between 1956 and 1994, a 38-year span, only 14 relevant studies were identified. The paucity of interest in this field could be linked to disease outbreaks associated with feeding uncooked or partially cooked food waste to animals particularly cattle and swine, to the Bovine Spongiform Encephalopathy (BSE) outbreaks of the 1980s, and to governmental legislation issued in response to these outbreaks. In 1980, for example, following the United States' struggle with hog cholera, vesicular exanthema, and foot-and-mouth disease, the country signed the Swine Health Protection Act that banned the use of untreated garbage as swine feed (Westendorf, 2000). The BSE outbreak in 1986, also known as "mad cow disease", significantly impacted global regulations on animal feed. The outbreak was first reported in the United Kingdom and was associated with feeding contaminated meat and bone meal to cattle (Sagiura et al., 2009).

Diverting home food waste to homegrown animals has been practiced for millennia. Even today, residents of rural areas grow chicken or swine and offer them waste food from homes and local restaurants. However, towards the end of the 20^{th}-

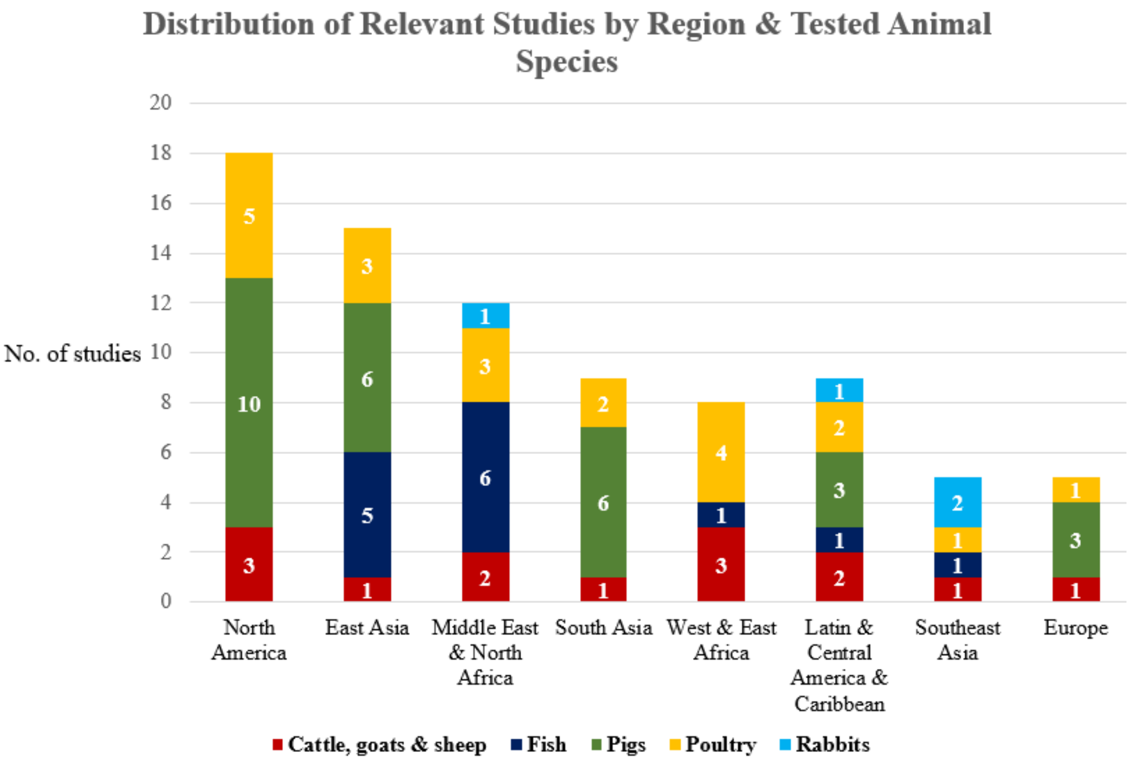
century interest in food waste diversion into animal feed on an industrial scale increased as food waste disposal became a more important matter of concern. Sadly, academic research into the growth performance of farm animals offered waste-based feeds remained limited (67 manuscripts between 1995 and 2019) (Figure 2).

Figure 2 Distribution of relevant studies on the recovery of food wastage as animal feed between 1995 and 2019



Relevant studies were found from various regions of the world (Figure 3). North America stood out as the most productive (18 articles) with a focus on pig feed. However, 12 out of the 18 studies from North America were published between 1956 and 1999. Recent publications on food-waste recovery as animal feed were mostly from South and East Asia, particularly from India (9 studies) (Nanthini et al., 2018; Kumae et al., 2014), South Korea (6 studies) (Lee et al., 2009; Paek et al., 2005), China (4 studies) (Cheng et al., 2016; Choi et al., 2016) and Japan (4 studies) (Bake et al., 2009; Iwamoto et al., 2005). Interest in recycled food waste into animal feed, especially fish feed, increased in the Middle East and North Africa (MENA) region with Saudi Arabia (4 studies) (Al-Shami & Mohammed, 2009; Al-Ruqaie, 2007), Lebanon (2 studies) (Nasser et al., 2018a; Nasser et al., 2018b) and Egypt (2 studies) (El Dasuqi et al., 2015; Soliman et al., 1978) being the most productive. Nigeria had the most publications in West Africa (7 studies) (Lawal et al., 2014; Adeyemo et al., 2013), which mainly concerned poultry and livestock feed manufacture. Relevant studies originating from Latin America were mostly performed in Brazil (5 studies) (Klinger et al., 2018; Silva et al., 2014). In Europe, there was a scarcity of studies on food waste recovery as animal feed (5 studies) (Marquez & Ramos, 2007; Kjos et al., 2000) probably resulting from food born disease outbreaks.

Figure 3 Distribution of relevant studies by region and tested animal species



Publication rates were highest in heavily populated countries, such as China and India, where food waste disposal and meeting food demands represent major concerns, and in those experiencing significant economic growth, such as Brazil (Table 1). A better economy would lead to improved incomes and purchase capacity, which would, in turn, raise food demand, especially animal protein. Additionally, greater consumption rates would result in more food waste generation, which means that implementing efficient food recovery pathways would become even more necessary. In Japan and South Korea, recovering food waste as animal feed has been a top priority of their waste management strategy, and has significantly decreased their dependence on imported animal feed (Sagiura et al. 2009).

