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FORESIGHT PROJECT ON GLOBAL FOOD AND FARMING FUTURES

Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use*

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SUMMARY

This review compares and contrasts postharvest food losses (PHLs) and waste in developed countries (especially the USA and the UK) with those in less developed countries (LDCs), especially the case of cereals in sub-Saharan Africa. Reducing food losses offers an important way of increasing food availability without requiring additional production resources, and in LDCs it can contribute to rural development and poverty reduction by improving agribusiness livelihoods. The critical factors governing PHLs and food waste are mostly after the farm gate in developed countries but before the farm gate in LDCs. In the foreseeable future (e.g. up to 2030), the main drivers for reducing PHLs differ: in the developed world, they include consumer education campaigns, carefully targeted taxation and private and public sector partnerships sharing the responsibility for loss reduction. The LDCs' drivers include more widespread education of farmers in the causes of PHLs; better infrastructure to connect smallholders to markets; more effective value chains that provide sufficient financial incentives at the producer level; opportunities to adopt collective marketing and better technologies supported by access to microcredit; and the public and private sectors sharing the investment costs and risks in market-orientated interventions.

INTRODUCTION

A preoccupation of the 21st century will be the equitable, rational and sustainable use of the natural resources that underpin the worldwide food supply, such as labour, land, clean water, oil and other agricultural inputs, because failure in this endeavour presages civil strife and starvation. World population has been predicted to reach 9·1 billion by 2050 and this will require a 70% increase in food production (FAO 2009). Almost all of this growth will occur in less developed countries (LDCs). There is no universal definition of LDCs: this term has been adopted in this review to mean countries where the bulk of agriculture depends on smallholders who have little or even no surplus for sale and which have a low GDP compared with, say, member states of the Organisation for Economic Cooperation and Development. Some countries, such as the Republic of South Africa, Brazil and China, are intermediate in having both large-scale farming and significant smallholder production. It is therefore timely to consider how minimizing postharvest food losses, including food waste, can help conserve resources and improve human well-being.

* The views expressed here are those of the authors, and may not be attributed to the Natural Resources Institute (UK), the Economic Research Service or the US Department of Agriculture.

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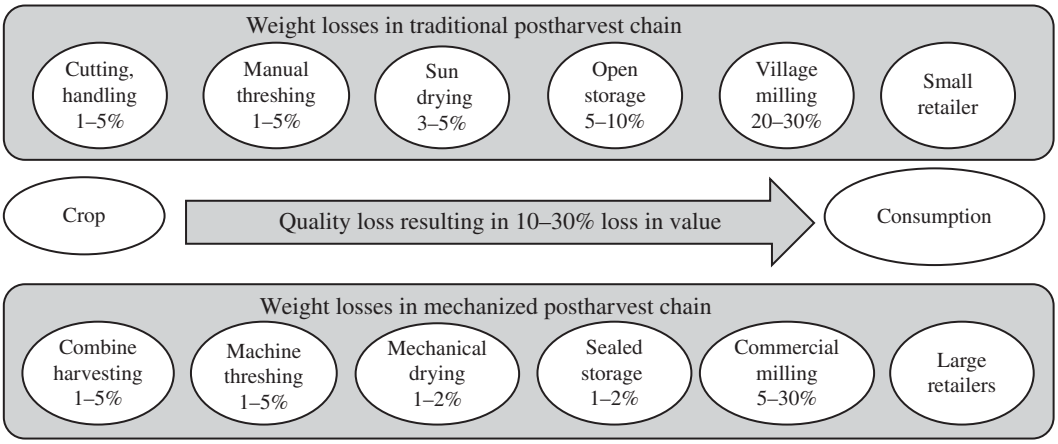

Fig. 1. Estimated losses (weight and quality) from the postharvest chain for rice in South Asia (Courtesy of Martin Gummert, International Rice Research Institute).

The term 'postharvest loss' (PHL) refers to measurable quantitative and qualitative food loss in the postharvest system (de Lucia & Assennato 1994). This system comprises interconnected activities from the time of harvest through crop processing, marketing and food preparation, to the final decision by the consumer to eat or discard the food. Losses of quantity (weight or volume) and quality (altered physical condition or characteristics) can occur at any link in the postharvest chain (Fig. 1). Economic loss can also occur if the produce is subsequently restricted to a lower value market. Here, 'food loss' is a subset of PHL and represents the part of the edible share of food that is available for consumption at either the retail or consumer levels but not consumed for any reason. 'Food waste' is the subset of food loss that is potentially recoverable for human consumption.

