Clean cold-chain development and the critical role of extension education

Lisa Kitinoja,* Vijay Yadav Tokala and Majeed Mohammed

Dr Lisa Kitinoja is the Founder and Board Chair (Oregon, USA); Vijay Yadav Tokala (Curtin University, Western Australia) and Dr Majeed Mohammed (University of the West Indies, Trinidad & Tobago) are members of the Board of Directors of The Postharvest Education Foundation, an international non-profit organisation dedicated to providing information, mentoring and training on food loss/waste reduction.

****Corresponding author: kitinoja@postharvest.org; www.postharvest.org***

Abstract

Perishable foods experience huge losses, and sometimes more than half of the total produce is lost due to poor post-harvest handling practices. A cold chain consists of a series of actors engaged in producing, transporting, storing, retailing and serving fresh, chilled and frozen foods. Availability of refrigeration and an unbroken cold chain is essential to manage qualitative and quantitative losses in perishables. The effectiveness of the cold chain relies on controlling product temperature at every step, and careful management of practices, technologies, capital and workers. Present refrigeration and cold transport technologies typically use either diesel fuel (expensive and a source of pollution) and/or electric power (often not available in rural areas). Promoting the expansion of existing technologies for cold-chain development will have the side effects of increasing pollution, greenhouse gas production and associated climate change. Clean cold-chain development is an environmentally sustainable way to achieve essential cooling and reduction in the post-harvest losses. Effective promotion of clean cold technologies is possible only through appropriate extension outreach, capacity-building and training activities. This paper focusses on the critical role of extension education in the implementation of clean cold-chain management in developed and developing countries.

Introduction

The capacity to ensure the availability of safe food for an increasing global population is becoming uncertain due to factors such as rapid climate changes and depletion of natural resources (FAO, 2009). It is estimated that nearly one third of all the food produced globally for human consumption is either lost or wasted. In the case of fresh perishable foods such as fruits, vegetables, meat, milk and milk products the losses can reach up to 50 percent of total production by weight or even more in some instances (Gustavsson *et al*, 2011). High food loss and waste are known to be due to the lack of knowledge, access to education/extension services, required post-harvest tools, supplies and cold-chain infrastructure. High food loss/waste results in losses of productive resources, nutritional value, market value and income.

Reducing post-harvest losses is increasingly being referred to as one sustainable way to achieve global food security and is a unique win-win strategy where food gaps are reduced and the natural resources used to produce food are conserved (Kitinoja *et al*, 2018). Lack of access to an affordable uninterrupted cold chain during different steps of supply, *ie* pre-cooling, packing, processing, transport, storage, distribution and marketing, is one of the main reasons for the losses in the perishable foods before reaching consumers (Kitinoja, 2014). For instance, an increase in temperature at any step along the food supply chain accelerates deterioration processes in food commodities, resulting in loss of natural colour, flavour, texture and nutrient levels (Global Panel, 2018). Apart from the physiological and nutritional degradation of the produce, the rise in temperature also promotes the accumulation of harmful microorganisms threatening food safety. According to the 'Q_{10} temperature coefficient' principle, the rate of degradation enzyme activity doubles for every 10°C rise in temperature. It follows that the storage life of fresh produce could be doubled with every 10°C reduction in storage temperature (Kitinoja, 2013a). However, promotion of the expansion of traditional cold-chain development, which relies on diesel fuel and/or electricity to provide cooling and cold transport, while needed for reducing food losses, also has the potential to increase pollution and greenhouse gas production.

Several methods and technologies are used for providing cold-chain services. These vary from a simple Zero Energy Cooling Chamber (ZECC) working on evaporative cooling principles to sophisticated mechanical refrigeration systems being used to maintain cool conditions during post-harvest handling (Chintada *et al*, 2017), cold storage and cold transport. The mechanical refrigeration systems are considered the most efficient cooling method developed to date and typically utilise electricity for stationary systems and diesel fuel for mobile systems. These systems can be extremely expensive when used to maintain low temperatures during post-harvest handling and storage, especially in tropical areas where average daily temperatures can reach more than 30°C. Even at this high cost, using cold-chain technologies can still balance the investment and start yielding profits, since a major portion of post-harvest losses in these areas is due to lack of temperature management (Kitinoja, 2014).