Table 1: Distribution of identified studies across the various countries of the world according to tested animal species

Tested Animal	Country	Region	References
Fish	Brazil	Latin America	Silva et al. (2014)
	China	East Asia	Cheng et al. (2016); Choi et al. (2016); Cheng et al. (2015); Mo et al. (2014)
	Iraq	Middle East & North Africa	Hussien (2016)
	Japan	East Asia	Bake et al. (2009)
	KSA	Middle East & North Africa	Al-Ruqaie (2007); Belal & Al-Jasser (1997)
	Lebanon	Middle East & North Africa	Nasser et al. (2018a); Nasser et al. (2018b)
	Malaysia	Southeast Asia	Hamli et al. (2013)
	Nigeria	West Africa	Lawal et al. (2014)
	Tunisia	Middle East & North Africa	Azaza et al. (2009)
Pigs	Brazil	Latin America	Corassa et al. (2013)
	Canada	North America	McNaughtonet al. (1997)
	Cuba	The Caribbean	Gonzalez et al. (1984)
	India	South Asia	Nanthini et al. (2018); Kumar et al. (2014); Deka et al. (2011); Saikia & Bhar (2010); Kumar et al. (2009); Narayanan et al. (2009)
	Japan	East Asia	Iwamoto et al. (2005); Irie et al. (1990)
	Mexico	Central America	Ramírez-Zúñiga et al. (2014)
	Norway	Europe	Kjos et al. (2000)
	Poland	Europe	Migdal et al. (2000)
	South Korea	East Asia	Lee et al. (2009); Kwak & Kang (2006); Moon et al. (2004); Chae et al. (2000)
	Spain	Europe	Marquez & Ramos (2007)
	United States	North America	Jones et al. (2004); Altizio et al. (2000); Myer et al. (2000); Myer et al. (1999); Westendorf et al. (1998); Myer et al. (1997); Kornegay (1974); Engel et al. (1957); Heitman et al. (1956)
Poultry	Brazil	Latin America	Viana et al. (2006)
	Canada	North America	Farhat et al. (2001)
	Cuba	The Caribbean	Rodriguez & Ocampo (1989)
	Czech Republic	Europe	Al-Hiti & Rous (1978)
	Egypt	Middle East & North Africa	Soliman et al. (1978)
	India	South Asia	Kamlesh & Saraswat (1997); Sethi (1983)

Table 1: Distribution of identified studies across the various countries of the world according to tested animal species (continued)

Tested Animal	Country	Region	References
Poultry	Iran	Middle East & North Africa	Shahryar et al. (2012); Saki et al. (2006)
	Japan	East Asia	Ruttanavut & Yamauchi (2012)
	Malaysia	Southeast Asia	Hossein & Dahlan (2015)
	Nigeria	West Africa	Adeyemo et al. (2013); Eniolorunda et al. (2008); Ayanwale & Aya (2006); Longe (1986)
	South Korea	East Asia	Cho et al. (2004)
	Taiwan	East Asia	Chen et al. (2007)
	United States	North America	Saleh et al. (1996); Day & Dilworth (1968); Harms et al. (1966); Damron et al. (1965)
Rabbits	Brazil	Latin America	Klinger et al. (2018)
	Indonesia	Southeast Asia	Prawirodigdo & Yuwono (2004)
	KSA	Middle East & North Africa	Al-Shami & Mohammed (2009)
	Vietnam	Southeast Asia	Nguyen Huu et al. (2009)
Ruminants	Brazil	Latin America	Passini et al. (2001)
	Egypt	Middle East & North Africa	El Dasuqi et al. (2015)
	India	South Asia	Makkar et al. (1984)
	Indonesia	Southeast Asia	Retnani et al. (2014)
	KSA	Middle East & North Africa	Aldosari et al. (1995)
	Mexico	Central America	Enríquez-Palos et al. (2019)
	Nigeria	West Africa	Eniolorunda (2011); Eniolorunda et al. (2011)
	South Korea	East Asia	Paek et al. (2005)
	Spain	Europe	Chinea et el. (1999)
	Uganda	East Africa	Katongole et al. (2009)
	United States	North America	Walker et al. (2004); Walker et al. (2002); Walker et al. (1998)

Within and across the various regions, there was a disparity in the number of studies targeting each animal species (Table 1). This variation could be linked to differences in food consumption patterns across the globe. Swine feeding studies were performed on a variety of pig species, including Duroc, Hampshire, Landrace, and Yorkshire among others. These studies were most numerous probably because pigs are omnivores and thus easy to feed a mixture of nutrients as is typically found in wasted food. Furthermore, publications were dominantly from North and Latin America, Europe and South and East Asia doubtless because pork is very popular and profitable in these regions. In 2017, the per capita consumption of pork was 30.3 kg in China, 29.8 kg in South Korea and 23.1 kg in the United States (OECD, 2017). In the MENA region, pork consumption is restricted by Islamic and Judaic laws, and consequently, there is little interest in pig feeding.

Studies involving poultry nutrition using feed wastage were found from all regions (Table 1). In terms of global market share, poultry meat is the second most-consumed meat (13.8 kg/capita in 2015) after pork (15.3 kg/capita in 2015) (FAO, 2015). Poultry meat is highly nutritious, its price is highly competitive compared to other types of meat and there are no religious obstacles that hinder its consumption (Valceschini, 2006). Chickens were the main tested species in avian feeding studies (19 articles), with one study performed on each of ducks and geese

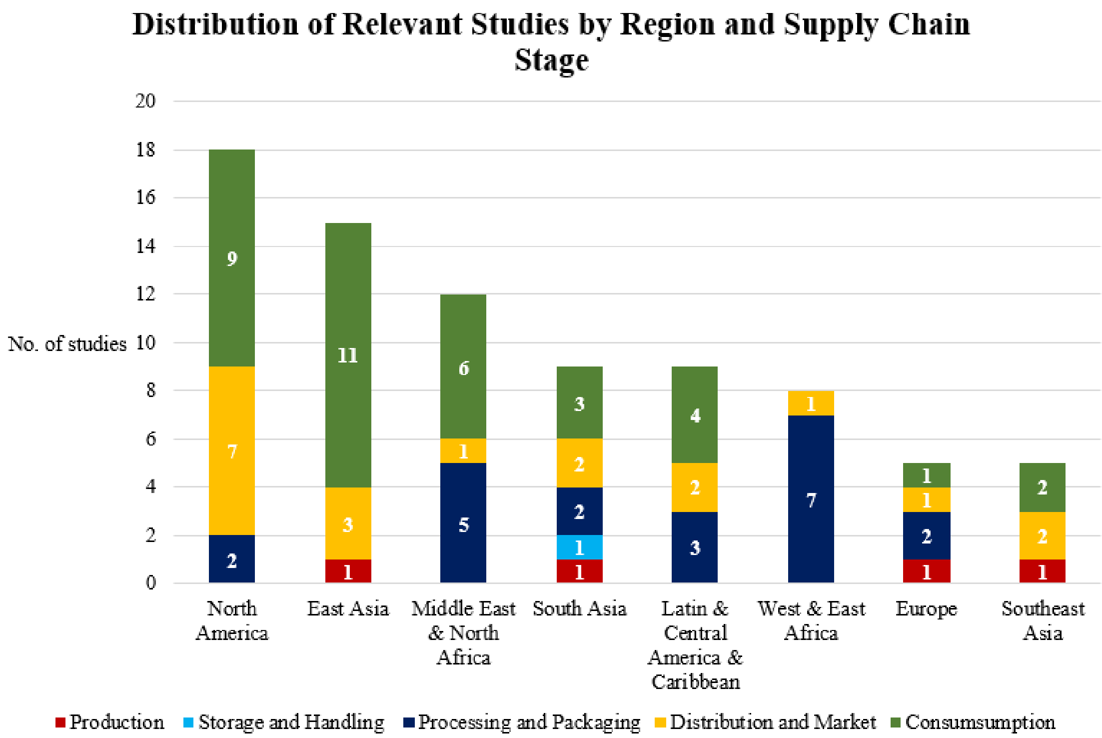
Identified studies on fish feeding originated mostly from East Asia and MENA (Table 1). In East Asia, the majority of relevant studies on aquaculture were published in China (4 studies). Fish protein has a very important role in China’s food security program. In fact, China accounted for 60.5% of global aquaculture production in 2015 (Mo et al., 2018). China relies on commercial fish feeds, commonly made from fishmeal and soybean meal, but these feeds can be quite expensive and fishmeal production has plateaued, which makes sustainability of feed ingredients a matter of concern. In many parts of the MENA region, governments have been taking initiatives to expand aquaculture to augment self-sufficiency and food security. The government of Saudi Arabia, for example, has invested $10.6 billion to expand annual aquaculture production up to 6 million tons by 2030 (Zawaya, 2017). However, reliance on imported commercial fish feeds might limit aquaculture expansion in the MENA region. Investigating locally available feed sources are thus becoming more pressing. Identified studies on fish feeding mainly targeted freshwater species, including Nile tilapia (7 articles), grass carp (4 articles), common carp (1 article), and African catfish (1 article). These fish species are omnivorous with fast growth rates and strong resistance to diseases (Azaza et al., 2006). Thus, they were excellent candidates for food waste feeding trials. Only one feeding study tested marine fish species: rabbitfish which tolerates high stocking densities and can accept artificial feed although algaevorous in nature (Nasser et al. (2018a).