Over the past few years, the rise and expansion of global supply chains and the renewed emphasis on efficiency and food safety has spurred a major paradigm shift in the way the postharvest system is conceived from a series of individual components to an integrated value chain linking producers and consumers through domestic and international trade (Fig. 2). Adopting this approach and the opportunities it presents can lead to greater systemic efficiency, food safety and quality, and a clearer picture of various participants and benefits derived along the value chain.

This short review contrasts what is known about food waste in developed countries with PHLs in LDCs to highlight the opportunity for improving resource use worldwide. Generally, data and information on PHLs are scarce, so this review pays most attention to the best-known examples. It relies heavily on research into general food waste in the USA and UK, and for LDCs on cereal losses in sub-Saharan Africa (SSA). In SSA, cereals account for nearly 40% of agricultural incomes (from FAOSTAT for 2003/04, http://faostat.fao.org, verified 13 October 2010), and it is expected that the principles in the approach to cereal loss reduction can be generalized to other agricultural commodities. Countries that are transitional between developed and less developed are not examined here, although the contrasting parts of their food economies would likely show some characteristics of both developed and less developed countries.

CRITICAL FACTORS GOVERNING PHL AND FOOD WASTE

As a product moves in the postharvest chain, PHLs may occur from a number of causes, such as from improper handling or biodeterioration by microorganisms, insects, rodents or birds. An important factor in developed countries is that a large amount of the food produced is not eaten but discarded, for reasons such as it was left on the plate after a meal or it passed its expiry date. In contrast, failure to consume available food in LDCs is not a reported concern; instead the low-quality food remaining in markets at the end of the day is sustenance for the very poor. The issue in LDCs is inefficient postharvest agricultural systems that lead to a loss of food that people would otherwise eat, sell or barter to improve their livelihoods.

Developed countries

Developed countries have extensive and effective cold chain systems to prolong product shelf-life. Additionally, more sophisticated management and new technologies continue to improve the efficiency with which food is brought into stores, displayed and sold. For example, 'just-in-time' production and the use of

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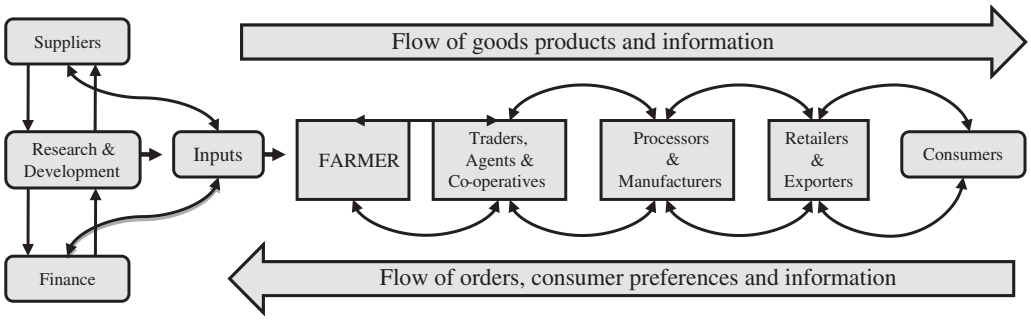

Fig. 2. A typical value chain (adapted from NR International http://www.researchintouse.com/nrk/RIUinfo/).

computerized stock control have dramatically decreased the volume of stock held within the food chain, driving down costs (Houghton & Portougal 1997). Competition and financial incentives drive the system, with supermarkets as the main drivers of food marketing chains.

A key factor in PHL is growing consumer intolerance of substandard foods (e.g. too small) or cosmetic defects such as blemishes and misshapen produce, and this has increased the rejection rate. For example, grading to satisfy the demand for greater product specifications has led to waste for some products. Food merchandizing has also changed with greater emphasis on coupons, discount offers and super-sizing of portions, leading consumers to increase their expectations of serving sizes and buy more than they need. Additionally, it has become common for US retail stores to create waste by having displays of fresh food that are far in excess of their sales. Some un-quantified amount of this excess is donated to feeding programmes. Donations may be limited by constraints on transportation and the time needed to get fresh foods to food recovery centres (food banks) that collect food for redistribution to feed the hungry at soup kitchens and shelters.

