The U.S. Government's Global Hunger & Food Security Initiative

EVAPORATIVE COOLING
FOR IMPROVED FRUIT & VEGETABLE STORAGE IN RWANDA & BURKINA FASO

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Appendix
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USAID FROM THE AMERICAN PEOPLE

HORTICULTURE INNOVATION LAB

UC DAVIS UNIVERSITY OF CALIFORNIA

MIT D-Lab

MIT D-Lab

MIT D-Lab works with people around the world to develop and advance collaborative approaches and practical solutions to global poverty challenges. The program's mission is pursued through interdisciplinary courses, research in collaboration with global partners, technology development, and community initiatives — all of which emphasize experiential learning, community-led development, and scalability. This research was made possible in part through support from Malcom B. Strandberg. D-Lab led the research design, development of the sensors and the survey instruments, data analysis, and preparation of this report.

Agribusiness Associates Inc.

Started by seasoned agribusiness professionals and led by Mr. Gurbinder Singh Gill, Agribusiness Associates Inc. is an international development consulting firm focusing on overcoming the biggest challenges in the agricultural sector. The firm has special expertise in offering comprehensive solutions to the agribusiness sector for enterprise development. Our team brings decades of experience in agricultural marketing, program development and management, agricultural technology and public-private partnerships. This research was made possible through projects implemented by Agribusiness Associates in Rwanda and Burkina Faso.

Horticulture Innovation Lab

The Feed the Future Innovation Lab for Horticulture is a global research network that advances fruit and vegetable innovations, empowering smallholder farmers to earn more income while better nourishing their communities. The program's research portfolio spans the value chain of fruit and vegetable production, from seed systems to postharvest processing, in Africa, Asia and Central America. The Horticulture Innovation Lab is funded by the U.S. Agency for International Development and led by a team at the University of California, Davis, as part of the U.S. government's Feed the Future initiative.

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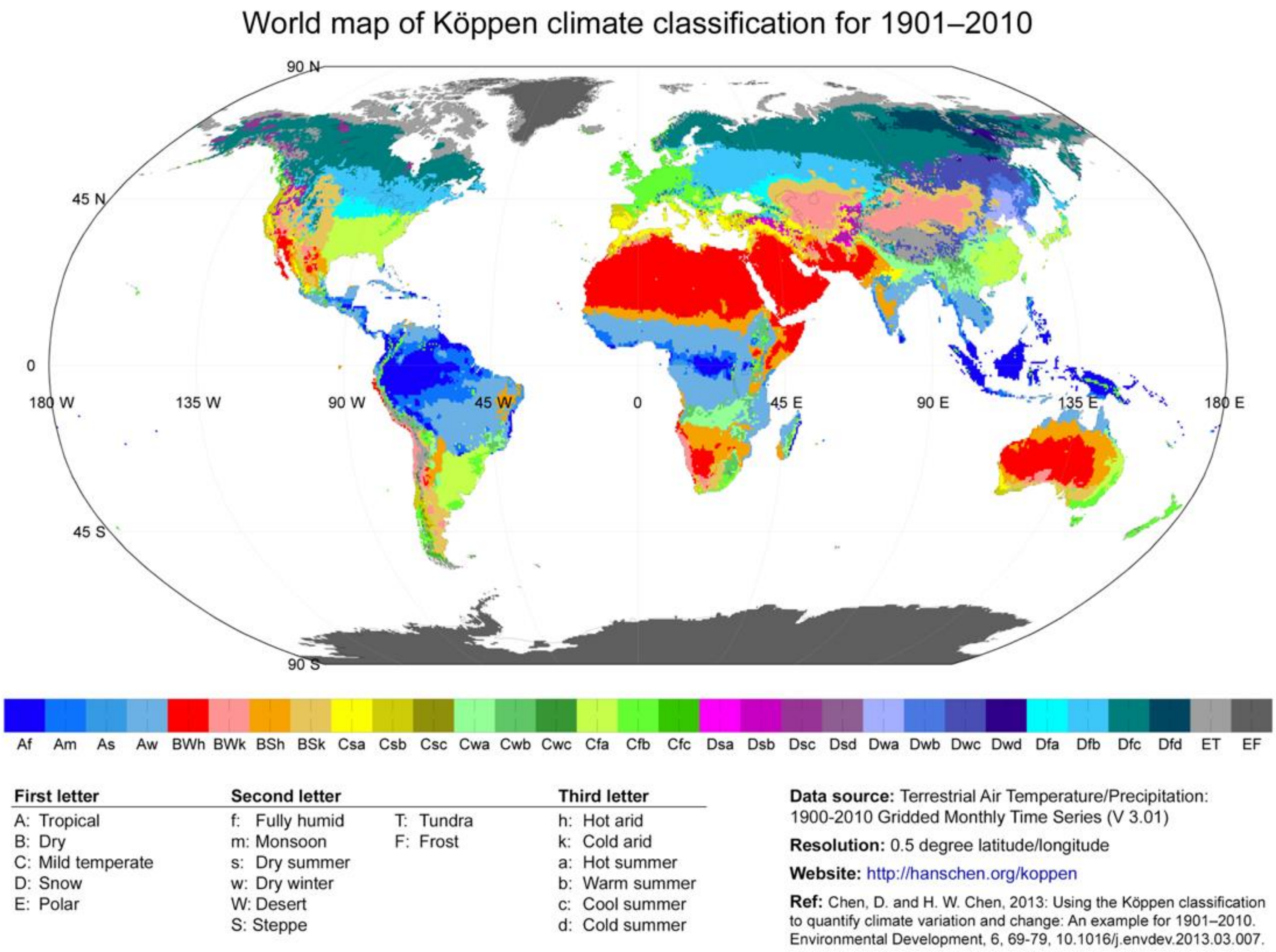
Appendix 1. Figures and Tables

Table 1. Evaporative cooling devices evaluated in this study

The table below indicates the number of each cooling and storage device type and where it is located.