Out of 14 identified studies on ruminant feeding, seven studies discussed sheep, five discussed cows, and two goats. Ruminant feeding experiments are scarce probably because unlike those on poultry and fish, they require the availability of large spaces to accommodate tested animals and have long experimental durations. For example, Walker et al. (2004) ran their experiment on cattle feeding for almost a year and a half.

Identified studies using human food waste for feeding rabbits were scarce (4 studies). Rabbits have sensitive digestive systems and cannot be offered meat products. They can only consume a small number of cereals and fruits otherwise their digestive system would become stressed. This limits their testing in food waste feeding trials since food waste is commonly a combination of various plant and meat products. Identified studies mainly tested White New Zealand rabbits.

Identified studies mainly focused on feeds from food waste generated at the consumption stage of the food supply chain (36 articles), and such studies were more numerous in developed regions, such as North America and East Asia (Figure 4). Feed made from food waste produced at the distribution and market stage was studied in 19 projects across all regions. In Africa, where food is mostly lost during the early stages of the supply chain, relevant studies primarily centered on food loss originating from the processing and packaging stage. There was a scarcity of articles on feeds made from food loss at the production (4 articles), handling, and storage stages (1 article). More attention ought to be given to the early stages of the food supply chain.

Figure 4 Distribution of relevant studies by region and supply chain stage



A variety of waste materials were tested in the identified studies. Forty-two articles (around 52% of the total retrieved studies) were performed on food waste collected from restaurants, cafeterias, hotels, households and/or retail stores (Hossein and Dahlan, 2015; Cho et al., 2007; Saki et al., 2006). Feed from these sources was generally a combination of plant and animal products and was used in pig (19 articles) (Ramírez-Zúñiga et al., 2014; Altizio, et al., 2000; Chae, et al., 2000), fish (10 articles) (Nasser et al., 2018a; Cheng et al., 2015; Mo et al., 2014), poultry (8 articles) (Adeyemo et al., 2013; Chen et al., 2007; Cho et al., 2004), and ruminant feeds (5 articles) (El Dasuqi, 2015; Paek et al., 2005; Walker et al., 2002). Around 21% of the identified studies tested biscuit and/or bakery wastes in poultry (7 articles) (Adeyemo et al., 2013; Shahryar et al., 2012; Saleh et al., 1996), pig (5 articles) (Iwamoto et al., 2005; Kumar et al., 2014; Corassa et al., 2013), ruminant (4 articles) (Enríquez-Palos et al., 2019, Eniolorunda, 2011; Eniolorunda et al., 2011; Passini et al., 2001), and rabbit diets (1 article) (Al-Shami and Mohammed, 2009). Bakery waste is a composite of bread, cookies, crackers candy, etc. whereas biscuit waste meal is mainly made from wheat flour, sugar, vegetable fat, skimmed milk powder, salt, ammonium bicarbonate, and butter. Use of fruit and/or vegetable waste as animal feeds were also common in ruminant (4 articles) (Retnani et al. 2014; Katongole et al., 2009; Chinea et al., 1999), rabbit (3 articles) (Klinger et al. 2018; Nguyen Huu et al., 2009; Prawirodigdo and Yuwono, 2004), pig (2 articles) (Migdal et al., 2000; Lee et al., 2009), and poultry feeding (2 articles) (Kamlesh and Saraswat, 1997; Sethi, 1983). Palm dates not meeting quality standards were also tested in fish (2 articles) (Azaza et al., 2009; Belal and Al-Jasser, 1997), lamb (1 article) (Aldosari et al., 1995), and poultry diets (1 article) (Al-Hiti and Rous, 1978). Three articles tested pasta or noodle waste in fish (2 articles) (Lawal et al., 2014; Silva et al., 2014) and poultry diets (1 article) (Eniolorunda et al., 2008). Other types of tested wastes included rejected cornflakes in poultry diets (Ayanwale and Aya, 2006) and rejected chocolate in pig diets (McNaughton et al., 1997).

B. Feasibility

The use of food wastage in animal feed was evaluated in terms of the wastes' nutritive attributes, the processing methods used to treat them, and the growth performance of animals offered these waste-based feeds. Reported nutritive attributes, including dry matter (DM), crude protein (CP), ether extract (EE; lipids), nitrogen-free extract (NFE; carbohydrates) and crude fiber (CF), along with optimal food loss/food waste inclusion levels and corresponding FCR values were obtained from the identified studies and summarized in Table 2. It should be noted that only studies reporting proximate compositions of the tested food waste prior to formulating experimental diets, i.e. before mixing it with other feed ingredients, were included in Table 2. Animal feeding results of the 81 retrieved studies can be found in Supplementary Tables 4-8.