Less developed countries

In LDCs, the main cause of loss is biological spoilage. Livestock products, fish, fruit and vegetables lose value very quickly without refrigeration. In contrast, roots, tubers and grain products are less perishable as they have lower moisture contents, but poor post-harvest handling can lead to both weight and quality losses. Cereal grain products are least susceptible to PHLs, but grains may be scattered, dispersed or crushed during handling. They may also be subject to biodeterioration (Grolleaud 1997; Boxall 2002) that may start as cereal crops reach physiological maturity, i.e. when grain moisture contents reaches 200–300 g/kg and the crop is close to harvest. While crops are still in the field, storage pests may make their first attack and unseasonal rains can dampen the crop and result in mould growth. Weather is a key issue at harvest. In developing countries with hot climates, most smallholder farmers rely on sun drying to ensure that crops are well dried before storage. If unfavourable weather conditions prevent crops from drying sufficiently, then losses will be high. If climate change leads to more unstable weather, including damper or cloudier conditions, PHLs may increase. Poor-quality food may also lead to significant health costs, including costs for co-morbidity associated with other health impinging factors such as HIV/AIDS. Suboptimal drying practices and poor storage of grain products can lead to the growth of mycotoxin-producing moulds, such as *Aspergillus flavus*, which produces aflatoxin, a potent carcinogen (Wareing 2002). Ingesting aflatoxin while infected with HIV/AIDS or malaria may lead to lower productivity, premature death and/or increased susceptibility to other fatal diseases (Wu & Khlangwiset 2010).

PROBLEMS ENCOUNTERED IN ESTIMATING PHL AND FOOD WASTE

Estimating PHLs is difficult, and is not very reliable. Actually measuring what has been lost implies that it is known what was there at the outset and this is usually not the case. Two main approaches have been taken, either to actually measure what has been lost or to use questionnaires to elicit subjective loss estimates from those who have experienced them.

Developed countries

Although there have been some studies on PHLs in the USA, none estimate total PHLs on-farm or during processing. Additionally, there are few peer-reviewed food waste studies in the USA (Muth *et al.* 2007). In the USA, food waste measurements rely on structured interviews, measurement of plate waste, direct examination of garbage and application of inferential methods using waste factors measured in sample

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populations and applied across the food system (Hall *et al*. 2009). Each method has its own challenges. Cumulative errors in inferential methods can arise if incorrect food waste factors are applied in early stages of the food system calculations (Hall *et al*. 2009).

A later section presents food loss estimates in the USA for 2008 using an inferential approach. In essence, the per capita losses for different food groups at the retail and consumer levels are summed and then multiplied by the US population on 1 July 2008 (304·06 million) (USDA/ERS 2010*a*).

Less developed countries

PHLs in LDCs are relatively unknown and are mostly guesstimates derived from questionnaires rather than actual measurements. Demands for simplified loss figures can lead to, for example, single national figures for maize PHLs representing many years. However, this approach may be misleading because '…post-harvest losses may be due to a variety of factors, the importance of which varies from commodity to commodity, from season to season, and to the enormous variety of circumstances under which commodities are grown, harvested, stored, processed and marketed' (Tyler 1982). It is therefore important not only to work with figures that are good estimates at the time and in the situation they are taken, but also to be aware that at other times and situations the figures will differ.

There have been systematic efforts to provide estimates of PHLs of cereal grains but, prior to the 1970s, most figures were anecdotal. A 1977 UN Food and Agriculture Organization survey on postharvest crop losses identified few well-supported figures (FAO 1977). This inspired the development of improved loss-assessment techniques (Harris and Lindblad 1978) and documentation of losses (National Academy of Sciences 1978). A recent upsurge of interest in PHLs of cereals led to the development of the African Postharvest Losses Information System (APHLIS – www.aphlis.net, verified 28 September 2010), which includes a network of local experts, a loss calculator and a free access database of key information (Hodges *et al*. 2010). The network contributes the latest agricultural data and verifies loss estimates, so that APHLIS provides well-founded percentage weight loss data based on transparent calculations.

