Review

Waste management to improve food safety and security for health advancement

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Economic growth inevitably influences the food chain. Growing demand with changes in lifestyle and health consciousness encourage use of packaged and pre-prepared foods. The needs of environmental protection from waste generated are largely overlooked, and a lack of knowledge about the impact on the environment and its health effects constitute food security/safety problems. Food production and waste generation directly affect resource (i.e., energy and water) consumption and often contaminate the environment. More pressure on food production has inculcated the use of pesticides, herbicides, antibiotics and chemical fertilizers which add to current global pollution. At least half of food grown is discarded before and after it reaches consumers. It is estimated that one third to half of landfill waste comes from the food sector. This landfill releases green house gases (GHG) as well as leachate which worsen soil and water quality and safety. Pharmaceutical and chemical contaminations from residential, industrial and agricultural sources make their way into nearby water and soil and can eventually affect our food systems. Phthalates, PFOA, BPA, commonly used in plastics and personal care products, are found in unacceptable concentrations in Taiwanese waters. They, too, contribute to food contamination and long-term health risk. Existing waste management strategies warrant more stringent norms for waste reduction at source. Awareness through education could reduce food waste and its consequences. This review encompasses impacts of food production systems on the environment, pollution which results from food waste, costs and economic advantages in food waste management, and health consequences of waste.

Key Words: food waste, human health, environmental contamination, food safety, waste management

INTRODUCTION

Modern technology and agricultural practices have been important in diminishing famine in the world. While we continue to increase food production to feed the growing global population, food insecurity is still prominent in many parts of the world.[1] Today over 800 million people worldwide live without access to sufficient and adequate food.[2,3] Factors contributing to this include socioeconomic disparities, intrinsic geography, climate, increasing food prices, growing urbanization, and inequality in food distribution. [4,5]

When famine and food scarcity became ubiquitous following World War II, regulations and subsidies such as the Common Agricultural Policy of the European Union helped to encourage crop growth that reached surplus.[1] As farmers perfected the tricks of the trade, small ranches expanded into corporate farms. It also became possible to grow crops in parts of the world where it had been previously impossible. Global economic growth further encouraged the overproduction of food, particularly in developed countries.

The problem now is that the entire food system is highly dependent on non-renewable energy and water supplies, both of which are depleting, as well as it is excessively wasteful.[1,4] Waste is generated through each phase of food production, and its environmental consequences are largely overlooked. They can come in the form of pesticides, green house gas (GHG) emissions, packaging and food scraps. Much of this waste goes to incinerators or landfills that are at or over full capacity, exacerbating problems with chemicals leaking into soil and water. Further, rotten food waste in landfills account for as much as 4% of the world's GHG, not to mention more emitted from animal slurry and farm waste.[6]

Food waste poses significant risks on food safety and security. The link is rarely acknowledged because food is often regarded as a disposable commodity in developed countries. Consequently, the long-term effects of food production become neglected. Policies often favour econ-

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omic growth in the food industry, rather than emphasize environmental protection and nutrition promotion.[7] According to the Waste and Resources Action Programme (WRAP), a third of the 21.7 million tons of food purchased in the UK is discarded annually.[8] In the United States, as much as half of the food grown there never gets eaten. American households waste 14% of purchased foods, 15% of which were unopened and did not reach the expiry date.[9] Particularly in developing countries in Africa, tons of food are trashed before it even reaches consumers due to lack of technology and infrastructure, insect infestation, microbial growth, damage, high temperatures and humidity.[10,11]

The role of waste management in promoting health warrants more attention. This review will cover the impacts of the food system on the environment, particularly the consequences of waste generation, as well as the environment's effect on food safety and security. Many of the adverse effects elicited by the environment were the result of anthropogenic activities. Several countries experiencing dwindling natural resources already understand that waste management and reduction are critical in securing sustainable food production and security.

THE EFFECTS OF FOOD PRODUCTION ON THE ENVIRONMENT

Water resources

Agriculture consumes 70% of the world's freshwater, most of which is used towards irrigated crops.[2,12] The problem is that it takes too much water to produce food that is ultimately wasted. It has been speculated that people waste more virtual water – water used to produce food – by trashing uneaten or spoiled food, than they use personally. While the average person will consume two or three litres a day, it takes 2,000-5,000 litres to produce the food they eat.[13] Changes are being made in agricultural practices to minimize water consumption. However, lack of awareness regarding the embedded costs of food production means food – and thus water – will continue to be wasted.