Evaporative cooling device	Region				Total
	Mulindi, Rwanda	Rubona, Rwanda	Busogo, Rwanda	Kamboinse, Burkina Faso	
Brick ECC	1	1	1	1	**4**
Clay pot in clay pot	1	1	1	1	**4**
Plastic container in clay pot	1	1	1		**3**
Metal container in clay pot	1	1	1		**3**
Clay pot in plastic dish	1	1	1		**3**
Plastic container in clay dish				1	**1**
Clay pot in metal dish				1	**1**
Clay pot in plastic dish				1	**1**
Totals	5	**5**	**5**	5	**20**

Figure 1. Koppen climate map



Evaporative cooling would be most effective in the areas classified as:
“Dry-Desert-Hot summer” climates (BWh represented in red) and
“Dry-Steppe-Hot summer” climates (BSh represented in orange).

Figure 2. Photos of evaporative cooling chambers (EEC)

Above are images of a brick evaporative cooling device at various locations in Rwanda.


Above are images of a brick evaporative cooling device in Rubona, Rwanda.



Above are images of a brick evaporative cooling device in Kamboinse, Burkina Faso.

Figure 3. Photos of clay pot coolers

Above are images of clay pot coolers with a clay pot in clay pot configuration at various locations in Rwanda.

Above are images of clay pot coolers with a plastic container in a clay pot configuration at various locations in Rwanda.

Above are images of clay pot coolers with a metal container in a clay pot configuration at various locations in Rwanda.

Above are images of clay pot coolers with a clay pot in a plastic dish configuration at various locations in Rwanda.

Figure 4. Sensor data collection equipment

The data-logger design for the study was developed in partnership with Sensen (http://www.sensen.co). Sensen develops low-cost, low-power and long-lasting dataloggers for use in remote settings. The products feature high modularity, designed around a central, adaptable datalogger. For this study, the central datalogger was connected to the following sensors:

- DHT22 sensors (3) to measure relative humidity and temperature
- BME380 sensors (2) to measure relative humidity, temperature, and pressure
- Soil moisture sensors (4) from Sparkfun (SEN-13322) to measure the moisture content of the sand.

Data was stored locally on a microSD card and retrieved from the data logger via bluetooth on an android device (phone or tablet) by field staff, which is then uploaded via a WiFi connection to a cloud-based data storage system.

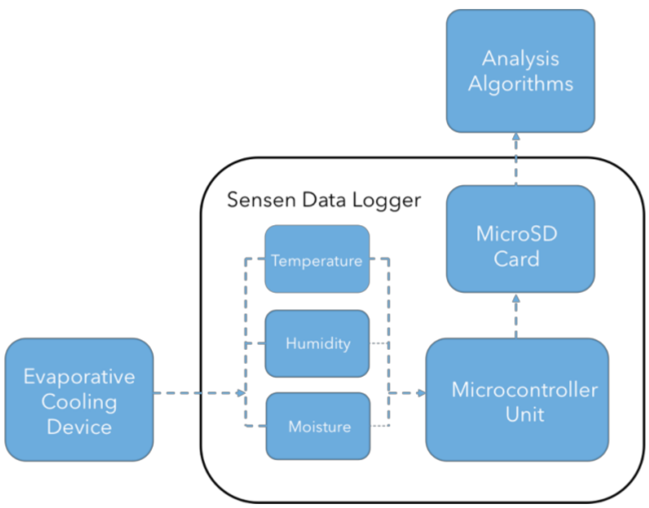
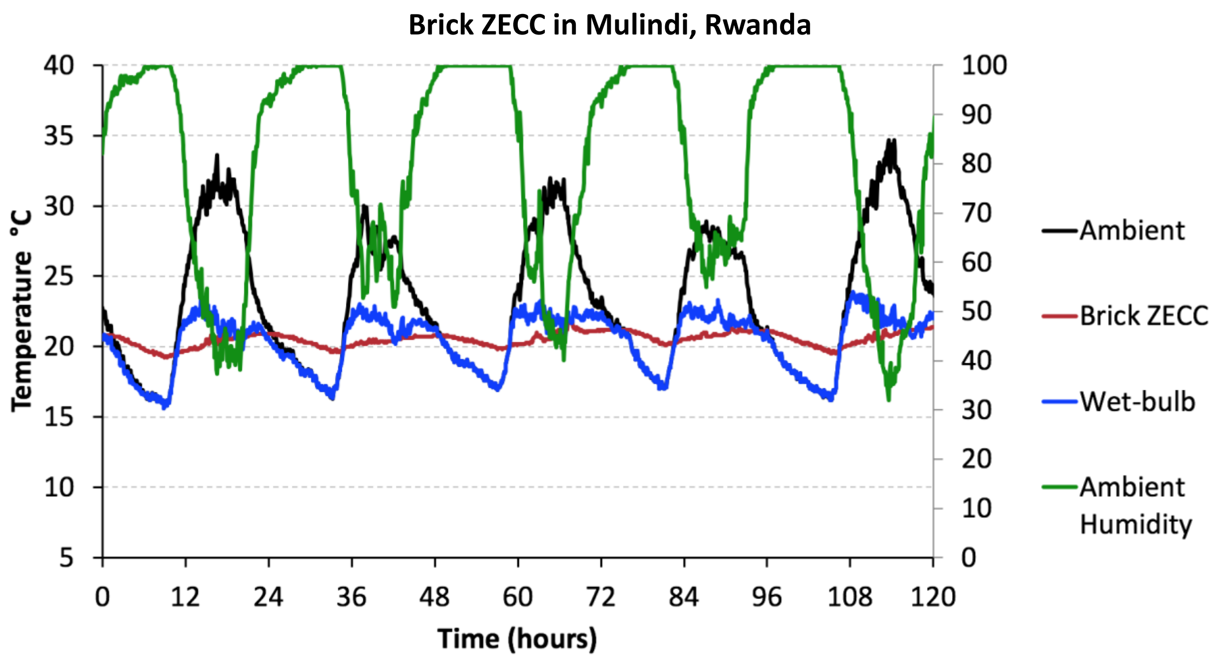


