Issue 160 • July 2023

edn

ECHO Development Notes

LOW-COST SEED STORAGE TECHNOLOGIES

Farmers and those serving them require reliable and ready access to quality seeds. We explored technologies related to vacuum sealing and desiccants and share our findings in this article.

POST HARVEST HANDLING OF FRESH PRODUCE

Food production is important, but farmers must also protect against crop loss prior to consumption or sale. Improving post-harvest practices helps farmers make profitable sales.

LOCAL TREATMENTS FOR MILLIPEDE CONTROL

We have heard reports of heavy millipede damage from West Africa, but also more recently from Uganda. We are trying to identify locally available products that might reduce damage.

Upcoming Events

Hope Against Hunger

 Selected material from *EDN* 1-100 is featured in the book *Agricultural Options for Small-Scale Farmers*, available from our bookstore (www.echobooks.net) at a cost of US$19.95 plus postage. Individual issues of *EDN* may be downloaded from our website (www.ECHOcommunity.org) as pdf documents in English (51-160), French (91-159) and Spanish (47-159). Earlier issues (1-51, in English) are compiled in the book *Amaranth to Zai Holes*, also available on our website.

ECHO is a non-profit Christian organization.

For further resources, including networking with other agricultural and community development practitioners, please visit our website: www.ECHOcommunity.org. ECHO's general information website can be found at: www.echonet.org.

ECHO
17391 Durrance Road
North Fort Myers, Florida 33917
USA

Editorial Team:
Managing Editor: Tim Motis
Design Editor: Stacy Swartz
Proofreaders: Robert Walle and Kathleen Pignato

Low-Cost Seed Storage Technologies

by Tim Motis

This article summarizes ECHO research published in Experimental Agriculture by Trail et al. (2022).

Introduction

Relevance

Farmers and those serving them require reliable and ready access to quality seeds. Where resources are scarce, farmers obtain as little as 10% of their seeds from commercial sources, relying on informal seed systems for most of their seeds (Coomes *et al.*, 2015). Informal seed sources include seeds that farmers produce themselves, exchange with other farmers, or purchase from local markets. Small-scale community seed banks play an important role in supporting in-country seed networks and crop diversity.

One way you can expand community access to seeds of diverse crops is to build capacity for small-scale seed saving entities to store orthodox ❶ seeds for periods of time longer than annual growing cycles. The ability to store seeds longer than one growing season provides farmers with the option of planting a crop that they may not have grown and saved seeds of in the previous growing season. Additional crop options increase resilience to agricultural challenges such as drought and pests.

❶ Orthodox seeds tolerate desiccation and can be stored under dry and freezing conditions. Examples of crops that produce orthodox seeds include cereal grains, legumes, and most vegetables.

Seed storage requirements

Prior to storage, seeds must be dry enough ❷ to prevent the growth of fungi such as *Aspergillus* spp. (Reader and Motis, 2017). Reducing seed moisture is particularly important for newly harvested seeds, as they may still have moisture from the field. Drying seeds in preparation for storage can be done with a simple seed drying cabinet, described by Motis (2010) in an *ECHO Technical Note* entitled 'Seed Saving: Steps and Technologies'.

❷ How dry should seeds be to prevent mold? The answer varies with crop and fungi species. Seed storage fungi will generally not be able to grow at seed moisture contents of less than 12% to 14% (Martin *et al.* 2022). Seed moisture is influenced by the humidity of the surrounding air. To prevent mold growth and stabilize seed moisture at acceptable levels, keep humidity levels below 65%.

Here we focus on storing seeds that have already been processed to remove field moisture, debris, and pests. Factors that affect seed storage life are seed moisture, temperature, and oxygen levels. Store seeds dry and cool, and under low oxygen. These conditions slow the metabolism of seeds, thereby prolonging storage life. In tropical environments, the main constraints to seed storage are high humidity and heat.

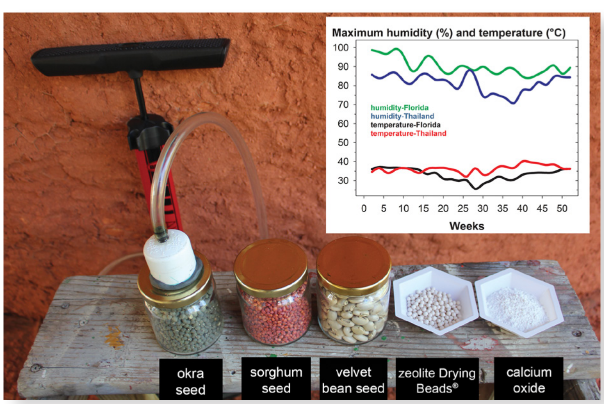

Figure 1. Technologies and ambient humidity and temperature under which seeds of okra, sorghum, and velvet bean were stored for a one-year period in Florida and Thailand. *Source:* Tim Motis