With the increase in concerns about environmental pollution, climate change and the rapid exhaustion of non-renewable resources, the pursuit of alternative clean cooling technologies has emerged. As a result, innovations such as solar-powered refrigeration systems and liquid-air-powered cryogenic engines have been developed (Kitinoja, 2014). Liquid air and phase change materials (PCMs) are being utilised in innovative ways to store cold. Successful transfer of these new 'clean cold-chain' innovations to the different stakeholders involved in the food supply chain is possible only through effective extension and training.

In this article, the role of extension education and some important methods of outreach for clean cold-chain development will be discussed along with current examples and success stories for each method.

Status and scope of the clean cold chain

Clean cold chains are cold chains that run on clean or green energy (the energy produced from renewable sources or alternative energy with zero emissions). Zero-emission cooling technologies and lower-emissions cooling methods have emerged; for example, solar refrigerators, charcoal evaporative coolers, solar-powered milk-chillers, and CoolBot-equipped cold rooms. These innovations reduce energy use and provide effective cooling, but are typically suitable for operation at a single fixed location and do not provide a solution for cooling throughout the food supply chain. Phase change materials can be 'charged' (cooled using any type of energy source), then utilised to keep foods or medicines cool using insulated storage structures or in specialised containers during shipping. Cryogenic engines powered by liquid air (or liquid nitrogen), in contrast to other innovations, not only provide zero-emission cooling but also have the capacity to be utilised as a full suite of cold-chain services (Kitinoja, 2014). Air liquifies when refrigerated to -196°C and can be stored conveniently in an unpressurised insulated tank. On exposure to ambient temperatures, the liquid air boils, resulting in expansion up to 700-fold with huge thrust and lots of cool air (Kitinoja, 2014). The Dearman engine was developed to channel the heavy thrust created by this expansion to operate a piston engine (Martin, 2012). The details about the Dearman engine and the role of liquid air technology in achieving all 17 United Nations Sustainable Development Goals have been presented by Dearman (2014) and Strahan (2016). Kitinoja (2014), in a study for the Liquid Air Energy Network (LAEN), detailed the prospects of technologies powered by liquid air (or liquid nitrogen) to provide clean cooling at every step of the food supply chain from farm to fork. The capacity of liquid air to be economically feasible was presented using case studies developed for Tanzania and India. The report also discussed the potential modifications in the liquid air technology to make it more suitable for use during pre-cooling, packing, food processing, transport, storage and marketing. Liquid nitrogen can also be utilised for food processing via individual quick freezing (IQF). Diesel-liquid air hybrid engines (heat hybrids) and liquid air engine technologies appropriate for small-scale users could revolutionise ways to reduce post-harvest losses of perishables by tapping into virtually unpenetrated markets. Like any other technology, successful implementation of the liquid air technology at field level would require intensive training and extension programmes.

The need for extension education and training

Extension education on the clean cold chain could be achieved through different methods and at various levels depending upon the target population. Each type of food has its own 'lowest safe temperature' during handling and storage, and recommended packaging, handling practices and optimal storage life. Apart from the use of simple 'clean-energy-powered' refrigeration units, other elements such as corrugated floors to promote uniform air circulation in vehicles, trailer insulation, proper door seals, and use of insulated walls to create heat transfer barriers are of paramount significance. Extension education and training are required to keep stakeholders informed regarding the thermal efficiency of cold storage facilities, trailers and marine containers, and how their functionality declines with years of use, until operators upgrade to a more advanced or modern unit.

It is ideal to have only products with the same cold-chain conditions transported or stored together, but this requires logistical planning to become a reality in fresh produce handling. Avoiding mixed loads may not always be possible, however, particularly in developing countries. Storage and warehouse facilities are critical components for a successful clean cold chain, but require extensive capital expenditure and have high maintenance costs. For stakeholders to justify such investment they need to be adequately informed on key issues such as storage air circulation, temperature and relative humidity control, and ethylene management, as well as proper record-keeping and food safety protocols. Each procedure needs to be validated and audited to ascertain whether it is achieving the intended effect of maintaining the cold chain within designated conditions. This can only be realised via staff training in key topics and with practical hands-on experience. Extension education is, therefore, a critical issue to ensure staff are able to correctly repair and maintain equipment, respond to alarms, identify issues and institute corrective actions. Warehouse staff should be encouraged to be proactive in checking and providing information about cooling methods, storage conditions and product temperature changes to the relevant personnel within the business.