Still an undervalued commodity, water is used inefficiently to grow thirsty crops such as alfalfa in arid California. It takes twice as much water to grow wheat in India and Brazil than in China and United States.[13] Furthermore, pressure on water resources increases significantly as consumption of animal products increases. Depending on the type of animal and methods of rearing, meat production uses up 8-10 times more water compared to cereal production.[2,12] For example, 1 L milk requires 600 L of water to produce, while 1 kg butter requires 18,000 L of water.[14] While fruits and vegetables leave behind a lower water footprint than farm animals, there is growing demand to grow crops for animal feed rather than for consumers.[11,15] In an era when food prices threaten to continue rising, it is unacceptable to see 1.2 billion tons of fodder – staple foods such barley and corn – to fuel global meat consumption rather than subscribing to a more sustainable diet.[16,17]

The Stockholm International Water Institute (SIWI) has set the goal to reduce food wastage by 50% by the year 2525. By minimizing post-harvest losses during transport, handling and in the household, countries can reduce or even negate water needed to grow food and ensure food security in the future.[2,18]

GHG Emissions

Diet patterns are shifting worldwide. With global economic growth came the demand for higher protein foods, especially animal derived foods, of which consumption has increased more than two and a half times since 1970.[16] Aside from being more water intensive, production of animal derived foods also releases more GHG compared to plant based foods.[19-21] Different food items' GHG contributions depend on their production techniques, degree of processing, transportation mode and distances, presence of red meat, amount of nitrogen fertilizer used, manure application, and storage method.[19]

It has long been known that gases such as carbon dioxide (CO_2), methane, and nitrous oxide pose serious implications on climate change.[21] More and more evidence point towards the sustainability and environmental benefits of a plant-based diet. According to the Food and Agriculture Organization of the United Nations (FAO), the livestock industry contributes 18% of all anthropogenic GHG emissions in the world.[16,22] Proportionally speaking, beef and pork can produce 30 times more CO_2 emissions than other protein rich plant foods such as beans. Ruminants are the principal contributors to methane emission from enteric fermentation. Vegetables and fruits emit $\leq$2.5 kg CO_2 equivalents/kg product, but the amount becomes similar to that of meats if they are transported by plane.[19]

Regardless of the type of food, wasting it means that scarce resources were used and harmful emissions were created completely in vain. Diet preference can impact food production demands and consequently the environment. By choosing more plant-based foods, consumers can promote environmentally responsible agricultural practices.

Land degradation

Land degradation is a global concern that is largely associated with human activities such as poor farming practices. In order to grow more food, the environment pays significant costs through deforestation, soil nutrient depletion, livestock overgrazing, and soil compaction. In 2008, Brazil lost 12,000 km^2 of the Amazon rainforest mostly to grow cattle and soy to serve as animal feed for European markets.[16] In turn, biodiversity is replaced with vast monocultures that rely heavily on pesticide and fertilizer applications.

The advent of industrially produced fertilizers helped farmers to achieve more consistent and higher crop yields.[1] Manufacturing of fertilizers and burning of fossil fuels have increased reactive nitrogen creation by 120% since 1970.[23] Nitrogen-based fertilizers are necessary to grow food to feed the global population, however the process is far from efficient. Plants and animals have low uptakes of 10-15% for reactive nitrogen, where the remaining ends up in the environment.[24] Accumulation of reactive nitrogen in soil, water and the atmosphere contribute to the greenhouse effect, acid rain, coastal oceanic "dead zones" and stratospheric ozone depletion.[24] Such unsustainable agricultural practice has become a threat to our food systems.

The wide availability and high cost effectiveness of fertilizers has promoted its over application and, as a result, nutrient surpluses in many countries. While nutrient accumulation and environmental pollution occurs in developed countries, exports of nutrients are rapidly depleting reserves in developing countries. For example in sub-Saharan Africa (SSA), the nitrogen balance deficit has increased from -22 kg nitrogen ha^{-1}/yr in 1983 to -26 kg ha^{-1}/yr in 2000.[1] This exacerbates the already serious food security concerns in the region, where it is a challenge to grow calorie rich foods for local consumption.