Research purpose

Many smallholder farmers in the tropics do not have electricity or access to equipment for climate-controlled seed storage. There are, however, low-cost technologies that can be used instead. The main objective of this research, therefore, was to test the effectiveness of some of these technologies for *keeping seeds dry* in a hot and humid environment. Our research is relevant to situations in which you 1) have already processed harvested seeds in preparation for storage or 2) need to store seeds that you have acquired (e.g., from a seed store) that are already dry.

Technologies tested

We explored technologies related to vacuum sealing and desiccants (Figure 1). Vacuum sealing removes air—along with water vapor and oxygen it contains—from a container. With less water vapor, humidity is reduced. Less oxygen not only slows respiration but reduces the activity of any insect pests that may be present. ECHO research in Asia showed that vacuum sealing, over a one-year period, prevented the population growth of bruchids (*Callosobruchus maculatus*) in cowpea seeds (Lawrence *et al.*, 2017).

We compared two vacuum-sealing technologies: a machine-sealer and a modified bicycle pump. The machine sealer withdraws air from polyethylene (plastic) bags. Of the two technologies, the machine sealer is the most expensive (300 USD or more). It is used primarily for food processing. Bicycle pumps are inexpensive (15 USD or less) and available worldwide. We used a modified bicycle pump to remove air from small (118 ml [4 oz.]) glass jars with plastic-lined, metal lids. An *ECHO Technical Note* entitled Vacuum-Sealing Options for Storing Seeds (Motis, 2019) explains how to modify and operate a bicycle pump to draw vacuum.❸

❸ Some bicycle pumps are easier than others to modify. The Technical Note explains why this is so. Also, at the bottom of the section on bicycle pumps, note instructions for modifying a pump with fewer parts.

Desiccants absorb moisture from the air, thus lowering humidity in the air surrounding seeds. We explored the use of two desiccants: Drying Beads® and calcium oxide. Drying Beads® are a zeolite-based product that absorbs water, holding it in microscopic pores. They are manufactured in Thailand by Rhino Research and have been used primarily in Asia. Information on their use is available on the manufacturer's website (http://www.dryingbeads.org/) which states that beads saturated with moisture can be reused by heating in an oven for two and-a-half hours at 250°C.

Calcium oxide, also known as burnt lime, is a powder made by subjecting calcium-carbonate-containing materials–like limestone, seashells, or wood ash–to high heat (500 to 1000°C [Teker Ercan, 2003; Suwannasingha *et al.*, 2022]). Combustion temperature influences the extent to which calcium carbonate will convert to calcium oxide. We have been able to achieve temperatures of 600°C and higher with a small forge used by blacksmiths. As calcium oxide absorbs water it converts to calcium hydroxide.❹ It is possible to convert calcium hydroxide back to calcium oxide, for reuse, by heating at 450 to (Materic and Smedley, 2011) to 600°C (Powers and Calvo, 2003).

❹ CAUTION This reaction produces heat. This is not a problem when absorbing water vapor in air, but do not allow calcium oxide to mix with water as a liquid. Also, avoid breathing in the dust of calcium oxide powder. In using calcium oxide for keeping seeds dry, place the calcium oxide in an envelope or cloth to avoid direct contact of the seeds with the calcium oxide.

To be effective, vacuum-sealing and desiccant approaches require hermetic (airtight) containers. The entry of air into a poorly sealed container causes loss of vacuum and faster desiccant saturation than with an airtight lid. Thus, we used glass jars with screw-on lids in conjunction with vacuum sealing and desiccants. In seed banks with climate-controlled storage space, desiccants may be removed from seeds once the seeds are dry enough for storage. We kept the desiccant with the seeds being stored, as this would be preferable in situations where ambient humidity cannot be controlled and could otherwise rehydrate the seeds.

Methods

When and where

We conducted the trial over a one-year period between 11 July 2017 and 16 July 2018. The study was implemented at two sites: the ECHO Asia Regional Impact Center in Chiang Mai, Thailand and at ECHO in Florida, USA. At each location, seed containers were kept in cardboard boxes outside under the ambient conditions (see Figure 1)

Figure 2. Containers used in evaluating seed storage treatments. *Source:* Nate Flood

❺ This meter works by heating the seeds (at a high temperature [at 120°C on the automatic mode]) until they stop losing weight. The machine calculates seed moisture by taking the difference between initial and final weight (initial weight minus final constant weight) and dividing that number by the initial weight. You can do this in an oven if you do not have a moisture meter. Crushing the seeds helps you achieve a constant weight more quickly than if you leave the seeds intact.

of screened-in porches. This allowed us to approximate the context in which many smallholder farmers in the world store their seeds.