The main objective of the extension education and training is the effective transfer of accessible practical knowledge from the research centres and universities to the growers, traders and all other stakeholders involved with production and supply systems (Van den Ban & Hawkins, 1996). For clean cooling and cold-chain development, this includes engineers, repair service workers, storage and transport operators, and private sector consultants. With the development of communication technologies, extension methods have evolved to reach audiences in every possible corner of the world. The wide range

of outreach methods include word-of-mouth communication, written reports, field visits, community training, information and communication technology methods, and e-learning programmes (Kitinoja & Tokala, 2018). The most appropriate outreach method is chosen on the basis of the needs of the target population. The education and understanding levels of target groups can be very diverse, and the most successful extension approach for promoting the implementation of clean cold-chain technology and management is possible only by choosing the most appropriate outreach method for each target audience.

McNamara & Tata (2015) listed the important principles to be considered when designing an extension programme to reduce post-harvest losses, some of which also hold for a clean cold chain. Understanding the target audience's knowledge, interests and choice of information sources, as well as their willingness to experiment with the new technology, is crucial in framing an extension programme. Audiences such as engineers, policy makers and other officials might be more interested in extensive written reports with detailed explanations of technology, environmental issues involved, efficiency and comparison with existing technologies. On the other hand, traders and growers usually prefer not to spend too much time learning about technology but are more interested in practical information on investment and returns, with technical facts related in a very brief and interactive way. Extension activities are mutual learning programmes, and feedback from the audience may lead to essential modifications needed for the technology to be successful. Implementing extension programmes in different phases involving various actors of the supply chain is essential for effective and viable clean cold-chain development.

Curriculum development for university students and professionals

Introducing the topics related to clean cold energy into the curriculum of major universities, especially the ones which offer agriculture and allied courses, would have a significant impact on the spread and success of the clean cold-energy concept. It would provide scope for an effective extension as well as for the development of new ideas, research and innovations relevant to local conditions. Examples include the University of Birmingham (UK) and the World Food Preservation Center LLC (WFPC). The Birmingham Energy Institute and the Institute for Global Innovation at the University of Birmingham lead worldwide efforts to provide education and professional development via conferences and workshops in clean cooling technologies and promote practical 'Cooling for All' (Strahan, 2016). Using phase change material (PCM), University of Birmingham scientists and their counterparts at China Railway Rolling Stock Corporation Limited (CRRC) Shijiazhuang, China have developed a truck-to-train reefer-style container that is easier and more efficient to operate than conventional equipment. Once 'charged', the PCM embedded container can keep the inside temperature between 5-12°C for up to 120 hours (UB, 2018).

The WFPC aims to provide world-class education and advanced technologies to young students, extension workers and scientists in developing nations, to create a team of experts and to conduct research to reduce food losses. Via a network of 28 universities and 3 agricultural research institutes around the world, WFPC has been designing curricula related to food security, nutrition, food loss reduction and food processing for agriculture universities as well as for secondary vocational schools in Asian, Latin American and African countries (Wilson, 2013).

Methods of outreach and examples of current extension programmes

Some of the important methods of outreach relevant to clean cold-chain development and examples for implementing each method include the following:

University-based outreach programmes

Apart from teaching and research, universities also play a critical role in extension work. Universities create a cadre of young professionals, who would serve as extension workers, trainers and consultants. Some of the universities are also actively involved in conducting workshops and training of trainers, preparing manuals for easy understanding of the concepts and providing consultancy for different technologies. Involving national and international universities that are actively involved in extension activities will facilitate dissemination of the clean cold-chain concept and effective adoption of the technologies. Two examples of university outreach include the University of California, Davis (UC Davis) and the Horticultural Innovation Lab (Hort Innov Lab). *Small-scale postharvest handling practices: a manual for horticultural crops*, published by UC Davis, includes a range of topics related to low-tech and energy-efficient post-harvest and processing technologies suitable for small-scale growers (Kitinoja & Kader, 2015) and introduces cold-chain technologies suitable for low-resource users. The manual was widely adopted in various regions of the world and has also been translated into more than 10 languages to reach more audiences. The Hort Innov Lab has funded projects in Rwanda, Burkina Faso and Tanzania to provide local growers, traders and marketers with Postharvest Training and Services Centers (PTSCs) with CoolBot-equipped cold rooms and ZECCs. For a post-harvest demo project in Uganda, a CoolBot-equipped cold room has been outfitted with solar panels to provide off-grid power.