Table 2 Major nutritional attributes of food loss/waste samples used in animal feeds, optimum loss/waste inclusion level and FCR values, as reported in literature

Reference	Country	Tested animal	Food loss/food waste	DM%		CP%		EE%		NFE%		CF %		Optimal inclusion level	FCR
				Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		
Azaza et al. (2009)	Tunisia	Fish	Date waste	92.9	-	2.4	-	0.3	-	85.5	-	2.1	-	30%	1.8
Bake et al. (2009)	Japan		RtFW-HFW-RFW	97.9	-	19.6	11.3	8.2	-	-	-	-	-	20%	1.5
Belal & Al-Jasser (1997)	KSA		Date waste	86.7	1.3	2.6	5.7	0.3	13.8	79.7	-	1.8	36.1	30%	1.2
Cheng et al. (2016)	China		HFW-RFW	93.2	0.1	31.1	10.8	13.3	13.6	-	-	5.7	-	53%	2.6
Hussien (2016)	Iraq		RFW-KFW	91.1	-	24.0	-	7.8	-	-	-	0.8	-	75%	3.1
Lawal et al. (2014)	Nigeria		Pasta waste	91.5	-	12.7	-	24.0	-	80.5	-	2.0	-	75%	0.9
Nasser et al. (2018a)	Lebanon		RFW	93.7	0.6	18.9	2.1	22.2	21.6	31.8	-	15.3	4.6	50%	2.03
Nasser et al. (2018b)	Lebanon		RFW	93.7	0.6	18.9	2.1	22.2	21.6	31.8	-	15.3	4.6	25%	1.1
Silva et al. (2014)	Brazil		Pasta waste	89.8	-	14.3	-	2.6	-	81.5	-	0.3	-	30%	2.5
Adeyemo et al. (2013)	Nigeria	Chickens	BiW	89.3	-	5.3	-	11.0	-	81.7	-	1.1	-	50%	2.5
Al-Hiti & Rous (1978)	Czech Republic		Date waste	95.2	-	8.1	-	1.8	-	-	-	9.1	-	10%	2.3
Chen et al. (2007)	Taiwan		KFW	87.6	2.4	15.8	3.4	16.0	3.2	-	-	10.8	1.1	5%	3.9
Cho et al. (2004)	South Korea		RFW	93.7	-	20.6	-	10.0	-	-	-	8.9	-	10%	3.3

CV: Coefficient of variation; DM: Dry matter; CP: Crude protein; EE: Ether extract; NFE: Nitrogen-free extract; CF: Crude fiber; FCR: Feed conversion ratio; CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; FrW: Fruit waste; HFW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste; VW: Vegetable waste;

Table 2 Major nutritional attributes of food loss/waste samples used in animal feeds, optimum loss/waste inclusion level and FCR values, as reported in literature (continued)

Reference	**Country**	**Tested animal**	**Food loss/food waste**	**DM%**		**CP%**		**EE%**		**NFE%**		**CF %**		**Optimal inclusion level**	**FCR**
				Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		
Damron et al. (1965)	US	Chickens	BW	93.1	-	8.3	-	13.7	-	-	-	0.9	-	10%	2.3
Eniolorunda et al. (2008)	Nigeria		Noodle waste	94.7	-	8.8	-	16.4	-	61.3	-	1.5	-	50%	1.9
Hossein & Dahlan (2015)	Malaysia		RFW	89.3	1.3	16.0	1.2	7.1	1.0	-	-	3.7	2.1	20%	3.5
Ruttanavut & Yamauchi (2012)	Japan		RtFW-RFW	82.1	-	15.8	-	-	-	-	-	2.0	-	20%	4.6
Shahryar et al. (2012)	Iran		BiW	92.0	-	12.6	-	4.1	-	-	-	2.6	-	24%	1.9
Sethi (1983)	India		FrW	-	-	6.9	-	1.9	-	-	-	-	-	12.6%	2.0
Viana et al. (2006)	Brazil		KFW	-	-	12.9	-	8.6	-	-	-	8.7	-	20%	3.0
Paek et al. (2005)	South Korea	Cows	KFW	85.3	1.5	20.1	6.0	9.1	16.8	-	-	9.7	21.7	50%	7.3
Walker et al. (1998)	US		CFW	46.1	20.8	29.4	24.6	15.8	20.5	-	-	-	43.2	50%	ADG 1.2kg/d
Walker et al. (2004)	US		RtFW	94.5	0.04	20.0	2.6	7.6	0.1	-	-	-	0.2	25%	ADG 0.7kg/d
Katongole et al. (2009)	Uganda	Goats	VW	28.7	0.8	8.3	0.5	-	-	42.0	1.26	-	-	82%	33.5
Altizio et al. (2000)	US	Pigs	RFW	96.1	-	13.2	-	8.9	-	-	-	-	-	32%	5.6

CV: Coefficient of variation; DM: Dry matter; CP: Crude protein; EE: Ether extract; NFE: Nitrogen-free extract; CF: Crude fiber; FCR: Feed conversion ratio; CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; FrW: Fruit waste; HFW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste; VW: Vegetable waste;

Table 2 Major nutritional attributes of food loss/waste samples used in animal feeds, optimum loss/waste inclusion level and FCR values, as reported in literature (continued)

Reference	Country	Tested animal	Food loss/food waste	DM%		CP%		EE%		NFE%		CF %		Optimal inclusion level	FCR
				Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV		
Chae et al. (2000)	South Korea	Pigs	RFW	-	-	25.0	0.8	17.3	16.7	-	-	-	-	20%	3.8
Deka et al. (2011)	India		KFW	23.1	-	14.1	-	7.1	-	60.6	-	4.2	-	-	3.8
Jones et al. (2004)	US		RtFW-CFW-RFW	89.7	-	17.8	-	-	-	-	-	-	-	20%	4.3
Kornegay (1974)	US		BW	-	-	9.5	-	11.0	-	-	-	2.3	-	24%	3.2
Kwak and Kang (2006)	South Korea		RFW	19.1	-	22.0	-	23.9	-	33.9	-	7.6	-	50%	3.5
Lee et al. (2009)	South Korea		FrW	93.6	-	19.5	-	11.3	-	-	-	6.2	-	4%	3.2
Myer et al. (1997)	US		RFW	88.6	-	15.0	-	13.8	-	-	-	10.3	-	40%	3.0
Myer et al. (1999)	US		RFW	91.6	-	14.4	-	16.0	-	-	-	14.5	-	40%	3.1
Myer et al. (2000)	US		RFW	92.1	-	22.4	-	23.2	-	-	-	2.3	-	40%	3.0
Narayanan et al. (2009)	India		BiW	84.5	-	8.7	-	10.2	-	64.2	-	0.3	-	-	3.2
Saikia & Bhar (2010)	India		KFW	-	-	19.1	-	11.0	-	59.5	-	4.4	-	-	3.4
Westendorf et al. (1998)	US		CFW	22.4	30.1	21.4	20.0	27.2	47.3	-	-	-	-	50%	3.4
El Dasuqi et al. (2015)	Egypt	Sheep	RFW-KFW	89.5	-	14.7	-	7.0	-	-	-	-	-	15%	6.9
Eniolorunda et al. (2011)	Nigeria		BiW	96.9	-	9.7	-	5.3	-	77.0	-	2.1	-	25%	5.0

CV: Coefficient of variation; DM: Dry matter; CP: Crude protein; EE: Ether extract; NFE: Nitrogen-free extract; CF: Crude fiber; FCR: Feed conversion ratio; CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; FrW: Fruit waste; HFW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste; VW: Vegetable waste;