Treatments

Treatments involved the previously mentioned technologies aimed at controlling humidity in seed storage containers. Between temperature and humidity, humidity in containers is easier to control, and we wanted to see if doing so would improve seed viability under ambient temperatures. The treatments we compared are listed in Table 1.

Table 1. Treatments corresponding to seed storage technologies tested in Thailand and Florida.

Treatment	Container type
1. Vacuum-sealing with modified bicycle pump	Glass jars (118 ml [4 oz])
2. Vacuum-sealing with machine sealer	Polyethylene (plastic) bags
3. Desiccant, using zeolite Drying Beads®	Glass jars (207 ml [7 oz])*
4. Desiccant, using calcium oxide powder	Glass jars (207 ml [7 oz])*
5. Nontreated seeds	Small paper bags

*Desiccants were placed inside the glass jars, in small breathable paper bags on top of the seeds to avoid direct contact of desiccants with seeds. They were kept at a seed-to desiccant ratio, by weight, of two to one (60 g of seed with 30 g of desiccant). To compensate for the volume taken up by desiccant, the glass jars for treatments 2 and 3 were larger than those for vacuum sealing.

Each treatment was tested with seeds of okra (*Abelmoschus esculentus*), sorghum (*Sorghum bicolor*), and velvet bean (*Mucuna pruriens*). For each crop, 60 g of seeds were stored per container. We randomly assigned each container to 1 of the 5 treatments, 1 of 3 seed types, 1 of 5 sampling times, and 1 of 4 replicates, for a total of 300 containers per location (Figure 2).

Measurements

For each treatment, we sampled seeds at 0 (initial baseline), 1, 3, 6, 9, and 12 months of storage. At each sampling time, we opened the containers assigned to that sampling time for data collection, leaving the remaining containers closed. By taking data from a different batch of seeds each time, we did not have to open and reseal containers over the course of the trial. At each sampling time we measured:

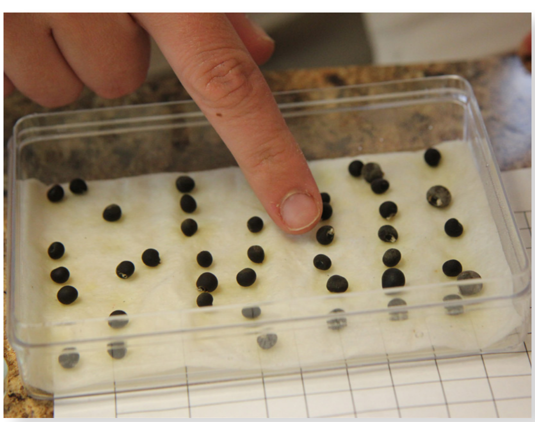

Figure 3. Germination testing of okra seeds in a petri dish. *Source:* Nate Flood

- **Seed moisture content:** We measured seed moisture content with a 5 g subsample of seeds for each container. Moisture content of crushed seeds was measured with a DSH-50-1 Precision Halogen Moisture Meter.❺
- **Seed germination percentage:** We tested a subsample of 50 seeds from each container for germination using the Petri dish method (Rao *et al.*, 2006; Figure 3). Petri dishes were placed in a germination cabinet (Seedburo® Model 548 [Florida]; a custom-built cabinet, like the one in Florida, was used in Thailand) that maintained temperature at 29 ± 2°C and humidity at 60 ± 5%.
- **Vacuum pressure:** Vacuum pressure was collected for treatment-two (bicycle sealing) and treatment-three (machine sealing) containers, just prior to opening the containers. To measure the level of vacuum in each container

we used a simple pressure gauge attached to a hypodermic needle (Figure 4). The needle was pushed directly into treatment-one polyethylene bags or through the tape covering the hole in each glass jar lid (through which vacuum was drawn). The aforementioned *ECHO Technical Note* explains the use of the pressure gauge and gaskets on jar lids.

Figure 4. Using a vacuum gauge to measure vacuum pressure. *Source:* Tim Motis

For this article we will focus mainly on findings for initial (month 0 baseline) and final (month 12) seed moisture and germination.