Post-harvest innovation platforms

A post-harvest innovation platform is a fixed location where extension workers, local post-harvest trainers, farmers and other stakeholders involved in the food supply chain meet to conduct training programmes to improve local capacity and share knowledge on improved technologies. Kitinoja & Barrett (2015) describe the key components of a post-harvest innovation platform for effective extension services. It should be a permanent venue with trained staff, equipped with essential technologies to provide consultancy, training

and demonstrations. An innovation platform for clean cold-chain development would have the capacity to provide demonstrations, services and advice, as well as include facilities for packing, cooling and/or temporary cold storage, leasing reefer vehicles and other equipment and tools for improved post-harvest handling. An example of an innovation platform is the PTSC established at the World Vegetable Center campus in Arusha, Tanzania. The PTSC offers demonstrations of a variety of tools and implements suitable for small-scale post-harvest handling and processing of horticultural crops. The PTSC also has a retail shop, storeroom facility and CoolBot-equipped cold room. Regular training and demonstrations are conducted for growers, traders and small-scale processors on different equipment, including evaporative cooling, cold storage, food processing and marketing options (Nenguwo *et al*, 2018).

Information and communication technologies (ICTs)

With the inception of the Digital Revolution, the world has witnessed rapid development in low-cost information-sharing and communication media. The use of ICTs in the field of agricultural extension has also increased proportionately, helping trainers and extension agents to reach a greater number of audiences effectively in a significantly shorter time. ICTs help overcome several barriers, such as time, distance, language and lack of proper infrastructure. Mobile phone services have proved to be a most effective way of gathering data as well as disseminating essential information to the wider population within a short time period (Tata & McNamara, 2018). An interactive video would be of interest for a wider range of audiences and transfer the message accurately in a better way than most other communication methods (Bello-Bravo *et al,* 2018). An example of post-harvest outreach via ICT is Scientific Animations Without Borders (SAWBO), which uses innovative ways of creating scientifically accurate short-length animated videos to create awareness on different topics in science, agriculture and health, which are translated into more than 100 languages in different dialects and accents, most appropriate to certain regions. These videos are available free via the SAWBO website and are also distributed on memory sticks, via video-enabled mobile phones and as mobile phone apps. This initiative plays a critical role in transferring the information accurately by overcoming barriers caused by literacy level, language, dialect and cultural differences (Bello-Bravo *et al*, 2018). SAWBO does not yet offer 'clean cooling' videos, but the programme welcomes ideas for future animated videos and can work with subject matter specialists on clean cold-chain development topics to develop new scripts and videos.

Written communication, publications

Dissemination of information through written reports and other publications has been a common practice for ages and is still very effective, especially when combined with online downloads. There are different modes of written communication used in agricultural extension, including journal articles, technical manuals and reports, white papers, books, brochures, posters, leaflets, booklets and newsletters. Each mode of written communication is unique in itself, with differences in length, depth of content, technicality, presentation and illustrations. The appropriate mode of communication is to be chosen on the basis of the target audience, their understanding level and the topic of interest. White papers on cold-chain development and reusable plastic crate systems (Kitinoja, 2013a & b) have been published by the Postharvest Education Foundation (PEF) and are free to download. Cold-chain assessment reports and results of field trials have been shared globally by the National Centre for Cold-chain Development (NCCD) in India. In a 2015 assessment report, the NCCD determined that India needed 70,000 packhouses, *"each equipped with a pre-cooler dispatch room for onwards transport links"*, while the country had only about 250 packhouses (NCCD, 2015), and as of 2018 the Government of India was reported to be developing plans for providing subsidies to support 2,000 new packhouses. In 2017-2018, Engineering for Change (E4C) worked with Massachusetts Institute of Technology D-Lab (MIT D-Lab) to incorporate their research on evaporative cooling chambers (ECCs), which are double-walled storage containers that use evaporative cooling principles to reduce the internal temperature of the chamber by up to 10°C below ambient temperature. These storage units are built with inexpensive local materials, such as brick and sand, to keep farmers' produce fresher for longer, resulting in an increase in saleable product and income. A detailed report of this technology function and designs are available on the MIT D-Lab website (MIT D-Lab, 2018).