Figure 5. Additional ZECC sensor data



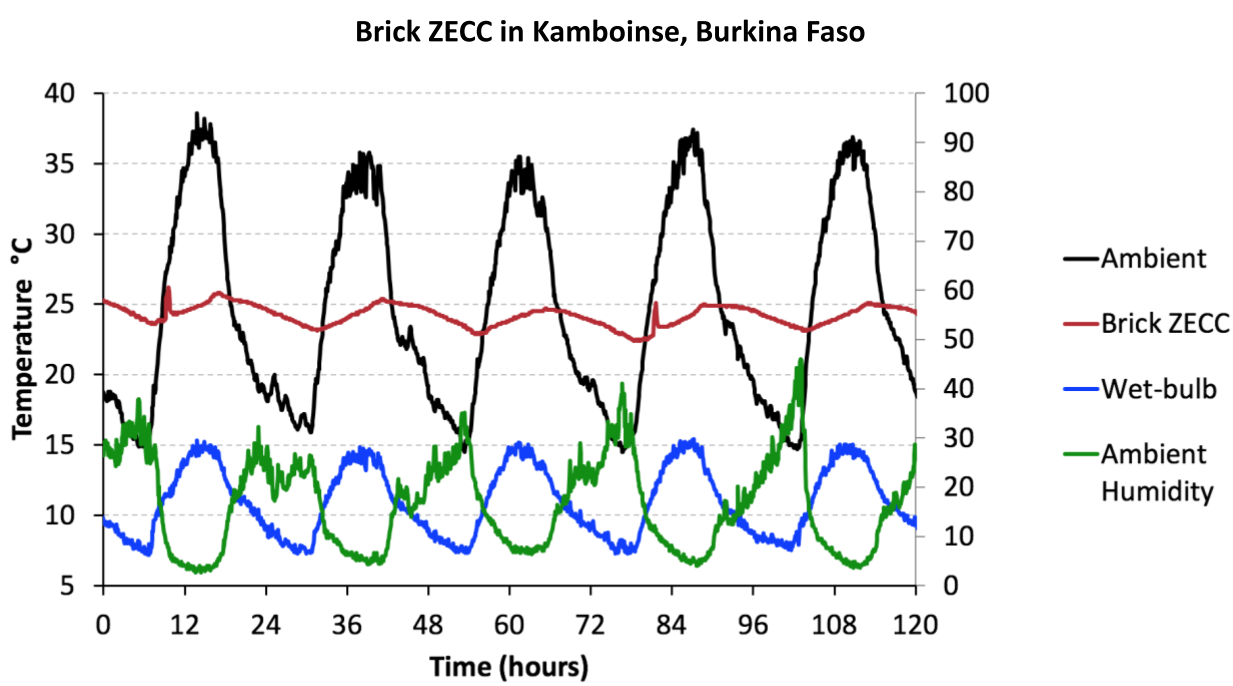
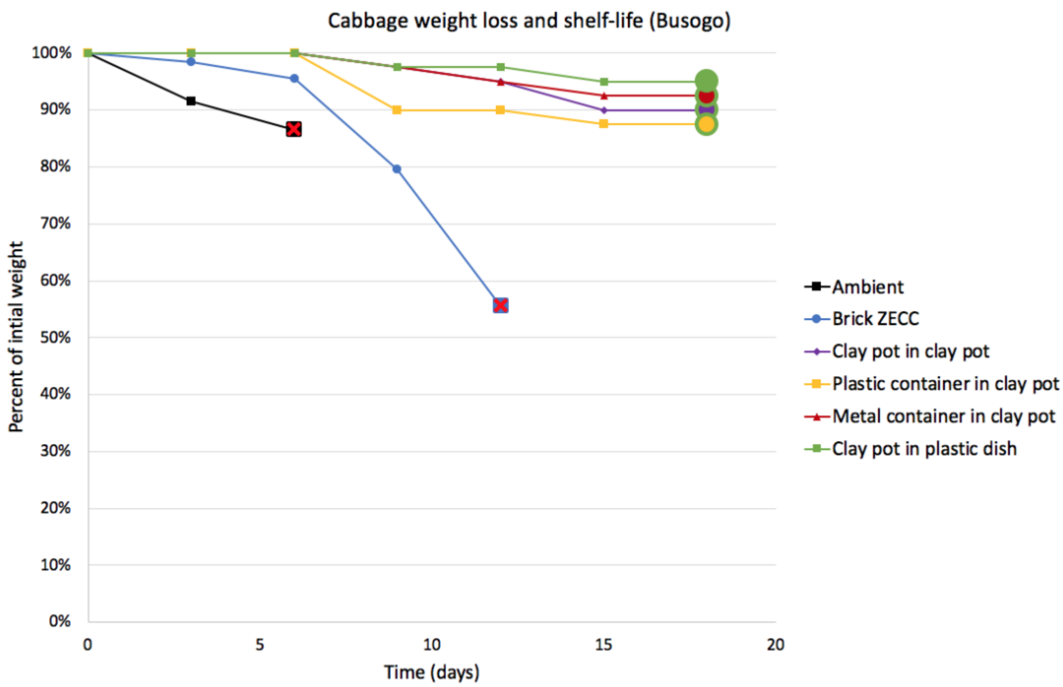