Findings

Seed moisture

The moisture content of seeds is influenced by the humidity of the surrounding air and the composition of the seed. Oil and water do not mix, but water is attracted to protein and starch (McDonald, 2007). We did not have the seeds analyzed for these components, but values in the literature are shown in Table 2. Initial values shown in Figure 5 indicate baseline seed moisture, just before treatments were set up. As seen in our initial moisture content values, the moisture content of seeds in a seed bank—under similar storage conditions—will vary with crop, which is due at least in part to differences in their composition. Perhaps the combination of high protein and starch explains why initial seed moisture content was highest in velvet bean seeds.

Table 3 shows general trends for the effect on seed moisture of the various treatments over time from month 1 to 12. Of the two vacuum sealing

Table 2. Reported values for oil, protein, and starch in seeds of okra, sorghum, and velvet bean

Crop	Oil	Protein	Starch	Source
Okra	14%	19-41%	7-37% carbohydrates	Ofori *et al*. (2020); Omoniyi *et al*. (2018)
Sorghum	5-8%	4-21%	56-75%	Mehmood *et al*. (2008); Khalid *et al*. (2022)
Velvet bean	6%	25-29%	39-41%	Baby *et al*. (2022; Omeh *et al*. (2014)

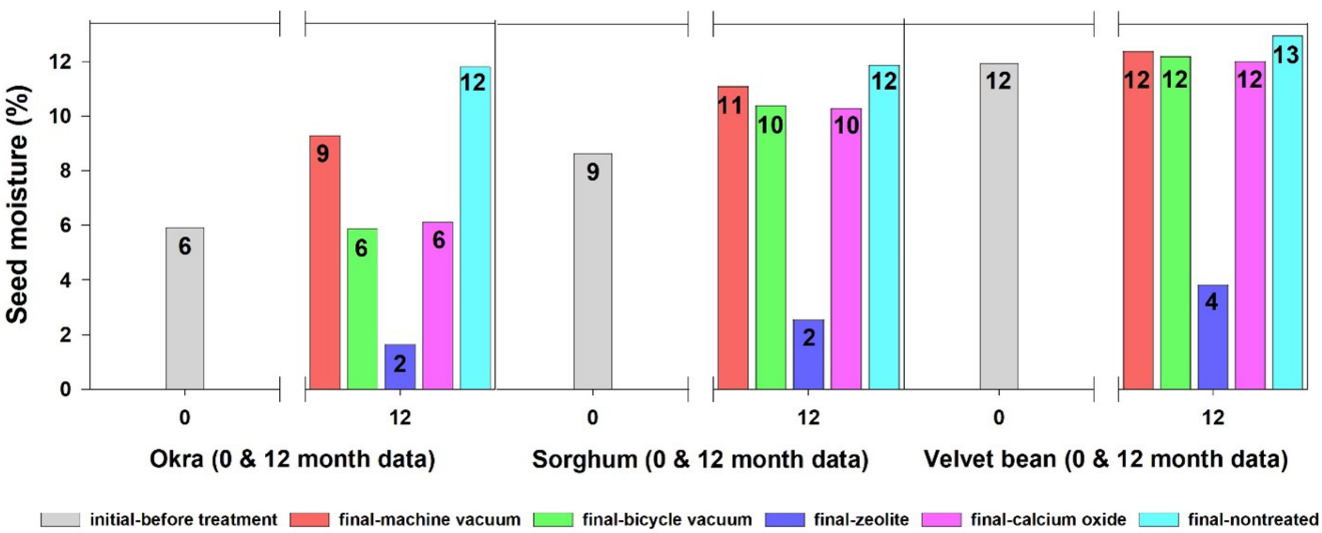

Figure 5. Moisture content of okra, sorghum, and velvet bean seeds as influenced by storage treatments. Data are shown for values measured before treatment (month 0) and after 12 months of storage under ambient conditions under outdoor screened porches. The value shown for each bar is an average of eight observations (four from Florida and four from Thailand).

treatments, only bicycle vacuum kept moisture content from increasing in seeds of all three crops. Both desiccants prevented increases in seed moisture over time. Drying Beads® was the only treatment that decreased seed moisture over time; it did so for all three crops. With no treatment, seed moisture fluctuated over time, with lowest and highest values coinciding with humidity levels during dry and rainy seasons, respectively. The highest moisture content recorded over the trial was 14%, at month 3 with nontreated velvet bean seed.

Table 3. Effect of time on seed moisture and germination for each treatment, as indicated by the statistical significance of time and overall trends over time.