Massive open online courses (MOOCs) and e-learning programmes

MOOCs are an online learning avenue aimed at unlimited participation and open access via the internet. The MOOC organisers provide participants with reading materials, lecture videos and quizzes. Access to interactive forums is provided to allow interaction among students and also with tutors to discuss, clarify concepts and receive feedback on assignments and quizzes (Kaplan & Haenlein, 2016). More recently, MOOCs and e-learning have undergone several innovative modifications and have emerged as a popular, low-cost and convenient mode of learning. They are an easy and interactive way to spread knowledge on relatively new topics such as clean cold development. Three current examples of online learning are provided by ADMI, PEF and the Food and Agriculture Organization of the United Nations (FAO). The ADM Institute for the Prevention of Postharvest Loss (ADMI) offers a MOOC titled 'Global postharvest loss prevention: fundamentals, technologies, and actors' to provide an overview of global post-harvest losses, post-harvest supply-chain activities, economics and also introductions to a network of actors working for post-harvest loss reduction. The MOOC is a four-week course offered through 'Coursera', an online learning platform. The programme covers staple foods and perishables, including cold-chain operations, and has been completed by thousands of participants. The 'PEF global postharvest e-learning program' offered by PEF is a mentor-guided programme with 10 assignments including

reading, fieldwork and written reports, ideally intended to be completed in one year. PEF provides free access to required training materials on cost-effective post-harvest handling practices, cooling technologies, cold storage and processing, and offers mentoring and feedback through email and social networking sites such as LinkedIn (Zagory & Holcroft, 2018). By the end of 2018, some 170 people from 30 countries had graduated from the course and were actively involved in various post-harvest training and outreach activities. In 2018, FAO began offering 6-hour e-courses in 'Food loss analysis' in English and French, covering food supply-chain topics including on-farm handling, cooling, storage, processing and marketing (FAO, 2018).

Crop-based projects

Every crop, especially each horticulture crop, has specific handling requirements at every step from production to marketing, often including the cold chain. Projects based on specific crops with significant economic and social importance in selected locations allow study of the gaps and requirements in detail, and any amendment in the supply chain would advantage a large part of the population dependent on the specific crop. The Rockefeller Foundation-funded 'YieldWise' project has launched a Mango Aggregation Center in Kenya, where growers and small businesses can prepare, pack, store in a large ZECC or a CoolBot-equipped cold room, solar dry or process mangoes into value-added products such as jam.

Collaboration between the public and private sectors

Collaboration between the private and public sectors has proven beneficial for the success of several developmental initiatives. The public sector plays a crucial role in providing support and finance for essential infrastructure such as transport links for large firms and incentives for small firms to establish new agribusinesses. Recent examples come from Rwanda, Nigeria and India. In 2016, the Alliance for a Green Revolution in Africa (AGRA) and UPL Limited, through a major public-private partnership launched the 'Million tons of cold storage in Africa initiative'. The initiative aims to mobilise USD 2 billion in the next decade to set up cold-storage facilities with a capacity of a million tonnes across sub-Saharan Africa (AGRA 2016). InspiraFarms, in partnership with the Ministry of Agriculture of Rwanda, aims to deliver a multi-unit refrigerated storage project, benefitting more than 100,000 smallholder farmers. *"In the third quarter of 2018, InspiraFarms commissioned ten modular, solar-powered Food Processing and Refrigerated Storage Facilities in six districts across four out of the five provinces of Rwanda. Each facility has a total area of 150 square meters that includes cold storage space, a processing area, an aggregation area, administrative and hygiene spaces, all running completely off-grid and in compliance with food safety standards"* (Rodriguez, 2018).

ColdHubs are walk-in, solar-powered cold-storage stations installed in farms and local marketplaces providing essential refrigeration and plastic crates to store fresh produce. The business model was developed and field-tested by the young entrepreneur Nnaemeka Ikegwuonu with the support of the Nigerian Federal Ministry of Agriculture and Rural Development. ColdHubs are now installed in Nigeria with the facility to store produce in a flexible pay-as-you-go mode (ColdHubs, 2018). In 2018, ColdHubs managed 14 cold-storage units and 3,000 plastic crates, estimating that their 550 customers saved 11,400 tonnes of food from spoilage (N'chekwa, 2018).