If agricultural land is not managed in a more sustainable manner, food security can worsen as it becomes impossible to grow crops anywhere. Nutrients removed from soil by plants and animals ought to be replaced accordingly. In areas with nutrient surplus, developments to minimize nitrogen use and improve its uptake by crops and animals can alleviate the negative impacts on the environment. Further, agricultural waste management strategies can emphasize recovery and reuse of nitrogen from manure and sewage.[24]

THE EFFECTS OF FOOD WASTE ON THE ENVIRONMENT

Waste generation

As much as half of all food grown is lost or wasted before and after it reaches the consumer.[9-11] It has been estimated that one third to half of the waste in landfills comes from the food sector, one quarter of which could have been consumed.[25,26] In Taiwan, 31% of municipal solid waste are made up of food scraps (Figure 1).[27] The magnitude of food wastage is believed to be even more staggering in countries where overproduction of food is prominent. Not only is this highly prodigal, it also create problems with waste management as landfills reach full capacity.[28] As garbage decomposes in landfills, leachate can leak into

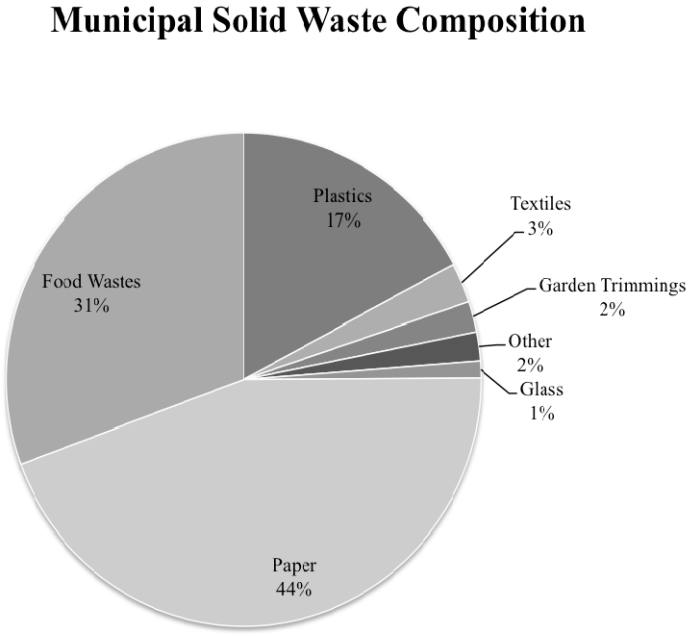

Figure 1. Municipal solid waste composition: Taiwan EPA and local environmental Protection Bureaus (2008)

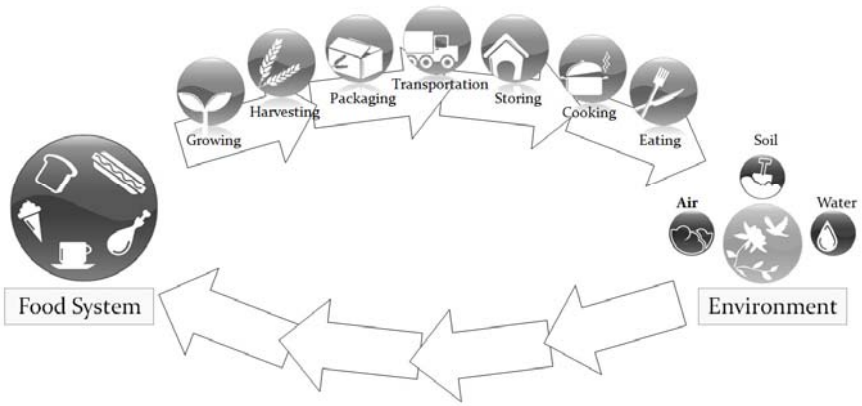

Figure 2. Waste can be produced through any one of several processes with health consequences

the soil and contaminate groundwater. Incinerating the trash can be problematic due to high moisture and salt content in the kitchen waste, which creates harmful compounds such as dioxins.[29]

The sheer volume of food waste is enough to severely impact the environment. Even more waste is created in the process of food production, from growing, harvesting, packaging, transporting, storing and cooking (Figure 2). The agricultural sector alone contributes enormously to global waste generation. In the US, 7 billion livestock produce 130 times more waste than the country's entire population.[21] If not treated properly, the generated waste can lead to food safety and public health problems. More remnants are left behind through farming, including chemical fertilizers, as described in Section 2.3, as well as pesticides, herbicides, and antibiotics. All these are human inputs that are eventually left behind in the system, contaminating the environment, and consequently the food that we eat.