		Statistical significance of time and overall trend over time*		
Seed parameter	**Treatment**	**Okra**	**Sorghum**	**Velvet Bean**
Moisture	Machine vacuum	*** (increase)	*** (increase)	NS (no change)
Moisture	Bicycle vacuum	NS (no change)	NS (no change)	NS (no change)
Moisture	Zeolite	*** (decrease)	* (decrease)	*** (decrease)
Moisture	Calcium oxide	NS (no change)	NS (no change)	NS (no change)
Moisture	No treatment	*** (fluctuate)	*** (fluctuate)	*** (fluctuate)
Germination	Machine vacuum	NS (no change)	*** (decrease)	NS (no change)
Germination	Bicycle vacuum	NS (no change)	** (decrease)	NS (no change)
Germination	Zeolite	NS (no change)	NS (no change)	*** (decrease)
Germination	Calcium oxide	NS (no change)	** (decrease)	NS (no change)
Germination	No treatment	*** (decrease)	*** (decrease)	NS (no change)

*The effect of time was statistically nonsignificant (NS) or significant at a P level of 0.05 (*), 0.01 (**) or, 0.001 (***).

Final (month 12) seed moisture values are shown in Figure 5. By the end of the trial, all storage technologies evaluated kept seed moisture content below that with no treatment. This was true for all crops. Storage technologies differed, however, in the extent to which they kept seeds dry. Only zeolite Drying Beads® reduced seed moisture below initial values. It brought seed moisture content levels down to less than 5% for all crops. Calcium oxide and bicycle vacuum sealing kept seed moisture values close to baseline values. Among the storage technologies tested, final seed moisture values were highest with machine sealing.

Seed germination

All seeds tested germinated well at the beginning (month 0) of the trial, with germination percentages of 88-96% (Figure 6). Between months 1 and 12, the germination percentage of okra and velvet bean remained stable with most of the treatments (Table 3). Sorghum germination declined over time with all treatments except zeolite Drying Beads®. Zeolite Drying Beads®, however, led to a rapid decline of velvet bean seed germination over time. With no treatment, we saw a significant decline in the germination of okra and sorghum but not velvet bean seeds.

At the end of the trial, germination with no treatment was 34% for okra and 0% for sorghum (Figure 6). Interestingly, velvet bean seed proved very tolerant of ambient humidity and temperature, with 96% of seeds germinating at month 12. Vacuum sealing (both machine and bicycle)

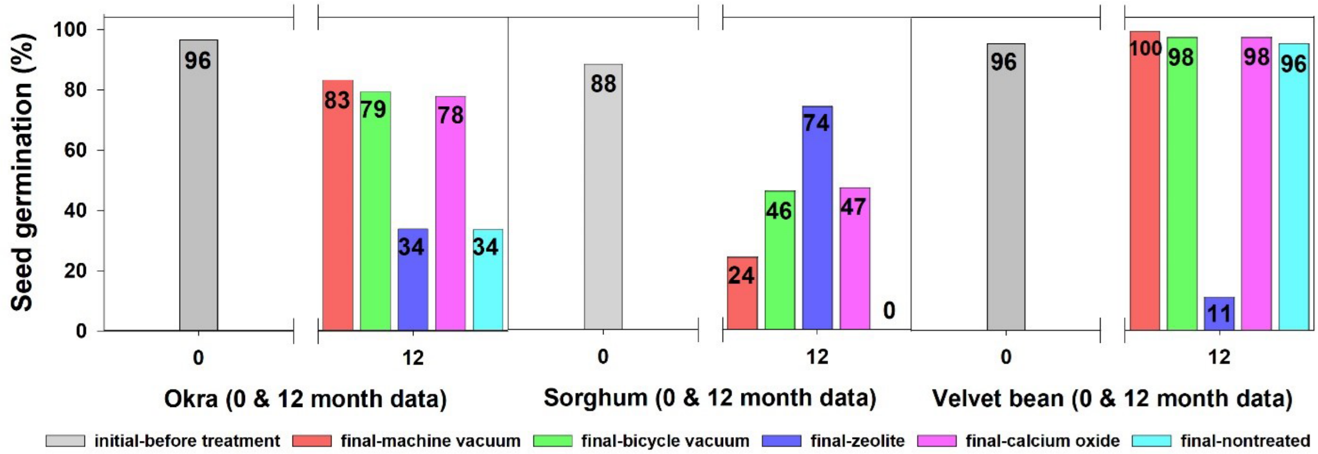

Figure 6. Germination percentage of okra, sorghum, and velvet bean seeds as influenced by storage treatments. Data are shown for values measured before treatment (month 0) and after 12 months of storage under ambient conditions under screened porches. The value shown for each bar is an average of eight observations (four from Florida and four from Thailand).

and calcium oxide resulted in final seed germination percentages of 78-83% for okra and 96-100% for velvet bean. With zeolite Drying Beads®, final germination percentages were highest with sorghum. Only zeolite Drying Beads® kept final sorghum germination above 70%.