The Global Alliance for Improved Nutrition (GAIN) identified gaps in the post-harvest handling systems all across the food supply chain and effects on nutrient levels of foods in Nigeria. To address these gaps, GAIN created the Postharvest Loss Alliance for Nutrition (PLAN) to bring together several private and public sector organisations to initiate research and exchange of knowledge and technology in order to collectively reduce post-harvest food losses and wastes (GAIN, 2018). PLAN engages SMEs in the food system to reduce post-harvest loss and increase the quality and quantity of nutritious foods reaching markets. In a recent case study on 'Promoting cold chain development in India', two key programmes were reviewed. The 'Integrated cold chain, value addition and preservation infrastructure scheme', implemented through the Ministry of Food Processing Industries, and the 'Cold storage and fruits & vegetables development program', implemented through the National Cooperative Development Corporation and state governments, are supported by NCCD. NCCD is guiding cold-chain users to be more environmentally friendly in their operations by supporting the investigation of alternative energy options such as geothermal sources (PLAN, 2018).

Competitions

The Global LEAP Awards identify and promote the world's best off-grid appliances, accelerating market development and innovation. Three competitions were held in 2018-2019, on the topics of refrigerators, solar water pumps, and the off-grid cold-chain challenge. Winners are invited to join the newly formed Efficiency for Access Coalition Investor Network, convened by Acumen. The network includes the Shell Foundation and 18 other leading investment organisations (Global LEAP Awards, 2018).

In Asia, the Rabobank Food Loss Challenge Asia was held in November 2018. The winner, Ecozen Solutions, is enabling the farm-to-fork movement of perishables in India by providing solar-based cold rooms at the farm level. Its business model involves the leasing of solar-powered cold rooms to farmers and connecting them via the platform to organised buyers who are looking to source perishables (Food Loss Challenge Asia, 2018).

Conclusions and recommendations

Temperature management throughout the food supply chain plays a crucial role in reducing post-harvest losses of perishable foods. Successful development and implementation

of the clean cold chain could solve many issues related to high food losses in an environmentally sustainable way. Low-tech evaporative cooling methods, solar-powered refrigeration systems, phase-change materials and liquid air technologies possess great potential to provide clean cooling along every step of the supply chain. These clean cold-chain technologies are suitable for small-, medium- and larger-scale agricultural businesses. There are various outreach methods available to suit a range of extension audiences, as a single method or technology cannot be considered a 'silver bullet' to achieve a sustainable solution. Competitions and online learning programmes can build awareness, while crop-based projects and extension programmes can field-test promising technologies. Many of the outreach methods typically used for reaching growers, traders, storage operators, transporters and marketers do not yet fully incorporate the many topics related to clean cold-chain development and management. A synergistic collaboration with different sectors, development of appropriate curriculum and training programme designs for different food supply chain actors and service providers, and effective implementation of various outreach methods, including training-of-trainers programmes and local post-harvest innovation platforms, will be essential for successful clean cold-chain development.

References

AGRA, 2016. Major initiative to boost cold storage capacity in Africa launched at Economic Forum in Rwanda. AGRA, 11 May. [https://agra.org/news/major-initiative-to-boost-cold-storage-capacity-in-africa-launched-at-world-economic-forum-in-rwanda/]. Accessed 24 December 2018.

Bello-Bravo J, Lutomia AN, Pittendrigh BR, 2018. Scientific Animation Without Borders (SAWBO) addressing educational gaps around value chains pertaining to postharvest losses. In: Mohammed M, Tokala VY, eds. *Postharvest extension and capacity building for the developing world*. Boca Raton, FL: CRC Press, 109-20.

Chintada VG, Satyanarayana KV, Manyam SC, Srilasya NK, Swati H, 2017. *Cold chain technologies – transforming food supply chains*. New Delhi: The Associated Chambers of Commerce and Industry of India (ASSOCHAM). [https://www.sathguru.com/news/wp-content/uploads/2017/05/Cold-Chain-Report.pdf]. Accessed 25 December 2018.

ColdHubs, 2018. ColdHubs: solar powered cold storage for developing countries. [http://www.coldhubs.com/]. Accessed 26 December 2018.

Dearman, 2014. *The cold economy – a liquid air solution for the developing world*. Liquid Air Energy Network, UK. [http://dearman.co.uk/wp-content/uploads/2016/05/The-cold-economy.pdf]. Accessed 25 December 2018.