Figure 5. Busogo, Rwanda Vegetable Shelf-Life

In the plots below the weight loss is shown as a percentage of the initial weight of the vegetable placed in the storage device. The ending data points with a circle with a green border represent chili pepper that was determined to be fully ripe at the conclusion of the experiment. The ending data points with a square and a red "X" represent chili pepper that was fully spoiled at the point of the experiment indicated.



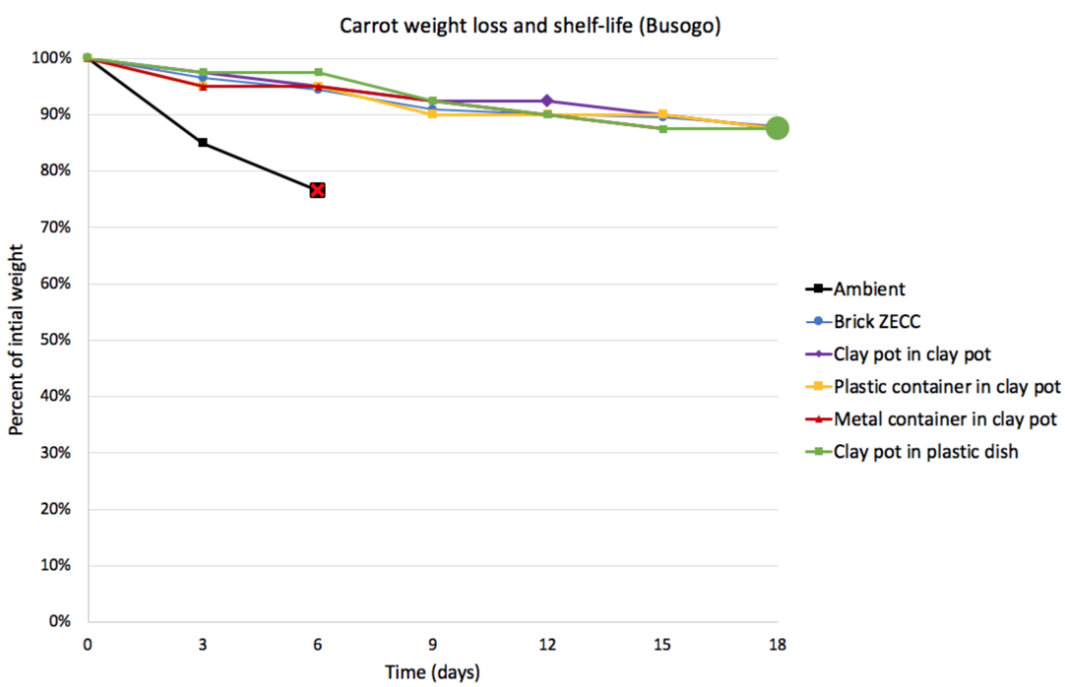
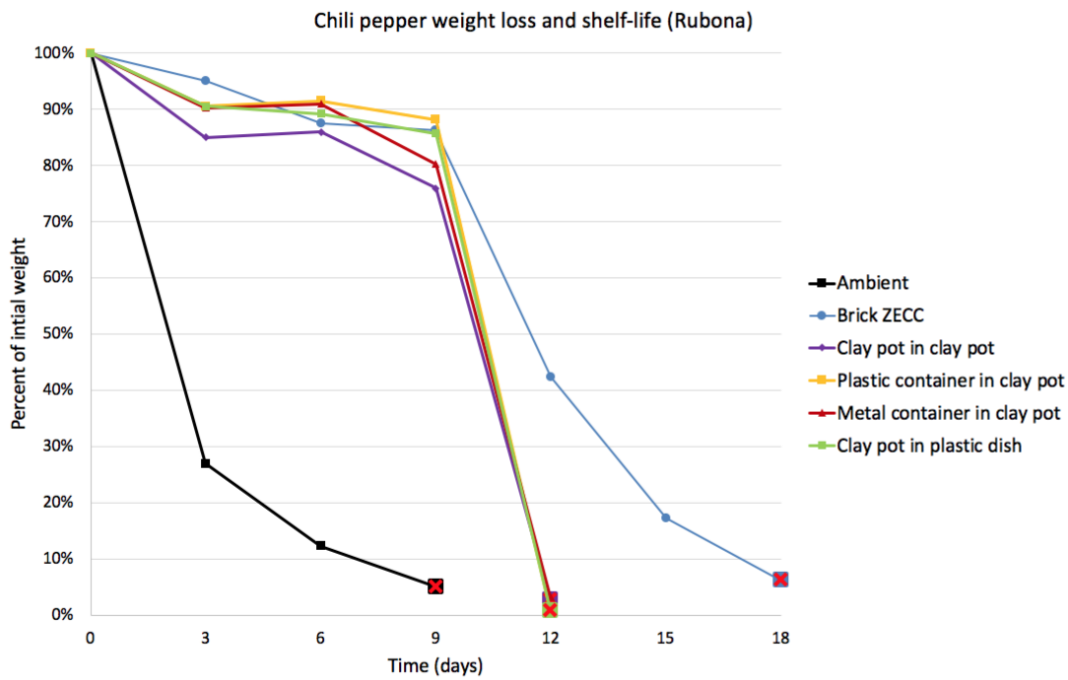