THE SCALE OF PHL/WASTAGE AND WHERE THEY OCCUR IN THE POSTHARVEST CHAIN

Data and resource limitations restrict PHL estimates to those portions of the chain of most interest to researchers or policy makers and to where loss-reducing interventions are believed to be most beneficial or cost-effective.

Developed countries

Widespread use of mechanization and cold chain technologies in developed countries keep on-farm PHLs lower than those in LDCs, although they may still occur, such as when mechanized harvesters damage portions of the crop. In the USA, and perhaps in other developed countries, most food losses appear to be food waste beyond the farm-gate, with greater amounts at the consumer level than from the actions of retailers. For this review, earlier loss estimates for the USA (Kantor *et al*. 1997) have been updated. The authors of this review estimate that from the 222 million tonnes of edible food supply in 2008, 0·09 (19·5 million tonnes) were lost at the retail level and 0·17 (37·7 million tonnes) at the consumer level, and so the total proportion of food lost was 0·26 (57·1 million tonnes) (Table 1). Losses on-farm and between the farm and retailer were not estimated because of data limitations for some food groups. Had these losses been included, the total loss would likely be over 0·30. When translated into loss of resources, food wastage in the USA is extraordinary with the production of wasted food requiring 300 million barrels of oil and 0·25 of the total freshwater consumption (Hall *et al*. 2009).

Meanwhile, the Waste & Resources Action Programme (WRAP 2009) estimates that 8·3 million tonnes of food and drink is wasted from UK households per year, and of this amount 5·3 million tonnes is 'avoidable' waste, 1·5 million tonnes is 'possibly avoidable' (e.g. potato skins) and 1·5 million tonnes is 'unavoidable' (e.g. peach pit). The total waste is 0·22 of all food and drink purchases brought into the home by weight and the avoidable waste is 0·14 (WRAP 2009). The average UK household of 2·4 people generated 270 kg/year of 'avoidable' and 'possibly avoidable' waste in their homes (WRAP 2009). Similarly, the average US household of the same size in 2008, both at home and away from home, e.g. by restaurants, wasted 297 kg of edible food (estimated by the current authors using USDA/ERS Loss-Adjusted Food Availability data, USDA/ERS 2010*a*).

Less developed countries

The largest PHLs usually occur on or near the farm, where the initial choice of crop type and variety and the success of harvesting and consolidation methods are fundamental in keeping losses low (World Bank 2010). Historically, most efforts to reduce PHLs have been on-farm, particularly crop storage, for reasons of food security.

The APHLIS system presents detailed weight loss estimates for eight different cereals in 16 countries of East and Southern Africa. Postharvest losses typically range from 0·05 to 0·35, varying by crop and geographical location (Fig. 3). Quality loss, lost market

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Table 1. *Estimated food loss in the USA*, 2008*

Commodity	Edible food supply *Tonnes '000*	Loss from edible food supply†					
		Retail food loss		Consumer food loss		Total retail and consumer food loss	
		Tonnes '000	%	*Tonnes '000*	%	*Tonnes '000*	%
Grain products	26973	3253	12	4771	18	8023	30
Fruit	30365	2605	9	4100	14	6705	22
Fresh	13377	1918	14	3024	23	4942	37
Processed	16987	687	4	1076	6	1763	10
Vegetables	50990	3123	6	7477	15	10600	21
Fresh	22285	2314	10	5320	24	7635	34
Processed	28705	809	3	2156	8	2965	10
Dairy products	37911	4246	11	6362	17	10607	28
Fluid milk	24704	2967	12	4347	18	7314	30
Other dairy products	13207	1279	10	2014	15	3293	25
Meat, poultry, and fish	39629	1236	3	9239	23	10475	26
Meat	21542	667	3	4994	23	5661	26
Poultry	15886	388	2	3704	23	4092	26
Fish and seafood	2202	180	8	541	25	722	33
Eggs	3982	396	10	600	15	996	25
Tree nuts and peanuts	1440	86	6	135	9	222	15
Added sweeteners	18797	2068	11	3346	18	5414	29
Added fats and oils	12001	2463	21	1653	14	4116	34
Total	222088	19474	9	37683	17	57158	26

* Excludes non-edible food parts, such as bones, hides, peels, skins, pits, cores and seeds.
† Totals may not add due to rounding.
Source: USDA/ERS (2010*a*) (7 March 2010).