FAO, 2009. *How to feed the world in 2050*. [Proceedings of the High-Level Expert Forum, 24-26 June 2009]. Rome: Food and Agriculture Organization of the United Nations. [http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf]. Accessed 24 December 2018.

FAO, 2018. FAO – food loss analysis case study methodology. [http://sdghelpdesk.unescap.org/e-learning/Food-loss-analysis-case-study-methodology]. Accessed 18 March 2019.

Food Loss Challenge Asia, 2018. Food Loss Challenge Asia. [https://www.foodlosschallenge.asia/]. Accessed 12 January 2019.

GAIN, 2018. Our programs [Postharvest Loss Alliance for Nutrition (PLAN)]. Glbal Alliance for Improved Nutrition. [https://www.gainhealth.org/programs/postharvest-loss-alliance-for-nutrition/]. Accessed 26 December 2018.

Global LEAP Awards, 2018. The Global LEAP Awards — Global LEAP. [https://globalleapawards.org/]. Accessed 12 January 2019.

Global Panel, 2018. *Preventing nutrient loss and waste across the food system: policy actions for high-quality diets*. Policy Brief No. 12. London: Global Panel on Agriculture and Food Systems for Nutrition.

Gustavsson J, Cederberg C, Sonesson U, van Otterdijk R, Meybeck A, 2011. *Global food losses and food waste – extent, causes and prevention*. Rome: Food and Agriculture Organization of the United Nations. [http://www.fao.org/3/a-i2697e.pdf]. Accessed 24 December 2018.

Kaplan AM, Haenlein M, 2016. Higher education and the digital revolution: About MOOCs, SPOCs, social media, and the Cookie Monster. *Business Horizons*, 59(4), 441-450.

Kitinoja L, 2013a. *Use of cold chains for reducing food losses in developing countries*. PEF White Paper No.13-03. La Pine, OR: Postharvest Education Foundation, La. [http://postharvest.org/Cold_chains_PEF_White_Paper_13_03.pdf]. Accessed 24 December 2018.

Kitinoja L, 2013b. *Returnable plastic crates (RPC) systems can reduce postharvest losses and improve earnings for fresh produce operations*. PEF White Paper No.13-01. La Pine, OR: Postharvest Education Foundation. [http://postharvest.org/RPCs_PEF_White_Paper_13_01.pdf]. Accessed 26 December 2018.

Kitinoja L, 2014. *Exploring the potential for cold chain development in emerging and rapidly industrialising economies through liquid air refrigeration technologies*. Liquid Air Energy Network, UK.

Kitinoja L, Barrett DM, 2015. Extension of small-scale postharvest horticulture technologies – A model training and services center. *Agriculture,* 5(3), 441-455.

Kitinoja L, Kader AA, 2015. *Small-scale postharvest handling practices: a manual for horticultural crops*, 5th edn. Davis, CA: Postharvest Technology Research and Information Center, University of California, Davis. [https://ucanr.edu/sites/Postharvest_Technology_Center_/files/231952.pdf]. Accessed 26 December 2018.

Kitinoja L, Tokala VY, 2018. Postharvest education, training and capacity building for reducing losses in plant-based food crops – a critical review (2010-2017). In: Mohammed M, Tokala VY, eds. *Postharvest extension and capacity building for the developing world*. Boca Raton, FL: CRC Press, 29-40.

Kitinoja L, Tokala VY, Brondy A, 2018. Challenges and opportunities for improved postharvest loss measurements in plant-based food crops. *Journal of Postharvest Technology*, 6(4), 16-34.

Martin J, 2012. Another zero-emissions powerplant emerges – the Dearman Engine runs on liquid air. New Atlas, 24 January. [https://newatlas.com/dearman-zero-emissions-engine/21201/]. Accessed 25 December 2018.

McNamara P, Tata JS, 2015. Principles of designing and implementing agricultural extension programs for reducing post-harvest loss. *Agriculture*, 5(4), 1035-1046.

MIT D-Lab, 2018. Evaporative cooling for vegetable preservation. [https://d-lab.mit.edu/research/food/evaporative-cooling-vegetable-preservation]. Accessed 29 December 2018.

N'chekwa, 2018. *ColdHubs Newsletter*, December 2018.

NCCD, 2015. *All India cold-chain infrastructure capacity (assessment of status & gap)*. New Delhi: National Centre for Cold-chain Development. [https://www.nccd.gov.in/PDF/CCSG_Final%20Report_Web.pdf]. Accessed 12 January 2019.