Vacuum pressure

Vacuum pressure (not shown) was steadily lost over time with the polyethylene bags used with the machine sealer. Conversely, glass jars used in conjunction with bicycle pump sealing prevented a decline in vacuum. Neither of the vacuum sealing technologies evacuated all of the air from respective containers.

Applications

Tolerance to ambient conditions varies with crop. Our findings showed that velvet bean seeds tolerated high heat and humidity much better than sorghum seeds. This shows that crops can vary significantly in their tolerance of unfavorable storage conditions.

Of the two vacuum sealing treatments, vacuum drawn on glass jars with a modified bicycle pump proved to be as or more effective in maintaining seed moisture content in storage than a much more expensive machine sealer. Our findings with vacuum sealing, in combination with previous findings from research at ECHO's Regional Impact Center in Asia, have the following implications:

- It is possible to store seeds well with modest levels of vacuum. The modified bicycle pump withdrew about 50% of the air from glass containers. Though the machine sealer was capable of a stronger initial vacuum, the polyethylene bags commonly used with it were not ideal for maintaining vacuum over a long period of time.
- Vacuum sealing can be implemented with very inexpensive technology. The cost of the pump is the main expense. If bicycle pumps in your area are difficult to modify for drawing vacuum, consider other approaches like brake bleeder pumps and syringes, as explained in *ECHO Technical Note #93*.

- Success with vacuum sealing requires a container that keeps air from diffusing in and out and that is well-sealed. If using glass jars, make sure the lids provide a good seal.

Both desiccants proved effective in maintaining baseline seed moisture content, but only the zeolite Drying Beads® reduced seed moisture over time. Calcium oxide is more widely available (as burnt lime) than zeolite Drying Beads® but takes more heat to reuse—after saturation with moisture—than zeolite Drying Beads®. Zeolite Drying Beads®, at the ratio used in the trial, dried seeds to the point where final germination percentages were adversely affected. Findings with desiccants have the following implications:

- Seeds can be kept dry with both calcium oxide and zeolite Drying Beads®.
- It is possible to achieve ultra-dry (below 5%) seed moisture with zeolite Drying Beads®. With respect to germination of seeds exposed to water immediately after storage, as would occur with seeds planted soon after storage, tolerance to ultra-dry conditions varied between crops. Ultra-dry storage can extend the storage life of sorghum, but seed banking personnel may want to experiment before implementing it with a wide variety of crops.
- Seed savers and seed banking personnel may want to experiment with the ratio of seeds to desiccant to come up with best practices for the crops they work with. With respect to zeolite Drying Beads®, the manufacturers website (www.dryingbeads.org) explains how to tailor the seed-to-bead ratio for specific crops.

Conclusion

You can keep seeds dry for at least a year with low-cost technologies. Vacuum sealing with a modified bicycle pump and calcium oxide are the two least expensive technologies tested in this trial. Zeolite Drying Beads® are also an inexpensive option that is extremely effective in keeping seeds dry.

Results of this trial are relevant to situations in which temperature is not controlled. Under high and fluctuating temperatures, it is possible to store seeds of some crops—without significant reductions in germination—by excluding humidity. Some seeds (e.g., sorghum in this trial) lose viability faster than others and may require drier conditions to slow the rate of loss in viability.

The authors suggest that future researchers test seed viability over time with varying levels of initial vacuum pressure. Such knowledge would be useful in documenting the effectiveness of a broad range of vacuum devices, including modified syringes less likely to remove as much air as a modified bicycle pump. Combining technologies for keeping seeds dry with those that keep seeds cool and/or stable is another promising area of study. An example of a technology that minimizes temperature fluctuation is earthbag construction, written about in an *ECHO Technical Note* entitled "Earthbag Seed Banks." If you have experience storing seeds under challenging conditions, let us know what you have learned.

References

Baby C., S. Kaur, J. Singh, and R. Prasad. 2022. Velvet bean (*Mucuna pruriens*): a sustainable protein source for tomorrow. *Legume Science* e178.

Coomes O.T., McGuire S.J., Garine E., Caillon S., McKey D., Demeulenaere E., Jarvis D., Aistara G., Barnaud A., Clouvel P., Emperaire L., Loufi S., Martin P., Massol F., Pautasso M., Violon C. and Wencelius J. 2015. Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy* 56, 41–50. doi: 10.1016/j.foodpol.2015.07.008

Feed the Future Innovation Lab (FFIL). 2017. Drying beads save high quality seeds. https://horticulture.ucdavis.edu/information/drying-beads-save-high-quality-seeds.