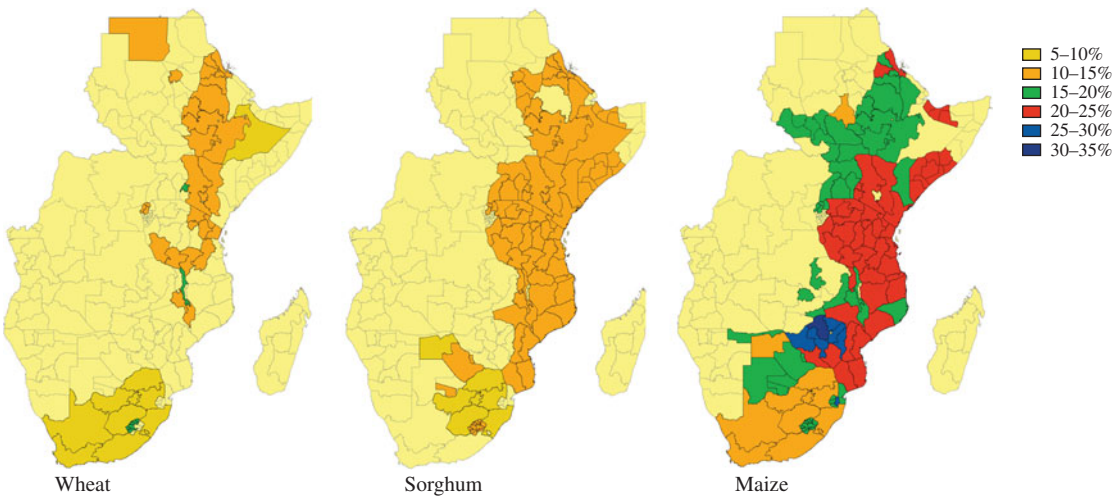

Fig. 3. Estimated % cumulative postharvest weight loss from production of wheat, sorghum and maize by provinces, for countries in east and southern Africa for 2007 (APHLIS, http://www.aphlis.net).

value and lost opportunity were not estimated. The aggregate gross postharvest weight loss for six major cereals in these countries is US$1.6 billion or 0·15 of total production value (US$11 billion, Table 2). This estimate can be extended to the whole of SSA, although data for a number of major producers

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Table 2. *Annual production of different grains in (tonnes)*, estimated % postharvest weight losses† and the financial value of weight losses for 16 countries‡ in east and southern Africa for 2007 (World Bank 2010)*

Grain type	Annual production for 16 countries‡ of east and southern Africa (million tonnes) 2005–07 average	Average local producer price (US$/tonne)*	Estimated value of production (US$ million)	Regional average % weight loss estimates	Value of weight losses (US$ million)
Maize	27·01	194·71	5258	17·5	920
Sorghum	4·72	250·05	1181	11·8	139
Millet	1·67	305·34	510	11·7	60
Rice	5·15	405·53	2089	11·5	240
Wheat	5·25	274·36	1441	13·0	187
Barley	1·71	281·53	481	9·9	48
Totals§	46·18		10960		1594

* From FAOSTAT (http://faostat.fao.org).
† From APHLIS http://www.aphlis.net.
‡ Countries: Botswana, Eritrea, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.
§ Totals may not add up due to rounding.

(notably Nigeria) are lacking. If it is assumed that PHLs are similar in other countries of SSA that produce cereals, then annual weight losses from SSA are valued at around US$4 billion a year out of an estimated cereal production value of US$27.4 billion. At this rate of production and mean losses, a mere 1% reduction in cereal PHLs could be worth about US$40 million annually.

INCENTIVES TO REDUCE PHL AND FOOD WASTE

This section describes how developed countries and LDCs have different incentives to reduce PHLs, including food waste.