Table 3 Descriptive statistics for nutritive attributes of food waste at retail and consumption stages and biscuit and bakery waste

	Food waste at retail and consumption stages					Bakery and biscuit waste				
	DM%	CP%	EE%	NFE%	CF%	DM%	CP%	EE%	NFE%	CF%
n	20	23	21	8	15	5	6	6	3	6
Minimum	19.1	12.9	7.0	32.3	0.8	84.5	5.3	4.1	64.2	0.3
Maximum	97.9	31.1	27.2	81.7	15.3	96.9	12.6	13.7	81.7	2.6
Mean	78.3	19.3	13.5	53.7	7.3	91.2	9.0	9.2	74.3	1.6
Median	89.6	19.1	11.3	59.5	7.6	92.0	9.1	10.6	77.0	1.6
SE	1.3	0.2	0.3	2.4	0.3	0.9	0.4	0.6	3.0	0.2
CV	34.1	25.4	46.1	36.0	61.2	5.1	26.2	40.3	12.2	58.8

DM: Dry matter; CP: Crude protein; EE: Ether extract; NFE: Nitrogen-free extract; CF: Crude fiber; Sample size: n; Standard error: SE

The mean values of each nutritional attribute for various food waste categories were pooled, and results are summarized in Table 3. On average, food waste collected at the retail and consumption stage, which usually contains plant and animal products, had 78.2% DM (SE 1.3%), 19.3% CP (SE 0.2%), 13.5% EE (SE 0.3%), 53.7% NFE (SE 2.4%) and 7.3% CF (SE 0.3%) (Table 2). This suggests that food waste collected at the retail and consumption stage is generally nutritious with a mean protein content (19.3%) almost double that of corn grain (8-10%). Bakery and biscuit wastes had on average a 91.2% DM (SE 0.9%), 9% CP (SE 0.4%), 9.2% EE (SE 0.6%), 74% NFE (SE 3%) and 1.6% CF (SE 0.2%) (Table 3). Vegetable wastes were high in fiber, which made them suitable for ruminant feeding. Palm date wastes generally had low protein and lipid content but were a good source of carbohydrates. Azaza et al. (2009) reported a date waste composition of 2.43% CP, 0.34% EE, 85.32% NFE and 2.12% CF.

The nutrient profile of food waste varied among sources (Tables 2 and 3). Compositions of post-consumer food waste were influenced by dietary traditions and geographical locations from which the food waste was collected. Food waste collected from traditional Lebanese restaurants, for example, had a much higher lipid and fiber content (22.2% EE and 15.3% CF) compared to restaurant waste collected in China (13.3% EE and 5.7% CF) or Iraq (7.8% EE and 0.8% CF). Although compositions of food waste are subject to seasonal variations, only a few studies assessed possible changes in the nutrient composition of food waste samples collected over a period of time (Kim and Kim, 2010). Waste processing methods might also change the nutrient profile of food waste. For example, heat treatment of food waste at 120^{o}C for 30 minutes using a rotating disk dryer resulted in a loss of nutrients compared to fermentation at 60-80 ^{o}C for 4 to 10 hours (Chen et al., 2015). However, the nutrient content of the resulting waste-based feed was adequate for animal feeding purposes using either of the said treatments (Chen et al., 2015). Accordingly, the extent that variation in nutrient content between heat-treated waste-based feeds and fermented waste-based feeds can have on animal growth performance might not be a major factor when choosing a wastage treatment method. The choice mainly hinges on variation in feed stability and safety resulting from various treatment methods, which are discussed in detail below A proper characterization of food waste variability and a cross-examination of nutrient profiles across various food waste treatment methods would be needed in order to integrate food wastage into commercial animal feeds. Often in developing nations, food waste is offered to swine and poultry as is. Feeds offered to fish have to be processed to improve the nutrient profile and water stability so it is technically more demanding. In all cases, if food waste is to be used in industrial farms, nutrient composition needs to be assessed by batch and the composition modified before being offered to livestock.

Three major food waste treatment methods were identified: wet-based methods, dry-based methods and fermenting/ensiling. Wet-based methods involve a simple heating step and result in high moisture feeds (70 to 80% moisture content). For example, Westendorf et al. (1998), reported cooking university cafeteria food wastes with steam at 100°C for around 4 hours. Wet-based feeds had the advantage of requiring minimal preparation. However, their shelf-life is generally limited to one or two days if not refrigerated and they are expensive to ship. Wet based feeds are thus good for local use. Kim and Kim (2010) reported that wet-based feeds were rarely transported any distance but rather were typically fed to animals at the same or proximate locations to the feed production sites. Dry-based methods involve drying food wastes to achieve a moisture content less than 20%. Dry feeds have a longer shelf life and a smaller bulk volume because of their low moisture content in comparison to wet feeds which makes them easier and less costly to store and transport. They are also easier to use in diet formulations. Choi et al. (2016) formulated a 75% food waste diet for carp by chopping food waste samples collected from hotels, removing their excess water through a squeezing machine, drying the mixture at 80°C for 6 hours to achieve a moisture content of 5 to 7% and grinding the dried mixture prior to mixing it with other feed ingredients, such as starch and fish meal and extruding. Jones et al. (2004) also reported grinding food waste mixtures collected from restaurants, cafeterias and retail stores, mixing and pelleting the mixture with other feed ingredients and then drying it in a fluidized bed dryer at 110 to 120°C for 4 to 7 minutes in order to formulate a 20% food waste diet for pigs. Finally, food waste treatment through ensiling (addition of microbial or yeast agents after heating/sterilizing) helped stabilize the feed mixture and prolong its shelf-life. For example, Moon et al. (2004) also reported aerobically fermenting kitchen food waste at 30 to 40°C for 24 hours using yeast, lactic acid bacteria, and *E. coli* after grinding the food waste and heating it to 140°C.