Sources of chemical remnant are not limited to farms. We also create and throw away tons of packaging, many of which contain new materials that can be carcinogenic. Rubbish also inevitably ends up as flotsam in the ocean, such as in stretch between Hawaii and California. The accumulated trash from around the world can amount to a million pieces of plastic per square km, or 100 million tons of floating garbage. That amounts to as much as 112 times more plastic than plankton, an important link in the marine food chain.[6]

It is evident that the food system lacks efficiency in production and resource consumption. There is an urgent need to shift our focus from food production towards waste and resource management.

GHG emission

Food production is more efficient in developed countries; however the total amount wasted is also greater. This is a huge environmental concern that cannot be overlooked, since wasted food rotting in landfills creates potent GHG such as carbon dioxide, methane and nitrous oxide.[19,30] Compared to CO_2, the global warming potential of methane and nitrous oxide are 21 times and 310 times higher, respectively.[11]

Moreover, diet patterns can also alter the amount of GHG released through food production. Foods that produce the least GHG (<1 kg GHG production/kg food product) are plant based and unprocessed, whereas beef, cheese, and imported fruits (if transported by plane) emit the most (>8 kg/kg product). Beef and pork can produce 30 times more CO_2 than other protein rich foods such as beans.[11,19]

FOOD SAFETY AND HEALTH

Water contamination

Just as plant crops boom with the use of pesticides and herbicides, livestock farms often rely on antibiotics and hormones to increase food yield. In the case of animals, they are not always raised in ideal conditions that are healthy or sanitary. To minimize the spread of contagious diseases among the livestock, the use of antibiotics has become common agricultural practice.

This extensive use of human and veterinary medicines (i.e., antibiotics used in agriculture and aquacultures) resulted in ubiquitous occurrence of pharmaceuticals and estrogens in our surface waters. Recent research has found Taiwanese water streams to be contaminated with pharmaceutical contamination from residential, industrial and agricultural waste streams. This poses a serious health risk to the public, and is likely to cause pathophysiological complications.[31] With the increasing water scarcity issue, more and more degraded/recycled water resources are being used for various purposes despite the invisible risks. In the past, these compounds were not typically targeted when treating waste and sewage waters. However, with evidence on these emerging contaminants, waste water management must be modified to address current safety concerns. Water safety is an essential need for consumers and the food industry. Whether it is for drinking, farming or food processing, safe water is crucial in ensuring public health.

Soil contamination

Landfill leachate, if not treated properly, can worsen pollution problems by creating even additional and more toxic leachate. This feedback provides the benefit of accelerating the decomposition of organic wastes; however it also speeds the release of GHG and increases the risk of leachate leaking into surrounding soil. Moreover, failure to properly collect the leachate means that leachate levels may rise and possibly cause overflow from the containing membrane. Adequate management of landfills are necessary to protect the surrounding environment from being polluted.

Food contamination

Modern technology has helped advance food production processes; however the same activities have resulted in polluted soil, air and water. Not surprisingly, these can be linked to a variety of illnesses. Ongoing changes in farming practices, for example, have resulted in lower dietary exposure to salicylates, which are produced by plants as a natural defense mechanism when they are infected. Salicylates have been shown to have a protective effect against bowel cancer. But in monocultures that are farms, there is no need for this mechanism to take place; in turn, the plants we consume may be lower in salicylates.[32] The lack of anti-cancer properties in the plant foods may have contributed to the rising incidence of bowel cancer.

Plastic additives such as phthalates and bisphenol A (BPA) and chemicals like perfluorooctanoic acid (PFOA), are used in food containers and personal care products. They are being found in higher amounts in many of our surface water systems and even drinking water supplies. Perhaps not surprisingly, they are also being found in higher amounts in humans and animal body. This is a concern because a research has shown young overweight females to have elevated levels of phthalates in their systems.[33] While it is not known whether the link is causative, it is likely the mechanism acts through hormonal disruptions.

