Global Food Security xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Global Food Security

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

Food waste for livestock feeding: Feasibility, safety, and sustainability implications

Zhengxia Dou[a,*], John D. Toth[a], Michael L. Westendorf[b]

[a] Center for Animal Health and Productivity, University of Pennsylvania, School of Veterinary Medicine, Department of Clinical Studies, 382 West Street Rd., Kennett Square, PA 19348, USA

[b] Rutgers, The State University of New Jersey, School of Environmental and Biological Sciences, New Jersey Agricultural Experiment Station, 84 Lipman Dr., Rm. 213F, New Brunswick, NJ 08901, USA

ARTICLE INFO

Keywords:
Food waste
Sustainability
Climate footprint
Waste management
Animal feeding
Food security

ABSTRACT

Food waste is a matter intrinsically linked with the growing challenges of food security, resource and environmental sustainability, and climate change. In developed economies, the largest food waste stream occurs in the consumption stage at the end of the food chain. Current approaches for dealing with the wasted food have serious limitations. Historically, livestock animals had functioned as bio-processors, turning human-inedible or -undesirable food materials into meat, eggs, and milk. Contemporary treatment technologies can help convert the food waste into safe, nutritious, and value-added feed products. Recovering consumption-stage food waste for animal feeding is a viable solution that simultaneously addresses the issues of waste management, food security, resource conservation, and pollution and climate-change mitigation.

1. Introduction

Food waste is a matter intrinsically linked to food security. Globally, an estimated 1.3 billion tons of food for humans is lost and wasted each year (Gustavsson et al., 2011), enough to feed more than one billion people. Food waste is also a resource and sustainability issue. The processes of food production consume vast resources of land, water, energy, fertilizer and other inputs, meanwhile engendering environmental adversities, e.g. biodiversity and habitat loss, soil and water degradation, and greenhouse gas emissions. With food being wasted, the resources and environmental impacts are sacrificed in vain. To sustainably meet the growing food demand amid climate change and dwindling resources, enhancing the utilization of food produced and cutting down waste is a necessity (e.g. Foley et al., 2011).

Food waste occurs at every stage of the food system from farm to fork (Xue et al., 2017). In developed countries, the largest waste stream is generated at the end of the food chain, including consumer-facing businesses (supermarkets, grocery stores, distribution centers; restaurants; institutional food services) and homes. For example, estimates of annual food waste in the U.S. food system amount to 9.1, 0.9, and 47.2 million tons (Mt) on farms, in manufacturing industries, and at the consumption stage in the end, respectively (ReFED, 2016). The latter consists of 22.7 Mt in consumer-facing businesses and 24.5 Mt in homes (together referred to as consumption-stage food waste hereafter). Currently, consumption-stage food waste is largely destined to landfills in many developed economies. For example, roughly 3/4 of food waste in the U.S. ends up in landfills according to a U.S. EPA estimate (2016). There are growing efforts worldwide to lessen landfill burdens, with alternative options currently promoted including composting, anaerobic digestion, incineration, or feeding to livestock animals (Kim et al., 2011; U.S. EPA, 2016). Notably, none of the options directly address sustainable food security challenges, except for livestock feeding.

Recovering food waste for animal feeding (ReFeed) is a viable option that has the potential to simultaneously address waste management (landfilling), food security, and resource and environmental challenges. Livestock animals function as bio-processors for converting food materials that are either unpalatable/inedible or no-longer-wanted by humans into meat, eggs, and milk. This would concomitantly ‘spare’ feed grains and relevant resources and environmental burdens associated with the production of the feed grains. Historically, feeding food waste and food production residuals to livestock animals has long been practiced in many parts of the world (Westendorf, 2000). However, the age-old practice lost its popularity with the advent of intensive animal feeding operations, which now operate with precision feeding using feed grains such as maize and soybeans for maximum productivity (Banhazi et al., 2012). Today, as the society strives to sustainably feed

Abbreviations: FDF, feeds derived from food waste; ReFeed, recovering food waste for animal feeding

* Corresponding author.
E-mail addresses: douzheng@vet.upenn.edu (Z. Dou), jdtoth@vet.upenn.edu (J.D. Toth), michael.westendorf@rutgers.edu (M.L. Westendorf).

https://doi.org/10.1016/j.gfs.2017.12.003
Received 17 November 2017; Received in revised form 7 December 2017; Accepted 9 December 2017

the growing population while mitigating environmental damages, there is a renewed interest in reinvigorating the practice (e.g. Stuart, 2009). For example, food waste repurposing to animal feed is identified as one of the food waste recycling solutions in the U.S. (ReFED, 2016). In Europe, "re-legalization" of the use of food waste for pigs could reduce the cropland associated with European pork production by 1.8 million ha (zu Ermgassen et al., 2016b). Also, the FAO recently sponsored an e-conference to promote food waste treatment technologies and encourage government support and public outreach (Thieme and Makkar, 2016).

To evaluate ReFeed as a national and global strategy for simultaneously addressing sustainable food security as well as waste management challenges, a comprehensive analysis with science- and field-based evidence demonstrating the feasibility, safety, and sustainability implications is needed. The objective of this article is to perform such an analysis while identifying existing data gaps. The article first examines the nutritive attributes of food waste, animal performance in feeding trials, and methods of food waste treatment for feeding (Section 2). Next, a synthesis of relevant resource and environmental implications is provided (Section 3), followed by discussion of potential health/safety issues as well as case studies from selected countries (Section 4). Section 5 explores potential concerns and ways to address them. Finally, concluding remarks are presented in Section 6.