Substitution levels in commercial animal feeds of traditional ingredients by food wastes ranged from 10% to 100%. Substituting commercial feeds with various levels of food waste resulted in varying FCR values, calculated as the ratio of feed intake to weight gain. Optimum food waste inclusion levels correspond to lowest recorded FCR values for various substitution levels in each study, i.e. those that gave the best animal growth performance (Table 2 and Tables 4-8). Animal growth performance in response to various food waste substitution levels depended on the source and quality of tested waste ingredients, animal species and age, and length of the feeding trials. Optimal food waste inclusion levels in Nile tilapia diets were between 20% and 25% and resulted in FCR values of 1.5 (Bake et al., 2009) and 1.1 (Nasser et al., 2018b). Food waste collected from restaurants could substitute 20 to 50% of commercial pig feeds with FCR values ranging between 3.0 and 5.6 (Kwak and Kang, 2006; Altizi et al., 2000; Chae et al., 2000; Myer et al., 2000; Myer et al., 1999). Cho et al. (2004) and Saki et al. (2006) reported an optimal inclusion level of 10% household food wastes in poultry diets which resulted in FCR values of 3.3 and 2.3, respectively. Optimal inclusion levels of biscuit wastes were 25% in sheep diets (5.0 FCR), 15% in pig diets (1.6 FCR) and 24% in poultry diets (1.9 FCR) (Corassa et al., 2013; Shahryar et al., 2012; Eniolorunda et al., 2011). Breadcrumbs could be utilized at 15% in rabbit diets to achieve an FCR value of 3.8 (Al Shami and Mohammed, 2009). When tested animals were fed commercial animal feeds, FCR values were typically 1.8 to 2.0 for chickens (Hossein and Dahlan, 2015), 1.0 to 1.5 for Nile tilapia (Nasser et al., 2018), 2.5 to 3.0 for rabbits (Nguyen Huu et al., 2009), 3.8 to 4.5 for pigs (Saikia and Bhar, 2010) and 4.0 to 5.0 for sheep (Walker et al., 2002). Reported FCR values of waste-based feeds were thus comparable to FCR values obtained when feeding animals traditional commercial diets. Several studies reported no significant differences in growth performance between animals fed experimental and control diets (Kwak and Kang, 2006; Myer et al., 1999).

C. Safety Policies

Untreated food waste could contain disease-causing bacteria and viruses. This was demonstrated by the foot-and-mouth disease outbreak in the UK in 2001 that resulted from feeding uncooked food waste to pigs (Ermgassen et al., 2016). That same year, the UK government banned the use of food waste in animal feeding, and a year later the EU followed suit by also issuing a ban on the use of food waste in animal feeding . The ban does not apply to food wastes that are not contaminated with meat, fish and other animal products (Ermgassen et al., 2016). These types of wastes, however, are limited to certain manufacturing byproducts and represent a small proportion of EU food wastes. However, as mentioned previously, appropriate heat treatments can render recovered feeds safe for animals by deactivating the potentially harmful bacteria and/or viruses that might be found in these types of feeds. Moreover, when offering the animals leftover human food, the disease issue is not relevant because specifications for human food are more stringent in general than for animal feed. Unfortunately, current EU bans restrict recycling food waste as animal feed, allowing the recovery of only 3 million tons of manufacturing food losses as animal feed out of the 102.5 million tons of food wastes produced in the EU annually (Ermgassen et al., 2016). Hopefully, with more rigorous scientific data, the ban will be lifted.

Unlike the EU, many countries in East Asia actively promote the inclusion of food loss and food waste into animal diets. In 2006, Japan and South Korea recycled 52.5 and 42.5% of food waste as animal feed, respectively (Ermgassen et al., 2016). In these countries, manufacturing feed from food losses and wastes, designated as Ecofeed, is centralized, heavily regulated and only done in registered facilities. Under the “Promotion of Utilization of Recycled Food Waste Act”, introduced in Japan in 2001, food wastage must be heated for a minimum of 30 minutes at 70°C in feed manufacturing facilities (Ermgassen et al., 2016). Household food wastes are currently not recycled as feeds in Japan since they might be contaminated with foreign objects, such as cutlery. Moreover, the use of meat wastes in cattle, goat and sheep diets is banned because of concerns about BSE. This disease has not been reported to affect fish, pigs or poultry (Ermgassen et al., 2016). Unlike Japan, South Korea permits the diversion of household food wastes into animal feed; wastes are first screened for potential contaminants before being heat-treated (Kim et al., 2011). Under the “Control of Livestock and Fish Feed Act” in South Korea, manufacturing wet-based feeds involves sterilizing food losses/wastes by heating to no more than 80°C and then mixing them with corn or rice husks to standardize moisture content to 70-80% (Kim et al., 2011). Pig dry-feed waste is sterilized and dried using air at 390°C (Kim et al., 2011).

It is difficult to determine whether the risk of animal disease outbreaks actually decreases if policies ban (EU policy) or regulate (Japan/South Korea policy) food waste use in animal feeds. Although the EU banned using food waste in animal feed, potentially illegal feeding occurs in smallholder farms under current "low-risk" legislation (Ermgassen et al., 2016). A survey of smallholder farms in the UK in 2015 indicated that 24% of respondents fed uncooked household wastes to their pigs (Gillespie et al., 2015), yet reports of disease outbreaks are not present nor do we believe they are imminent.

D. Logistical Concerns and Industrial Practices

Most presently identified feeding studies omit discussion of logistical concerns of integrating recycled food wastes into animal feeds on an industrial scale. Instead, they tended to focus on pilot-scale laboratory experiments. Examining geographical locations of producers, feed-recovery facilities and potential buyers and consumer acceptance as well as investigating collection and handling processes of food losses and wastes prior to reaching feed-recovery facilities would be essential for the commercial utilization of recycled feeds in livestock and/or fish diets. The geographical spread and high moisture content of food waste, especially consumption-stage food waste, would require efficient and timely collection, transportation and handling processes to ensure safety and cost-effectiveness. Such optimal processes require advanced logistics tools and GIS-based digital mapping. These are usually the remit of engineers rather than biologists and collaboration among fields of study is still lacking.

Existing industrial feed-recovery facilities generally differ in their methods of operation, such as the types of food waste they can process, the feed drying methods that they use and whether or not they accept packaged goods that require an additional sorting step prior to processing. In 2007, there were 171 registered feed-recovery facilities in Japan, and each facility accepted a specific type of food wastage. For example, 55 facilities processed food waste, 30 handled expired food from retail stores, and 22 treated milk, fish and other animal products (Sugiura et al., 2009).

An array of processing methods could be used to prepare reliable and consistent animal feed from food losses and/or wastes. Ogino et al. (2007) reported three distinct processing methods used in three feed-recovery facilities in Japan, including drying food waste by steam-heated with natural gas, drying by frying under low pressure, and flash vacuum drying using energy from heavy oil and waste heat. Cooking and drying are usually the processes that require the most energy but are also the sections most easily performed using renewable green energy.

CHAPTER IV

CONCLUSION

Animal feeding studies identified in the present systematic review suggest that food losses and wastes are generally nutritious, can be converted into safe feeds by modern technologies and can be partially incorporated in animal diets without compromising animal growth performance. Future research should address the variability in the nutrient profile of food losses and wastes through systematic sampling procedures and comprehensive nutrient analyses. The information generated would be critical in enabling commercial integration of waste-based animal feeds in precision-feeding regimes. In addition to nutrient variability, logistical concerns of waste collection, transport and handling represent the most challenging aspects of industrial production of recovered feeds.