Developed countries

The food industry will minimize PHLs and food waste when they have financial incentives to do so. However, small profit margins in the sector limit options for dealing with food waste. Food by-products are usually incorporated into other marketable products and so are only marginal losses. In the USA, the largest supermarket chains and many other companies provide food to charitable organizations. The US business environment is favourable towards food redistribution, because there are tax incentives to do so, there is legal protection from Good Samaritan laws and it can help improve corporate image (Stuart 2009).

Companies are penalized for generating excess agricultural production and food waste as they must pay for its disposal in landfills or by incineration. Governments have incentives to monitor landfill use and promote efficient means of reducing the amount of waste that goes to landfills to limit their costs and to decrease risks to the environment, such as the production of methane gas, which has been linked to climate change, and leachate (a mixture of liquid waste, organic degradation by-products and rain water), which has the potential to contaminate groundwater. In the USA, there is increased interest in diverting food and other organic wastes away from landfills. Future diversion will be governed by incentives such as climate change mitigation policies and landfill organics bans (Levis *et al.* 2010).

Most consumers in developed countries have weak financial incentives to minimize food waste because they have access to an abundance of inexpensive, readily available food. In the USA, over a period of about 80 years (1929–2008), food expenditure by families and individuals as a share of disposable personal income decreased from 23·4 to 9·6% (USDA/ERS 2010*b*). In general, most consumers in the USA do not appear to be concerned about food waste and this may also be true in other developed countries. If consumers were better informed about the amount and value that they waste annually, including its share relative to their household's budget, they might waste less. The WRAP study in the UK found that the average household throws out £480 (US$745) of food and drink each year. In an earlier study by WRAP, almost 0·70 of the 284 households that kept 1-week diaries of their discarded food were subsequently committed to discarding less food (WRAP 2009).

Less developed countries

At the level of individual households in SSA, reduced PHLs could increase food availability by both

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reducing physical losses and increasing income from the improved market opportunities that could be used to buy food (World Bank 2010). Furthermore, reducing PHLs instead of increasing the amount of food grown would save scarce production resources and may lessen environmental harm. This is because increased production can lead to more intensive farming or to an expanded area under cultivation, both of which may damage the environment, especially when poor rural households farm in fragile ecosystems or on marginal land.

Mechanization, introduced at least in part to reduce PHLs, may also reduce labour requirements. For example, in Vietnam the introduction of an improved grain dryer reduced the labour required to dry 1 tonne of rice from 46 person hours to 7. This enabled affected children to spend more time in school and adults to engage in more profitable off-farm activities. Drying costs, measured as the opportunity cost of family labour, were reduced from 0·10 of the crop value to 0·04 (Goletti and Wolff 1999). The achievable benefits depend on the opportunity cost of labour, which in many rural areas of SSA was very low because of the existence of few other economic activities. This opportunity cost has arisen recently due to migration, aging farming populations and the HIV/AIDS pandemic, and thus the introduction of some labour-saving technologies may now be viable options in SSA.

STRATEGIES TO REDUCE PHL AND FOOD WASTE THROUGH TO 2030

This section outlines potential strategies to reduce PHLs, including food waste, in both developed countries and LDCs.

Developed countries

In the USA, there is no widespread or visible political or social momentum to reduce PHLs and food waste. The US Environmental Protection Agency (1999) promotes their 'food recovery hierarchy', which shows the order of preferred methods to use excess food and food waste. This includes recovery of wholesome food to feed the hungry and poor, providing food for livestock and zoo animals, recycling for industrial purposes and composting to improve soil fertility. One industrial purpose being explored in the USA, the UK and other developed countries, is the use of anaerobic digestors to take feedstock, food and agricultural waste and wastewater plant biosolids to produce biogas and other valuable outputs (e.g. compost material). However, digestors need a continuous supply of materials to remain profitable and there is some concern that this could divert food from feeding programmes.

Stuart (2009) provides an expanded list of ideas about how consumers, retailers, governments and other groups can reduce food waste, although financial costs, logistical hurdles and consumer preferences may stand in the way. For many commodities in developed countries, food loss has declined in recent decades (Buzby *et al*. 2009) and new loss-reducing technologies are under development. Research and reliable loss estimates for the different foods and stages in the postharvest chain are needed to identify where food waste can be minimized efficiently. More research is also needed on how agricultural policies, such as output-based subsidies, might promote overproduction and thus increase food waste and whether other policies could provide meaningful incentives to reduce food waste. The WRAP programme is mapping waste along the food supply chain for selected foods in the UK, which should lead to recommendations for improving supply chain management. Interdisciplinary research is also needed to understand how improvements in supply chain management and technology implementation can decrease PHLs, particularly regarding preharvest–postharvest linkages.