2. Feasibility

2.1. Overview and boundaries

Recently-published work on feeding food waste to livestock animals mostly originates from South Korea, Japan, Taiwan, India, and South American countries. Pig feeding dominates those studies, although other animal species have been tested as well, including poultry (Chen et al., 2007), beef and dairy cattle (Angulo et al., 2012; Paek et al., 2005), and small ruminants (Summers et al., 1980).

A variety of food waste materials, varying in source and type, have been used in feeding studies. These food wastes can be categorized into three major types: (i) manufacturing co-products/ byproducts, with typically uniform and known ingredients, e.g. wheat middlings, oilseed meals, etc., (ii) food preparation or processing refusals/residuals, such as those from large-scale bakeries or produce processing/packing facilities, (iii) a hodgepodge of wasted food from food service places (e.g. restaurants, cafeterias) or homes, with the content unpredictable. This article focuses on studies using the consumption-stage food waste for animal feeding. This is because manufacturing co-products/byproducts and food-processing refusals/residuals are already routinely used in animal feeding. For instance, in the United States, 10.9 Mt milling co-products, 30.4 Mt oilseed meals, and 2.5 Mt animal proteins, plus an estimated 27 Mt brewing and ethanol co-products are fed to livestock animals on an annual basis (Ferguson, 2016). This feeding practice is favored by economies of scale and predictability of quantity and quality of the byproduct materials. In fact, manufacturing byproducts are not included in the food waste estimates in the U.S. (ReFED, 2016). On the other hand, consumption-stage food waste, being the largest waste stream generated in the food chain, presents the greatest challenge. Its recovery and treatment for animal feeding has a tremendous significance, given its magnitude and the limitations of other management options.

2.2. Nutritive attributes of food waste

Results pooled from 23 trials (summarized in Table 1) in the literature had the means and coefficients of variation for major nutrition parameters in consumption-stage food waste samples as: dry matter 21.7% (CV 25.0%), crude protein 19.2% (24.5%), crude fiber 6.2%

Table 1
Major nutritional parameters of food waste samples for the purpose of livestock animal feeding, as reported in the literature.

Reference	Sample type	*n*	DM%		CP%		EE%		NFE%		Fiber%		Ca:P
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
Chen et al. (2007)	DFW	5	87.6	2.4	15.8	3.4	16.0	3.2	–	–	10.8	11.1	1.51
Chen et al. (2015)	Method 1	60	20.2	37.6	25.5	34.9	28.1	25.3	31.6	19.6	7.3	46.6	–
	Method 2	60	19.4	43.8	28.3	32.5	25.3	31.2	23.0	40.9	6.9	52.2	–
	Method 3	60	18.8	21.8	30.6	25.3	31.5	26.0	28.6	27.6	3.0	63.3	–
García et al. (2005)	Restaurant	28	39.6	18.7	27.5	23.3	28.8	29.5	26.9	49.1	2.3	47.8	–
	Household	34	33.1	32.6	16.3	29.4	11.3	35.4	41.8	33.5	12.4	62.1	–
Jin et al. (2012)	Restaurant	6	22.8	5.4	28.6	11.9	31.5	6.7	–	–	3.1	61.3	–
Kornegay et al. (1965)	Restaurant	30	16.0	28.3	15.3	24.1	24.9	33.0	50.7	18.3	3.3	42.6	–
	Institutional 1	28	13.7	23.7	13.9	23.2	11.6	57.0	67.4	10.6	2.8	53.1	–
	Institutional 2	30	21.4	11.3	15.3	14.1	17.8	27.5	57.8	11.1	2.8	28.9	–
	Military 1	28	27.5	24.1	15.6	22.5	34.0	31.3	41.9	16.8	2.9	48.3	–
	Military 2	28	23.8	11.7	16.3	21.3	30.0	24.8	45.7	16.7	2.7	23.7	–
	MSW	21	16.6	46.3	17.5	26.2	21.4	33.9	44.0	24.3	8.4	54.1	–
Kwak and Kang (2006)	Restaurant	–	19.1	–	22.0	–	23.9	–	33.9	–	7.6	–	–
Murray Martínez et al. (2012)	Restaurant	5	24.3	–	5.6	–	9.3	–	8.2	–	0.6	–	–
Myer et al. (1999)	Trial 1	–	11.4	–	15.0	–	13.8	–	–	–	10.3	–	1.59
	Trial 2	–	8.4	–	14.4	–	16.0	–	–	–	14.5	–	1.66
Paek et al. (2005)	Household DFW	–	85.3	1.5	20.1	6.0	9.1	11.0	–	–	9.7	21.6	–
Summers et al. (1980)	Institutional	–	24.3	48.4	18.9	57.0	16.9	63.8	–	–	–	–	3.33
	Household	–	21.0	23.0	16.1	24.6	16.9	52.1	–	–	–	–	6.67
	Restaurant	–	24.4	45.9	20.3	37.9	22.9	62.7	–	–	–	–	1.33
Westendorf et al. (1998)	Restaurant	36	22.4	30.1	21.4	20.0	27.2	47.3	–	–	–	–	0.84
Westendorf et al. (1999)	Restaurant, Institutional	63	27.0	19.3	20.8	27.5	26.3	30.4	–	–	–	–	1.44

Abbreviations:
DM: dry matter.
CP: crude protein.
EE: ether extract lipids.
NFE: nitrogen-free extract carbohydrates.
DFW: dried food waste.
MSW: food waste from municipal solid waste.