Figure 6. Rubona, Rwanda Vegetable Shelf-Life

In the plots below the weight loss is shown as a percentage of the initial weight of the vegetable placed in the storage device. The ending data points with a circle with a green border represent chili pepper that was determined to be fully ripe at the conclusion of the experiment. The ending data points with a square and a red "X" represent chili pepper that was fully spoiled at the point of the experiment indicated.



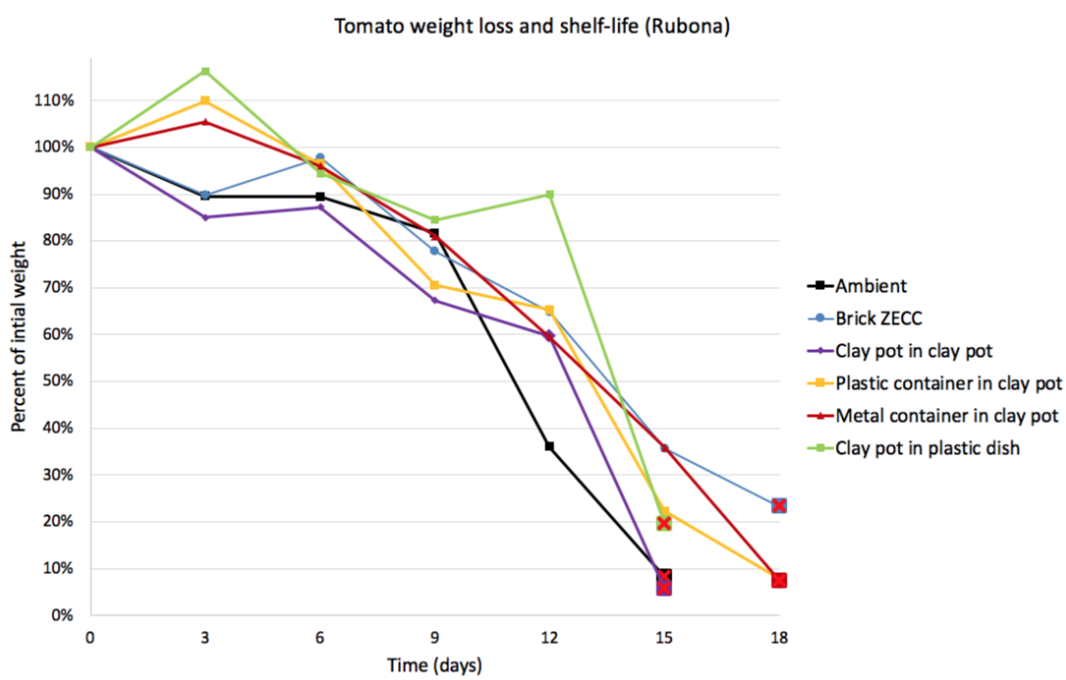
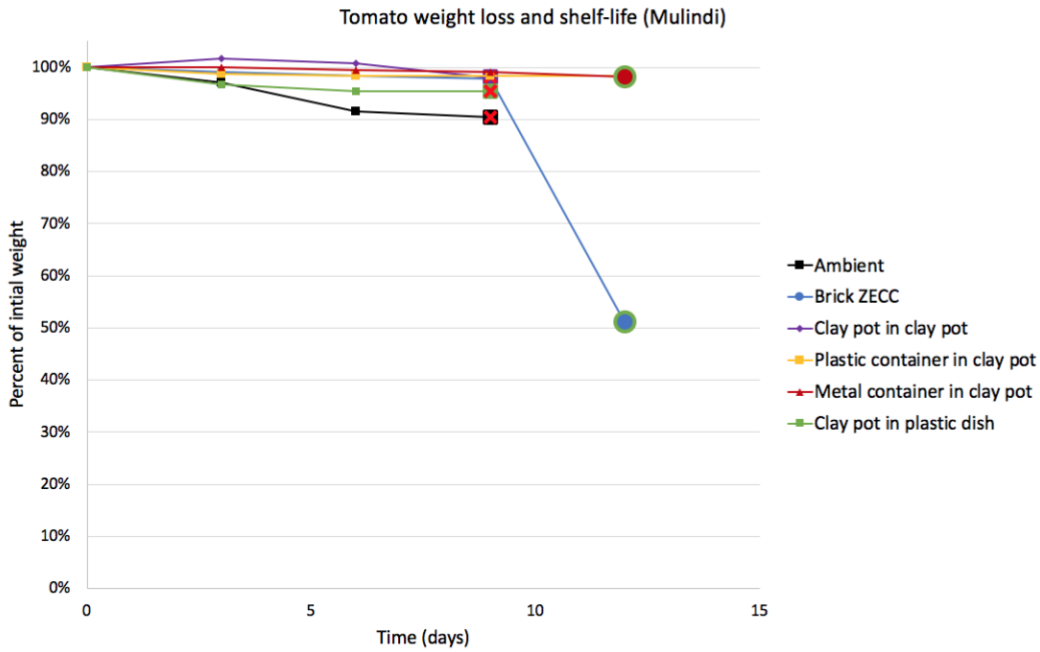
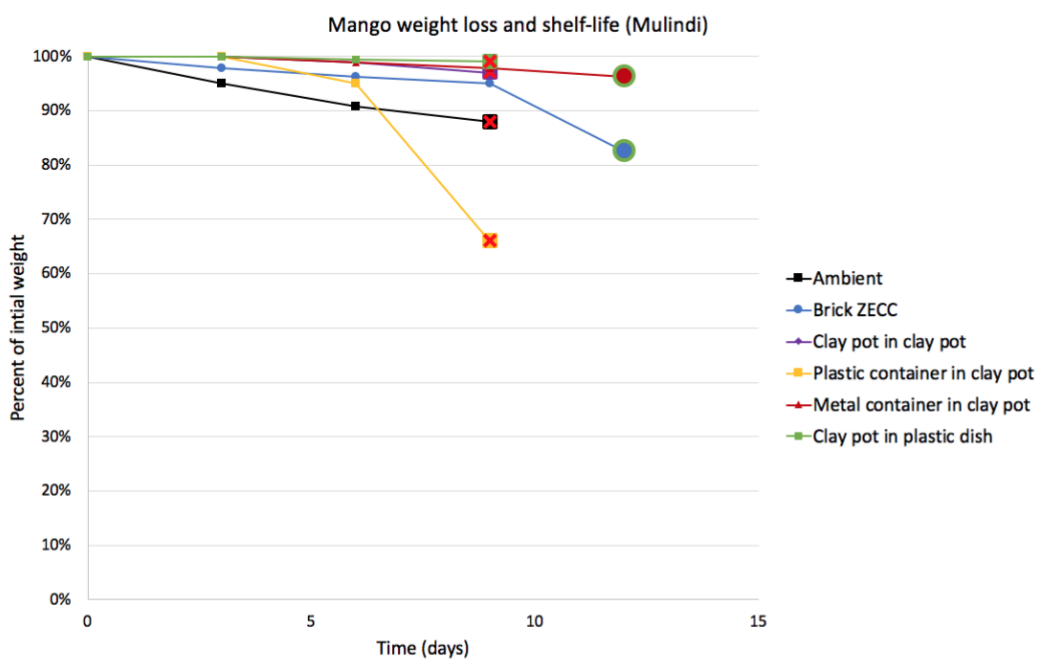
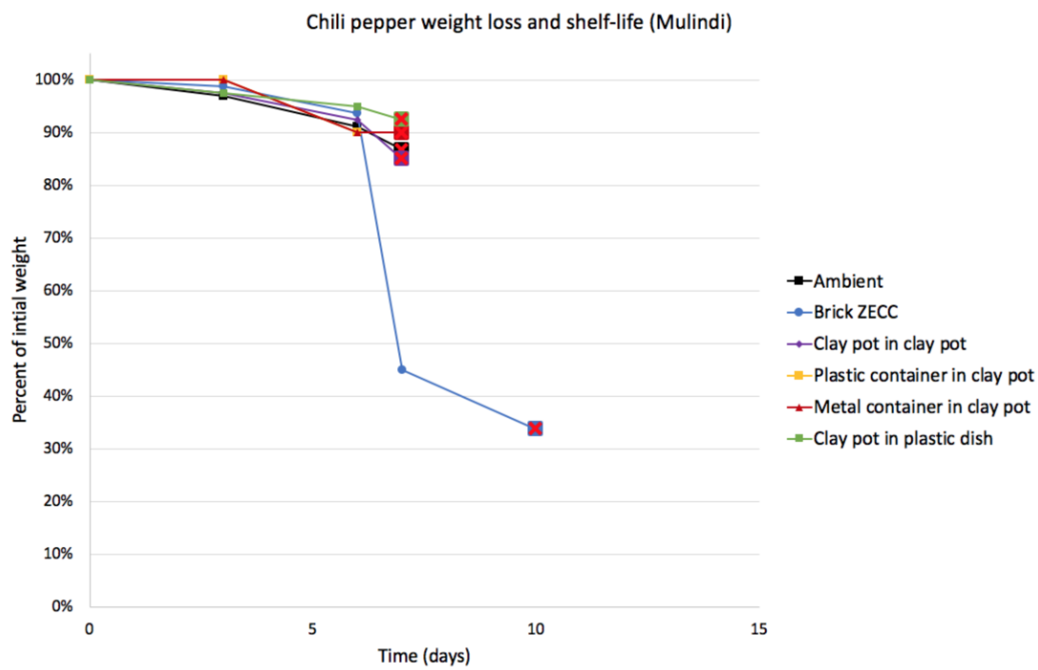