Another example of food supply contamination was found to increase risk of diabetes in a cohort study. Yucheng ("oil disease") victims, Taiwanese women who

consumed rice bran oil contaminated with polychlorinated biphenyls (PCBs) and polychlorinated dibenzofurans (PCDFs) between 1993 and 2003, were found to have higher incidences of diabetes.[34] There is also evidence of hormonal effects through transplacental exposure to dioxins and PCBs. Thyroid function and growth hormone levels were higher in newborn females, but not males. These hormonal functions are crucial for healthy infant development.[35]

COSTS AND ECONOMICS

Although public health should be the priority when addressing food industry and waste management regulations, there are also economic costs to consider. Food production depends closely on cost effectiveness as well as market structures. It is also important to determine whether all waste is costly to the environment. Current and future costs must be weighed; what is cheaper for our generation may not be affordable for that of our grandchildren. Alleviating food insecurity today would be futile if it worsened the situation tomorrow. While acknowledging the trade-offs in the food system (i.e., Pros and Cons), it would be valuable to define the extent of food waste's impact on health. This way, perhaps a sustainable and affordable food system can be achieved.

ETHICS AND EQUITY

There are important ethical and equity issues to consider when dealing with food waste management. The obvious one would be the staggering amount of foods being trashed in affluent countries, while nearly a billion people experience food insecurity each day. In most of the developed world, food is relatively cheap and portions are increasingly large.[10] The contrast between prevalence in obesity and metabolic syndrome in developed countries vs. diseases related to malnutrition in developing ones has long been proof of unequal food distribution worldwide. Overproducing foods in already wealthy countries is not a sustainable solution to this problem.

Both food producers and consumers need to learn how to use food more efficiently. Understandably, for cafeterias, restaurants and supermarkets, it is easier to toss unsold foods than to worry about consumers getting sick from consuming spoiled products. Food producers do not want to be liable for food spoilage.[10] While the financial costs of food production may be worthwhile, the environmental costs are simply not. Further, public health recommendations must be developed to educate consumers on the environmental impacts of their food choices, rather follow the wishes of food industry lobbyists.[11]

The issues facing our food system are complex, extend across many sectors and require integrated solutions. The most effective way to address them is through integrated food policies and implementation strategies.[11]

FUTURE OPPORTUNITIES

Changing the mind-set

In the past, food producers, retailers and consumers had been less concerned with proper waste management methods. The priority was to maximize food sales, and giving away or selling foods past their prime involved risks that may undermine sales. From an economic standpoint, it made sense to simply trash anything that was deemed unsellable. Regulations against irregularly shaped fruits and vegetables prevented as much as 20% edible produce from being sold in Europe.[36] Additionally, because of confusing food labelling and lack of knowledge on how to prepare foods past their prime, consumers frequently throw away food in fear of eating spoiled foods.[7]

Reducing waste related to food is an achievable goal with considerable benefits: economic savings, environmental protection, and increased food availability for those who need most. Retailers and consumers must abandon the attitude where food wastage is viewed as financially affordable. Reconnecting with how food is grown would help people understand its true value. It would also help adjust perceptions of how food should look like; wonky shaped fruits and vegetables are not nutritionally inferior and need not be discarded by vendors.

Furthermore, manufacturers can adopt the "cradle-to-cradle" approach when evaluating the food system. The end of a product's lifecycle, or its disposal step, can be brought back to the beginning through recycling or reusing. This can alleviate the need for manufactured supplies and natural resources. Waste can also be burned to create energy, or processed to make animal feed, fertilizer, chemicals, or fuel. Rather than treating waste as inconvenient by-products, improving waste management provides great opportunities to minimize its volume, as well as using trash as a resource itself.[6]

Problem defining and solving: Opportunities for food security and health advancement through waste reduction

Although a third of the food waste in the UK comes from packaging alone, reducing packaging material alone is not the solution. Advisory groups such as WRAP advocate waste reduction by encouraging meal planning, smaller meal portions, encouraging food preservation and preparation of foods past their prime.[25, 37] These actions would also help consumers combat obesity.[25] While addressing the issue of food waste will involve consumer education, there is also significant work that can be done at industry level, for example through changes to supply chains and more accurate use of best by dating.[11]