Khalid, W. A. Ali, M.S. Arshad, F. Afzal, R. Akram, A. Siddeeg, S. Kousar, M.A. Rahim, A. Aziz, Z. Maqbool, and A. Saeed. 2022. Nutrients and bioactive compounds of *Sorghum bicolor* L. used to prepare functional foods: a review on the efficacy against different chronic disorders. *International Journal of Food Properties* 25(1):1045-1062.

Lawrence, B., A. Bicksler, and K. Duncan. 2017. Local treatments and vacuum sealing as novel control strategies for stored seed pests in the tropics. *Agronomy for Sustainable Development* 37:6. DOI 10.1007/s13593-017-0415-0

Martin, I., L. Gálvez, L. Guasch, and D. Palmero. 2022. Fungal pathogens and seed storage in the dry state. *Plants* 11(22): 3167, https://doi.org/10.3390/plants11223167

Materic, V. and S.I. Smedley. 2011. High temperature carbonation of $Ca(OH)_2$. *Industrial & Engineering Chemistry Research* 50(10):5927-5932.

McDonald, M. B. 2007. Seed moisture and the equilibrium seed moisture content curve. *Seed Technology* 29(1):7-18.

Mehmood, S., I. Orhan, Z. Ahsan, S. Aslan, and M. Gulfraz. 2008. Fatty acid composition of seed oil of different *Sorghum bicolor* varieties. *Food Chemistry* 109(4):855-859.

Motis, T. 2010. Seed Saving. *ECHO Technical Note* no. 63.

Motis T. 2019. Vacuum-sealing options for storing seeds. *ECHO Technical Note* no. 93.

Ofori, J., C. Tortoe, and J.K. Agbenorhevi. 2020. Physiochemical and functional properties of dried okra (*Abelmoschus esculentus* L.) seed flour. *Food Science and Nutrition* 8:4291-4296.

Omeh, Y.N., D. Akachukwu, and O.U. Njoku. 2014. Physiochemical properties of *Mucuna pruriens* seed oil (MPSO), and the toxicological effects of a MPSO-based diet. *Biokemistri* 26(3):88-93.

Omoniyi, S.A., M. A. Idowu, and A.A. Adeola. 2018. Potential domestic and industrial utilizations of okra seed: a review. Annals. *Food Science and Technology*. 19(4):722-730.

Powers, T.H. and W.J. Calvo. 2003. Moisture regulation. In Ahvenainen R. (ed), Woodland Publishing Series in Novel Food Packaging Techniques. Cambridge: Woodhead Publishing, pp. 172-185.

Reader, S. and T. Motis. 2017. Are my seeds dry enough to store? *ECHO Development Notes* no. 36.

Rao N.K., J. Hanson, M.E. Dulloo, K. Ghosh, D. Nowell, and M. Larinde. 2006. Manual of seed handling in genebanks. In: *Handbooks for Genebanks* No. 8. Rome: Bioversity International, pp. 28-29.

Suwannasingha, N., A. Kantavong, S. Turnkiijjanukij, C. Aenglong, H-B. Liu, and W. Klaypradit. Effect of calcination temperature on structure and characteristics of calcium oxide powder derived from marine shell waste. *Journal of Saudi Chemical Society* 26(2):101441.

Trail, P., T. Motis, S. Swartz, and A. Bicksler. 2022. Low-cost seed storage technologies for development impact of small-scale seed saving entities in tropical climates. *Experimental Agriculture* 57(5-6):324-337.

Extending Postharvest Life of Fresh Produce: After-harvest handling

by Robert Walle

Food production is important, but farmers must also protect against crop loss prior to consumption or sale. Fresh fruit and vegetables are high in value but susceptible to spoilage. Improving post-harvest practices helps farmers make profitable sales. This can be a difference between a successful farming business and simply growing crops.

Consider all the needed handling of produce so that it is of acceptable ripeness and quality to the end user. Depending on the value chain, the end user could be an intermediary or the ultimate consumer of fresh produce.

Many postharvest practices require large-scale investment in infrastructure and/or energy. Transporters and harvesters prioritize their own economies, making it hard for small-scale farmers to gain income. Intermediaries and retailers generate most profit off-farm, with processes unavailable to the small-scale farmer. This article concentrates on simple postharvest practices small-scale farmers can implement to increase their earnings from harvested produce.