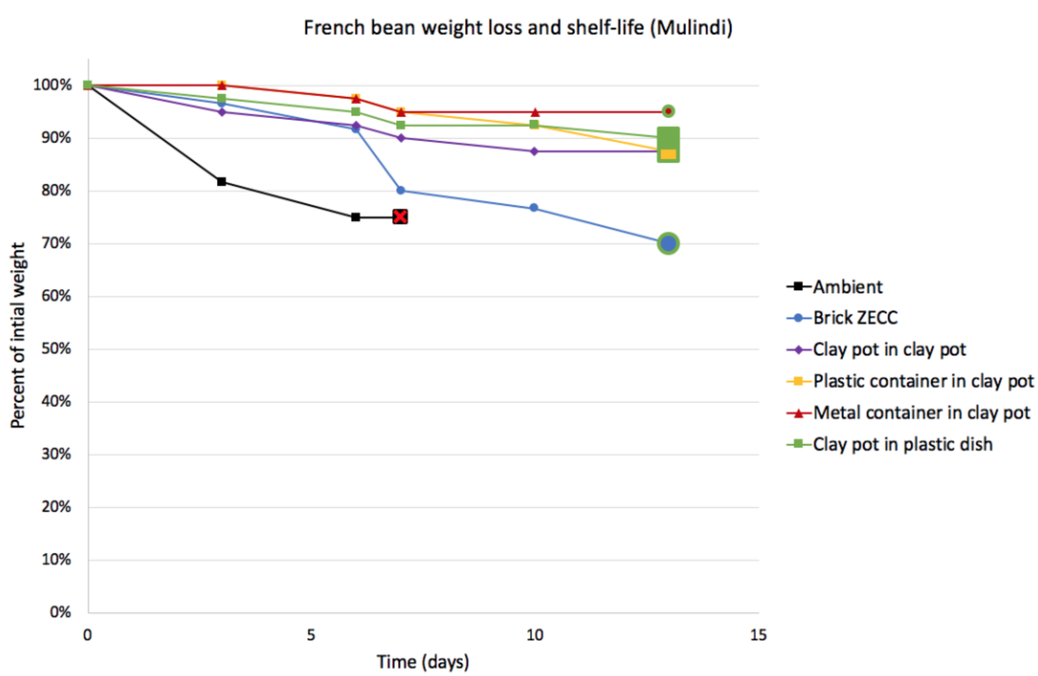
Figure 7. Mulindi, Rwanda Vegetable Shelf-Life

In the plots below the weight loss is shown as a percentage of the initial weight of the vegetable placed in the storage device. The ending data points with a circle with a green border represent chili pepper that was determined to be fully ripe at the conclusion of the experiment. The ending data points with a square and a red "X" represent chili pepper that was fully spoiled at the point of the experiment indicated.






Chili pepper weight loss and shelf-life (Mulindi)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of intial weight
0
5
10
15
Time (days)
Ambient
Brick ZECC
Clay pot in clay pot
Plastic container in clay pot
Metal container in clay pot
Clay pot in plastic dish


French bean weight loss and shelf-life (Mulindi)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of intial weight
0
5
10
15
Time (days)
Ambient
Brick ZECC
Clay pot in clay pot
Plastic container in clay pot
Metal container in clay pot
Clay pot in plastic dish

Appendix 2. Questionnaires for Interviews

Questionnaire 1. Users and non-users of evaporative cooling devices

Survey No: ___________

A. INTRODUCTION

1. Good morning/afternoon. My name is ______________. I am part of the Reducing Postharvest Losses in Rwanda project, conducting a survey related to vegetable production, consumption and storage in your area. We would like to ask you some questions that should take no more than 30 minutes of your time. Your name will not appear in any data that is made publicly available. If you do agree to participate in this interview feel free to decline to answer any of the questions. Do you consent to be interviewed?
2. Does the respondent agree to participate in the survey? Yes *(tick)* [ ]
3. Name of respondent ________________
4. Enter the phone number of the respondent ________________
5. Enter the Region ________________
6. Enter the Village ________________
7. Please record GPS (if possible) _______________

B. GENERAL HOUSEHOLD ASSESSMENT

I would like to ask some questions about your household / family

1. Gender: Male [ ] Female [ ]
2. How old are you?
3. What is your position in the household?
4. How many people live in your household?
5. How many people are under 18 years old?
6. What is the primary source of livelihood or income in your household?\
7. Do you or others in your household have any other jobs or roles in the community?
8. Do you belong to any organizations or community groups? If yes, what type of group?

   [Example: Farmers' association, cooperative, NGO, savings group]

   a. [If yes] What type of group?
   b. [If no] Does ANYONE ELSE in your household belong to any organizations or community groups? If yes, what type of group?

      [Example: Farmers' association, cooperative, NGO, savings group]
9. Do you or anyone in your household produce or farm any food products? What types of crops are grown?

C. PRODUCTION AND PURCHASE OF AGRICULTURAL PRODUCTS

1. Do you or anyone in your family grow vegetables? YES [ ] NON [ ]
   [Facilitate with examples with production of vegetables, cereals, fruits, legumes]

	Vegetable type			
Where do you produce these crops?				
What time of year are these vegetables harvested?				
Are the crops grow consumed or sold?				
Where you sell the crops?				
How much do you sell these crops for? (Are there seasonal or other variations in the price?)				
How do you transport the products for sale?				
kg sold per week				
kg of vegetable spoilage				
Storage method (material, price, as many details as possible)				

2. Does your household / family buy fruits or vegetables? YES [ ] NO [ ]
   [Facilitate with examples with production of vegetables, cereals, fruits, legumes]

	What kind of food is purchased?	Where do they buy them?	How far away is this place?	How often do you go to this place?	What quantity of vegetables is purchased?	How much does this quantity of vegetables cost?
	Example: ***bananas***	***Weekly market***	***5 km***	***Once each week***	***5 kg per week***	***2000 Fcfa for 1 kg***
1.						
2.						
3.						