APPENDIX

DETAILED SYSTEMATIC REVIEW RESULTS

Table 4: Cattle, sheep and goat feeding results, as reported in literature

Reference	**Country**	**Animal**	**Food loss/ food waste**	**Supply chain stage**	**Processing method**	**Duration (days)**	**Optimum feed inclusion level**	**FCR at optimum level**
Aldosari et al. (1995)	KSA	Lambs	Discarded dates	Processing & Packaging	Grinding-Soaking-Drying	63	30%	6.95
El Dasuqi et al. (2015)	Egypt	Lambs	RFW-KFW	Consumption	Drying-Grinding-Pelleting	56	15%	6.86
Chinea et el. (1999)	Spain	Goats	Discarded bananas & banana rachises	Production	Ensiling	17 weeks	10%	6.05
Eniolorunda (2011)	Nigeria	Rams	BiW	Processing & Packaging	Sun drying-Milling	84	25%	5.01
Eniolorunda et al. (2011)	Nigeria	Rams	BiW	Processing & Packaging	Sun drying-Milling	84	25%	5.03
Enríquez-Palos et al. (2019)	Mexico	Lambs	BiW	Processing & Packaging	-	60	7%	4.27
Katongole et al. (2009)	Uganda	Goats	VW	Market	Chopping-Sun drying	100	82% sweet potato vines	33.5
Makkar et al. (1984)	India	Buffalo calves	Discarded potatoes due to cold storage	Handling & Storage	-	140	6 kg potato waste with 50g groundnut	8.52

FCR: Feed conversion ratio; ADG: Average daily growth (kg/d); CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste; Vegetable waste: VW;

Table 4: Cattle, sheep and goat feeding results, as reported in literature (continued)

Reference	Country	Animal	Food loss/ food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Paek et al. (2005)	South Korea	Steers	KFW	Consumption	Grinding-Dehydrating	547	50%	7.3 for 6 to 12 months - 12.4 for 13 to 24 months
Passini et al. (2001)	Brazil	Steers	BW	Market	Grinding-Pelleting	120	10%	4.76
Retnani et al. (2014)	Indonesia	Sheep	VW	Production	Chopping-Drying-Pressing-Heating-Forming	56	100%	ADG:2.27 kg/d
Walker et al. (2004)	US	Cows	RtFW	Market	Grinding-Pelleting	143	25%	ADG: 0.69 kg/d
Walker et al. (2002)	US	Lambs	CFW	Consumption	Pulping-Extruding	21	-	T1: 4.17; T2: 9.09
Walker et al. (1998)	US	Cows	CFW	Consumption	Pulping	T1: 99; T2: 190; T3: 225	50%	ADG: T1:1.07; T2: 1.02; T3: 1.16

FCR: Feed conversion ratio; ADG: Average daily growth (kg/d); CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste; Vegetable waste: VW;

Table 5: Fish feeding results, as reported in literature

Reference	Country	Species	Food loss/food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Al-Ruqaie (2007)	KSA	Nile tilapia	Bread waste-fish market waste	Market	Drying-Grinding-Extruding	56	52% with vitamins	1.88
Azaza et al. (2009)	Tunisia	Nile tilapia	Discarded dates	Processing & Packaging	Pitting-Drying-Grinding	75	30%	1.8
Bake et al. (2009)	Japan	Nile tilapia	RtFW-HFW-RFW	Market-Consumption	Fry cooking-Grinding	70	20%	1.46
Belal & Al-Jasser (1997)	KSA	Nile tilapia	Discarded dates	Processing & Packaging	Pitting-Drying-Grinding	63	30%	1.19
Cheng et al. (2016)	China	Grass carp	HFW-RFW	Consumption	Chopping-Drying-Grinding-Pelleting	56	53%	2.62
Cheng et al. (2015)	China	Grass carp	HFW-RFW	Consumption	Chopping-Pressing-Drying-Grinding-Pelleting	365	75% cereals	0.28
Hamli et al. (2013)	Malaysia	Nile tilapia	KFW	Consumption	Fermentation-Filtration	84	0.05%	mean weight gain:22.435g
Lawal et al. (2014)	Nigeria	African catfish	Discarded pasta	Processing & Packaging	Crushing-Milling	56	75%	0.88
Mo et al. (2014)	China	Grass carp	HFW	Consumption	Chopping-Drying-Grinding-Pelleting	183	35%	2.02
Silva et al. (2014)	Brazil	Nile tilapia	Discarded pasta	Processing & Packaging	Drying-Milling-Pelleting	50	30%	2.5
Choi et al. (2016)	China	Grass carp	HFW	Consumption	Chopping-Drying-Grinding-Pelleting	35	53% cereals	1.88
Hussien (2016)	Iraq	Common carp	KFW-RFW-slaughterhouse wastes	Consumption	Drying-Grinding-Pelleting	365	75%	3.13
Nasser et al. (2018)	Lebanon	Nile tilapia	RFW	Consumption	Grinding-Drying-Milling-Extrusion-Drying	56	25%	1.1
Nasser et al. (2018)	Lebanon	Nile tilapia	RFW	Consumption	Grinding-Drying-Milling-Extrusion-Drying	56	50%	2.03

FCR: Feed conversion ratio; HDW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste;

Table 6: Pig feeding results, as reported in literature

Reference	Country	Food loss/ food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Altizio et al. (2000)	US	RFW	Consumption	Milling-Pelleting-Fluidized bed drying	14	32%	5.6
Chae et al. (2000)	South Korea	RFW	Consumption	Drying-Milling	T1: 38 - T2: 43	T1 & T2: 20%	T1: 3.04– T2: 3.75
Corassa et al. (2013)	Brazil	BiW	Processing and Packaging	No processing	21	15%	1.64
Deka et al. (2011)	India	KFW	Consumption	No processing	75	Fed *ad libitium*	3.75
Engel et al. (1957)	US	HFW-RFW	Consumption	Sorting-Cooking by steam-Grinding	66	Fed *ad libitium*	6.01
Gonzalez et al. (1984)	Cuba	KFW	Consumption	-	time to increase weight from 26 to 95 kg	50%	3.78
Heitman et al. (1956)	US	Residential garbage	Consumption	Sorting-Cooking by steam	83	Fed *ad libitium*	9.43
Irie et al. (1990)	Japan	Residential garbage	Consumption	Frying in oil or heating with steam	42	Fed *ad libitium*	-
Iwamoto et al. (2005)	Japan	Breadcrumbs	Market	Reduced pressure drying	time to increase weight from 67 to 110 kg	50%	4.54
Jones et al. (2004)	US	RtFW-RFW-CFW	Market-Consumption	Grinding-Pelleting-Fluidized bed drying	42	T1 & T2: 20%	T1: 4.3– T2: 4.7
Kjos et al. (2000)	Norway	RFW-BW	Consumption	-	91	60%	1.91
Kornegay (1974)	US	BW	Market	Drying	time to increase weight from 15.38 to 53.48 kg	24%	3.15

FCR: Feed conversion ratio; CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; HFW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste;

Table 6: Pig feeding results, as reported in literature (continued)