Incentives from the government may work to reduce household waste in certain societies. In the UK, for example, a "pay as you throw" and "earn as you recycle" scheme had been proposed. The idea is that the greenest households could earn an honorarium at the expense of the most wasteful. However, despite local support, policy authorities did not implement this idea since this system still has loopholes.[28] There are concerns of possible conflict of interests, where the industry may voluntarily reduce packaging, but households were fined for waste they did not want in the first place.[38] Further, incentive schemes must consider possible positive or adverse changes in public behaviour. For example, consumers may illegally dump their trash or use counterfeit special bags to avoid the fees involved in the incentive program.

Aside from waste reduction, there are ways to stimulate better waste management. In Taiwan, local governments employ "reusable garbage separation plants" to sort and classify municipal solid waste (MSW).[39] Efforts to implement diversified kitchen reuse programs, including

sorting food waste as feed for pigs, have been quite successful. Community involvement has been positive particularly in urban areas where kitchen waste amounted to 20-30% of all household waste in Taiwan.[29] Since Taiwan's Environmental Protection Administration established integrated waste collection and treatment programs, MSW declined from 8.35 million tons in 2000 to 7.51 million tons in 2005. Additionally, it helped change the composition of MSW being sent to landfills and incinerators. Reduction in food waste proportion and salt content, for example, will reduce dioxin emissions from incinerators. This prevents toxic contamination, and encourages a safer environment in which live and grow foods.[39]

There are also great opportunities to reduce waste through innovation. Research could investigate how the non-food yield of crops can be used in less wasteful ways. Improved technologies also provide opportunities for new materials, such as nanoplastic or bioplastic packaging that can monitor food spoilage; however safety should be confirmed before implementing mass usage.

There are already great efforts to protect the environment for causes of sustainability and climate change. Less attention has been paid in how waste management can promote health through improving food safety and security. It is imperative to change the current food system into one that is less wasteful and more efficient. Overproduction of food must be restricted, as well as excessive use of chemicals and natural resources. Raising public awareness can encourage healthier and more sustainable dietary choices. Furthermore, these are indirect but noteworthy ways to prompt waste reduction.

AUTHOR DISCLOSURES

No author has a conflict of interest in regard to this paper.

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以廢棄物管理角度探討食品安全與人體健康

隨著人類經濟成長、交通運輸的便利與生活型態和健康意識的改變，使得食物供需鏈產生了無可避免的變化，亦使得人們對已處理包裝食物(真空包裝食材及冷凍微波食品)之需求日益增加。而在目前的研究裡，我們對這些新增需求所產生之相關廢棄物(包裝、運輸、處理等不同過程所產生廢棄物)對於環境負荷、食品安全及其所引發之人體健康衝擊之關連性與相關知識都相當缺乏。繁瑣的食物處理過程與其廢棄物的產生都會直接造成資源的消耗與環境的負荷。現今食物農業與畜牧業的生成過程中常會大量的使用殺蟲劑、除草劑、抗生素和化學肥料等，而這些化學物質的過量使用常連帶污染了我們周遭生活的水與土壤環境，並最終反撲進入到我們的食物供需鏈裡。根據研究指出，鄰苯二甲酸化鹽類、全氟辛酸、雙酚 A 等食材包裝與食品運輸中常用塑膠製品之化合物已於台灣水域中出現無法接受之濃度，而這些被檢測出的化合物同樣會污染我們的食物與造成人體健康上的慢性危害。現今廢棄物管理政策僅著重於降低包裝、運輸、處理等步驟之廢棄物產生量，卻忽略了教育民眾可從一開始就選擇低污染性、低廢棄物產生量之食物。如本土食材相對於進口食材之低運輸污染、新鮮食材相對於真空包裝食材之低包裝污染、多食用蔬菜相對於食用肉類之低生產污染。本文重點包含食物生產過程中所產生相關廢棄物之污染及其對食物生產之衝擊、相關廢棄物管理之成本經濟分析及該廢棄物污染對人體健康之影響。

關鍵字: 食品廢棄物、人體健康、環境污染、食品安全、廢棄物管理