Nenguwo N, Marealle R, Kessy R, 2018. Lessons learned from a postharvest training and services center in Arusha, Tanzania. In: Mohammed M, Tokala VY, eds. *Postharvest extension and capacity building for the developing world*. Boca Raton, FL: CRC Press, 151-60.

PLAN, 2018. *Putting business to work*. PLAN Case Study Brief. Postharvest Loss Alliance for Nutrition.

Rodriguez P, 2018. InspiraFarms delivers a multi-unit cold storage project in Rwanda. InspiraFarms, 27 November. [http://www.inspirafarms.com/blog_cold-storage-project-rwanda/]. Accessed 11 January 2019.

Strahan D, ed, 2016. *Clean cold and the global goals*. Birmingham, UK: Birmingham Energy Institute, University of Birmingham. [https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/Clean-Cold-and-the-Global-Goals.pdf]. Accessed 25 December 2018.

Tata JS, McNamara PE, 2018. Impact of ICT on agricultural extension services delivery: evidence from the Catholic Relief Services SMART skills and Farmbook project in Kenya. *The Journal of Agricultural Education and Extension*, 24(1), 89-110.

UB, 2018. UK and China scientists develop world-first cold storage road/rail container. University of Birmingham, UK, 21 December. [https://www.birmingham.ac.uk/news/latest/2018/12/scientists-develop-world-first-cold-storage-roadrail-container.aspx]. Accessed 11 January 2019.

Van den Ban AW, Hawkins HS, 1996. *Agricultural extension*. 2nd ed. Oxford, Malden, MA: Blackwell Science.

Wilson CL, 2013. Establishment of a World Food Preservation Center. *Agriculture & Food Security*, 2(1), 1.

Zagory D, Holcroft D, 2018. Global postharvest e-learning programs via The Postharvest Education Foundation. In: Mohammed M, Tokala VY, eds. *Postharvest extension and capacity building for the developing world*. Boca Raton, FL: CRC Press, 89-100.

Newsflash

Launch of Cooling for All Secretariat

Access to cooling is not a luxury. It's about fresh food, safe medicines and protection from heat for populations in a warming world. It's an urgent development challenge that could have important ramifications for our climate. It is an issue of equity that requires fast action to protect the most vulnerable. It is vital for economic productivity by allowing workers, farmers and students to work in comfortable environments.

In response to this urgent development and climate change priority, Sustainable Energy for All (SEforALL) has established a Cooling for All Secretariat to help deliver universal access to cooling.

The Cooling for All Secretariat will serve to promote awareness of the need for universal access to sustainable cooling, provide data and knowledge about the issue, and help coordinate focussed responses.

Universal access to sustainable cooling is a multifaceted challenge and an important one if we are to achieve the Sustainable Development Goals and fulfil the Paris Agreement. Productive economies, a stable climate and millions of lives depend on sustainable access to cooling.

Often thought of through the prism of comfort cooling, the challenge of providing cooling for all goes well beyond air conditioners. The cold chains that support the safe delivery of medicines and the sale of agricultural products are vital to giving families comfort that a vaccine is safe and enabling farmers to sell their goods further afield at a higher price.

The Secretariat will have a number of important objectives. It will develop tools for government and civil society to measure access to cooling and deploy solutions based on cooling needs. It will publish an annual 'Cooling for All outlook' to benchmark progress on closing access-to-cooling gaps while setting required targets. It will work with industry, donors and international organisations to design pilot projects.

As temperatures soar, populations grow and cities expand, these actions are necessary if we are to achieve the speed and scale needed to deliver sustainable and affordable access to cooling for all.

Governments, cities, the private sector and the international community have to take urgent action to finance and demonstrate solutions that meet the cooling needs of those most at risk.

This includes focussing on innovations and investments to keep agricultural cold chains clean and intact to reduce hunger and malnutrition, increase the income of poor farmers, and drastically reduce food wastage.

In rural villages, renewable energy can power cold storage in medical clinics, so that families can take their children to be vaccinated with confidence that it will be effective.

Cities can employ simple tools such as painting roofs white and planting more trees to mitigate high temperatures and protect workers from heat so they can be more productive. The employment of district cooling and other solutions will also reduce overall energy demand for cooling and lessen reliance on inefficient air conditioners and other cooling devices.