Reference	Country	Food loss/ food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Kumar et al. (2014)	India	Bread waste	Market	No processing	91	50%	4.41
Kumar et al. (2009)	India	KFW	Consumption	-	238	100%	-
Kwak & Kang (2006)	South Korea	RFW	Consumption	Grinding-Fermentation-Drying	56	50%	3.5
Lee et al. (2009)	South Korea	Dropped apples	Production	Fermentation-Pelleting-Drying	133	4%	3.22
Marquez & Ramos (2007)	Spain	RtFW	Market	Mincing-Drying-Pelleting	84	17%	2.86
McNaughton et al. (1997)	Canada	Chocolate discarded during quality control	Processing & Packaging	Milling-Pelleting	111	30%	2.94
Migdal et al. (2000)	Poland	Discarded peanuts during sorting, toasting & packing	Processing & Packaging	Cooking in peanut oil-Cooling	55	10%	-
Moon et al. (2004)	South Korea	KFW	Consumption	Grinding-Heating with steam-Fermentation	terminated when target weight was achieved	Fed *ad libitium*	3.16
Myer et al. (2000)	US	RFW	Consumption	Grinding-Pelleting-Drying	time to increase weight from 63 to 112 kg	40%	2.98

FCR: Feed conversion ratio; CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; HFW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste;

Table 6: Pig feeding results, as reported in literature (continued)

Reference	**Country**	**Food loss/ food waste**	**Supply chain stage**	**Processing method**	**Duration (days)**	**Optimum feed inclusion level**	**FCR at optimum level**
Myer et al. (1999)	US	RFW	Consumption	Grinding-Pelleting-Drying	time to increase weight from 63 to 112 kg (T1) & from 77 to 108 kg (T2)	T1: 40% - T2: 40%	T1: 0.34 – T2: 0.32
Myer et al. (1997)	US	RFW	Consumption	Grinding-Pelleting-Drying	time to increase weight from 63 kg to 112 kg	40%	2.98
Nanthini et al. (2018)	India	Candy waste	Processing & Packaging	-	84	15%	4.50
Narayanan et al. (2009)	India	BiW	Processing & Packaging	No processing	56	Fed *ad libitium*	3.18
Ramírez-Zúñiga et al. (2014)	Mexico	KFW	Consumption	Drying-Milling	22	100%	-
Saikia & Bhar (2010)	India	KFW	Consumption	-	time to increase weight from 13.2 kg to 53 kg	-	3.41
Westendorf et al. (1998)	US	CFW	Consumption	Cooking by steam-Cooling-Blending-Oven drying- Grinding	40	50%	3.4

FCR: Feed conversion ratio; CFW: Cafeteria food waste; BW: Bakery waste; BiW: Biscuit waste; HFW: Hotel food waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste;

Table 7: Poultry feeding results, as reported in literature

Reference	Country	Species	Food loss/food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Adeyemo et al. (2013)	Nigeria	Chickens	BiW	Processing & Packaging	-	56	50%	2.47
Al-Hiti & Rous (1978)	Czech Republic	Chickens	Discarded dates	Processing & Packaging	Pitting-Mash form for starter-Pelleting for finisher	49	10%	2.26
Ayanwale & Aya (2006)	Nigeria	Chickens	Rejected cornflakes	Processing & Packaging	Grinding	63	60%	-
Chen et al. (2007)	Taiwan	Chickens	KFW	Consumption	Grinding-Fermentation-Drying	112	5%	2.09 for 0-4 weeks -3.15 for 4-8 weeks -3.90 for 8-16 weeks
Cho et al. (2004)	South Korea	Chickens	KFW	Consumption	Fluidized bed drying	42	10% with 5% higher protein	3.31
Damron et al. (1965)	US	Chickens	BW	Market	Drying	56	10%	2.32
Day & Dilworth (1968)	US	Chickens	BW	Market	Drying	28	15%	1.53
Eniolorunda et al. (2008)	Nigeria	Chickens	*Indomie* noodle waste	Processing & Packaging	-	56	50%	1.9
Farhat et al. (2001)	Canada	Ducks	**Discarded granola bars-BW-noodle waste-canned food waste**-soy-bean curd -brewer's grains -Pogo waste-old peanuts-peanut skins	Processing & Packaging	Mixing-Grinding-Pelleting	63	100% for Pekin ducks-50% for Muscovy ducks	6.81 for Pekin ducks-11.47 for Muscovy ducks

FCR: Feed conversion ratio; BW: Bakery waste; BiW: Biscuit waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste;

Table 7: Poultry feeding results, as reported in literature (continued)

Reference	Country	Species	Food loss/food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Harms et al. (1966)	US	Chickens	BW	Market	Drying	28	10%	1.71
Hossein & Dahlan (2015)	Malayasia	Chickens	RFW	Consumption	Grinding-Soaking-Drying	63	20%	3.5
Kamlesh & Saraswat (1997)	India	Chickens-	Cauliflower waste	Production	Ensiling with cauliflower silage containing diets	140	30%	1.63
Longe (1986)	Nigeria	Chickens	BiW	Processing & Packaging	-	84	50%	2.56
Rodriguez & Ocampo (1989)	Cuba	Geese	KFW	Consumption	-	70	Fed *ad libitium*	2.0
Ruttanavut & Yamauchi (2012)	Japan	Chickens	RtFW-RFW	Market	Fermentation-Drying-Grinding	126	20%	2.367 for starter - 2.768 for grower - 4.593 for finisher
Saki et al. (2006)	Iran	Chickens	KFW	Consumption	Drying-Milling	42	10%	2.26
Saleh et al. (1996)	US	Chickens	BW	Market	Grinding-Drying	42	25%	1.436 for starter- 1.734 for finisher
Sethi (1983)	India	Chickens	Rejected banana	Market	Chopping-Fermentation-Drying	18	12.6%	1.98
Shahryar et al. (2012)	Iran	Chickens	BiW	Processing & Packaging	-	42	24%	1.89
Soliman et al. (1978)	Egypt	Chickens	RFW	Consumption	Drying-Grinding	70	50%	3.65
Viana et al. (2006)	Brazil	Chickens	KFW	Consumption	Grinding-Heating-Drying	42	20%	2.97

FCR: Feed conversion ratio; BW: Bakery waste; BiW: Biscuit waste; KFW: Household/kitchen food waste; RFW: Restaurant food waste; RtFW: Retail food waste;

Table 8: Rabbit feeding results, as reported in literature

Reference	Country	Species	Food loss/food waste	Supply chain stage	Processing method	Duration (days)	Optimum feed inclusion level	FCR at optimum level
Al-Shami & Mohammed (2009)	KSA	New Zealand White	Rejected dates-breadcrumbs	Processing & Packaging-Market	Milling-Blending with steam & molasses-Oven drying	40	15% breadcrumbs with 0% dates	3.83
Klinger et al. (2018)	Brazil	New Zealand White x Flemish Giant	Sweet potato vines	Market	Drying	46	15%	3.55
Nguyen Huu et al. (2009)	Vietnam	New Zealand White x local breed	Vegetable market waste	Market	No processing	56	86 g of cauliflower and water spinach with paddy rice	3.74
Prawirodigdo & Yuwono (2004)	Indonesia	New Zealand White x Flemish Giant	Fruit & vegetable market waste	Market	Sun drying-Grinding	35	10%	4.08

FCR: Feed conversion ratio;

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