Less developed countries

The postharvest systems of LDCs need considerable investment to create more formal markets and improve their performance to a point where PHLs can be substantially reduced. Some of these improvements need to take the form of public 'goods' including infrastructure such as the development of networks of all-weather feeder roads so that crops can get to market, a problem especially acute in Africa where transport costs can be five times those in Asia (World Bank 2009). Suitable market institutions need to be developed and promoted to enable marketing groups and individuals to best respond to market demand. Collective marketing can take various forms and for grains may include inventory credit schemes and Warehouse Receipt Systems to accelerate the efficient removal of the crop from the farmer into safe centralized storage (Coulter and Shepherd 1995).

Successful markets depend on a consistent supply of better-quality produce and this can be achieved by adopting/adapting improved technologies that also lower PHLs. There are a wide range of such technologies (World Bank 2010), but these are beyond the scope of this review. New technologies and approaches can be introduced through innovations systems and learning alliances (World Bank 2006), but adoption will depend on producers seeing a clear direct or indirect advantage, particularly financial benefit, and potentially on their access to credit. For a sustainable approach to PHL reduction, an intervention has to be planned within the context of the relevant value chain, and more than one type of intervention may be required. External agencies (public or private sector) need to develop and manage the introduction of interventions, but it is only the

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behaviour of actors within the value chain that can assure sustainability. Market-orientated interventions need to be managed wholly or partly by the private sector while public–private sector partnerships are necessary to share investment costs and risks.

CONCLUSION

The world population is increasing faster than the growth in the food supply, and the resources used for creating food are all becoming increasingly scarce. Reducing postharvest food losses must be an essential component in any strategy to make more food available without increasing the burden on the natural environment.

In both developed countries and LDCs, incentives are needed to encourage the reduction of PHLs and food waste. In developed countries, losses close to the farm are considered to be relatively low and any further reduction is subject to commercial priorities. Losses by food processors and retailers are constrained by the financial costs of disposing waste via landfills or incineration. Ideas to reduce PHLs and food waste that are worth exploring include the following:

- Consumer education campaigns to increase knowledge and awareness of appropriate portion sizes, food purchasing skills, meal planning, using leftovers, what is safe to eat, food discard behaviour and interpreting sell-by or use-by dates. The literature provides evidence that once people are aware of the value of their losses, then there is commitment to handle food better.
- Tax foods with the highest waste to increase their income elasticity.
- Increase cost of and tax on waste disposal, particularly food by-products and food waste. This may, however, provide adverse incentives for illegal dumping.
- Develop private (e.g. retail, community groups and waste industry) and public sector (local, state and Federal governments) partnerships to jointly reduce food waste and share responsibility.

In LDCs, the incentives to reduce PHLs are much greater as loss reductions can directly improve the livelihoods and food security of the poor, and, potentially, food safety and quality with associated health benefits. Further, adopting improved methods, especially mechanization, can liberate time to spend on more profitable off-farm activities.

Looking forward, it would be beneficial for developed countries to provide national estimates of food waste and information on where to target resources to decrease food waste efficiently. For LDCs, there is a wide range of priority areas for further research effort but key among these must be studies on the implications of climate change for on-farm PHLs and options for smallholder adaptation, and the development of an authoritative approach to cost–benefit analysis for postharvest interventions, in order to guide policy making and the efficient use of resources. Research is needed into building the capacity of the private sector to service smallholders' needs.

The drivers for change up to 2030 differ between developed countries and LDCs. In the developed world, they include consumer education campaigns, carefully targeted taxation, and private and public sector partnerships sharing the responsibility for loss reduction. The LDCs' drivers include more widespread education of farmers in the causes of PHLs, better infrastructure to connect smallholders to markets, more effective value chains that provide sufficient financial incentives at the producer level, opportunities to adopt collective marketing and better technologies supported by access to microcredit, and the public and private sectors sharing the investment costs and risks in market-orientated interventions.

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