D. VEGETABLES AND STORAGE

1. For the foods you mentioned, what storage methods do you use for each?
   [Ask individually for each type of food]

Type of food	What type of storage do you use?	With this method, how long do you typically store this food?	With this method, how long until this food spoils?	What are the reasons for spoilage?	Are there any other storage methods you would prefer for this food?
***Example:* okra**	***Metal container***	***4 days***	***6 days***	***mold***	***4 days***

2. I would like to understand a little more about your stated storage methods

Specified storage type	Does this form of storage use electricity?	How much food can you store with this method?	What are the benefits of this storage method?	What are the weaknesses of this storage method?	How much does this method of storage cost you?
***Example:* Metal container**	***No***	***50-60 kg***	***Extends the shelf life of vegetables***	***Regular follow-up is required***	***$200 to make, nothing to operate***

3. Are there any other methods of storing food that you would prefer to use? YES [ ] NO [ ]

Which storage method do you prefer?	Why do you prefer this storage method?	Why you are not using this method of food storage?	How much will this storage method cost you for the purchase and / or operation?
Example : refrigerator	***Long shelf life***	***I don't know where to buy it / No electricity***	***Do not know***

We thank you for accepting to be interviewed and for spending your valuable time with us.

Questionnaire 2. Fruit or vegetable vendors

Survey No: ___________

Good morning/afternoon. My name is _______________. I am part of the Reducing Postharvest Losses in Rwanda project team, conducting a survey related to vegetable production, consumption and storage in your area. We would like to ask you some questions about products that you sell. This interview should take no more than 15 minutes of your time. Your name will not appear in any data that is made publicly available. If you do agree to participate in this interview feel free to decline to answer any of the questions. Do you consent to be interviewed?

8. Does the respondent agree to participate in the survey? Yes *(tick)* [ ]
9. Name of respondent _________________ Phone number of the respondent _________________
10. Enter the region and location of vendor _________________

Ask the following questions about each fruit or vegetable the vendor sells	**Fruit or Vegetable type** (*Examples: tomtatoes, mangos, avacados, bannans, pineapple*)			
Where do you purchase this food?				
How much do you purchase this food for? Are there seasonal or other variations in the price?				
How much do you sell this food for? Are there seasonal or other variations in the price?				
How many kg do you sell per day? (or other units)				
Do you have any issues with spoilage of this food?				
How many kg of vegetable spoilage per day? (or other units)				
What method of storage do you use for this food? (material, price, as many details as possible)				
Would you prefer another method of storage? If so, what type of storage and what benefits would this provide?				

We thank you for accepting to be interviewed and for spending your valuable time with us.

Questionnaire 3. Clay pot and container vendors

Survey No: ___________

Good morning/afternoon. My name is _______________. I am part of the Reducing Postharvest Losses in Rwanda project team, conducting a survey related to vegetable production, consumption and storage in your area. We would like to ask you some questions about products that you sell. This interview should take no more than 15 minutes of your time. Your name will not appear in any data that is made publicly available. If you do agree to participate in this interview feel free to decline to answer any of the questions. Do you consent to be interviewed?

11. Does the respondent agree to participate in the survey? Yes *(tick)* [ ]
12. Name of respondent _________________ Phone number of the respondent _________________
13. Enter the region and location of vendor _________________
14. Ask the vendor what type of items they sell and fill out the table below
    ***[Examples: clay pots, metal or plastic containers*]**

Product type **(take photographs and describe the materials and size of the product)**	What is this product typically used for?	How much does this product cost?	How many do you sell per week?	Who typically purchases this product?	Will you deliver this product to a customer?

We thank you for accepting to be interviewed and for spending your valuable time with us.

Authors & Acknowledgements

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Dr. Verploegen received a Ph.D. from the Massachusetts Institute of Technology in Polymer Science in Technology and joined D-Lab's research group in 2014. He has over 10 years of experience developing technologies for the energy sector, including waste remediation systems for the oil and gas industry and solar cells. He is passionate about helping organizations based in low-income regions identify technologies, products, and distribution strategies to increase energy access and improve agricultural productivity in their communities.

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Ms. Ekka is an International Development Consultant with ten years of experience in agriculture and inclusive finance with expertise in agricultural value chain development and finance, postharvest management, business development and microfinance. She is passionate about scaling up impact-oriented solutions using an inclusive multi-stakeholder approach. She is the Project Manager for Reducing Postharvest Losses in Rwanda Project and Improving Postharvest Practices for Tomatoes in Burkina Faso Project. Ms. Ekka received an MBA from University of California, Davis in 2015.

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Mr. Gill has 24 years in agricultural value chain, business development, public-private partnerships (PPPs), corporate affairs (government and industry associations) and business cycle (startup, turnaround, M&A prospecting, integration) in India and international markets, covering corporate strategy including market entry, sales and marketing, project management, and acquisitions and managing integrations. Mr. Gill is an innovative and performance-oriented agribusiness leader with proven success in managing relationships and fostering collaboration with various stakeholders to support strategy execution.

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