Figure 7. Foam mesh protecting papaya and allowing ventilation. Applied by workers in the field during harvest.
Source: Robert Walle

Harvest

Proper harvesting of fruits and vegetables is the first step in a lengthy process culminating in sale and consumption. Reducing damage (bruises, cuts, surface abrasions, or crushing) during harvest improves quality at this stage in the value chain. Wagner *et al.* (2000) identified bruising as the number one postharvest injury to tomatoes. Motis (2022) provides examples of simple practices such as harvest bags and gentle handling that small-scale producers can apply.

Leaving some crops in the field until sale or transport is possible. Farmers leave crops such as carrots (*Daucus carota*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*; roots), and potatoes (*Solanum tuberosum*; tubers) in the field until they are sold or transported. Watch for crop exposure to pests and diseases until the sale.

Protective Layers. Many farmers use crop leaves to protect harvested crops during transport. This is most common for Cruciferous crops (broccoli, cauliflower, cabbage). These leaves carry dirt and disease that later post-harvest processes must remove. Exporters can provide farmers with foam mesh sleeves to protect their produce before transport (Figure 7).

Small-scale producers have some advantages in harvesting such as flexibility and frequency of harvest. They can harvest earlier when fruits and vegetables are firmer and transport easier. They can harvest later, when crops are the most flavorful for the consumer. Farmers can also harvest more frequently to meet and respond to market demand (Kitinoja and Kader, 2015).

Sorting

Consumer demand, often shaped by cultural preferences, determines the characteristics of fruit and vegetables that fetch the best prices. Sorting lets farmers present a product of uniform size, ripeness, and quality. Farmers can earn more by using sorting criteria based on market-desired characteristics. Sorting also eliminates produce with defects. Remove damaged (un-sellable) and diseased produce (propagating rot and diseases to the rest of the crop) before other postharvest practices. This reduces the spread of disease later in the value chain and improves the economics of storage space.

Size. Rings that correspond to size or grades (specific diameters) are a common tool for workers sorting produce. We can make rings of standard sizes using wire to measure the size of fruits and vegetables (Post-harvest Innovations Plan Series no. 2, 2012). Workers mount the rings over containers to facilitate sorting operations and reduce effort (FAO, 2004). Minimize rough handling and use containers that protect produce from bruising and damage.

Color. Fruit color shows the product's stage in the ripening process. Tomatoes turn red when they are the ripest and ready to eat. But tomatoes harvested at the "breaker" stage, when the color first changes from green to red, are the most valuable as far as fruit most likely to survive transport. Post Harvest Innovation Series (no. 4, 2012) showed that color sorting raised the value of tomatoes, cucumbers, and chili peppers. Marketers can use digital photography to create simple color charts that reflect local market preferences. For consistency, take photos on the same day, time, and background.

After sorting, farmers market the product. Most intermediaries will have a general standard for acceptance of a product at the field gate. They will be more likely to accept produce that has already been sorted to meet the standard for quality. Field buyers will have some sort of penalty system to motivate farmers to give them a quality product before further processes such as chilling.

Temperature

Temperature is the driving force for water loss in freshly harvested produce. Table 4 illustrates the connection between temperature, shelf life, and water loss of produce.

Harvested produce exposed to the sun loses a large amount of moisture because of the heat, affecting its shelf life and quality. In one hour, tomatoes will be at least 15 °C warmer in the sun than in the shade (Kitinoja and Kader, 2015).

Table 4. Weight Loss, Storage, and Temperature (Kitinoja and Kader, 2015)

Temperature (°C)	Theoretical shelf life (days)	Weight loss (%)
0	100	1
10	45	3
20	20	6
30	10	12
40	4	25

Shade. Shade is the simplest and easiest way of cooling fresh produce. Keep fruits and vegetables cool and humid to help maintain freshness, to the extent possible. Reducing temperature reduces respiration and slows down the metabolic processes associated with ripening. Outdoor markets are subject to temperature changes and high winds, leading to drying and wilting. These marketplaces can often benefit from the increased use of shading and protection from prevailing winds (Kitinoja and Kader, 2015). Use trees that are in convenient places or make simple shade structures as shown in (Post Harvest Innovation Plan Series no. 1, 2012).

Night air cooling. As day turns to night, temperatures naturally drop. Night air cooling uses cooler night-time air to replace warmer air in structures (Kitinoja and Kader, 2015). Fans for air flow increase the cost of this approach. Recall the importance of insulation and ventilation to maximize the benefits.

Evaporative cooling. Farmers can use the process of evaporation to cool produce without electricity, enabling small-scale producers to store products at a slightly reduced temperature prior to consumption or transport to market. Evaporative coolers employ the endothermic process of evaporation. As water changes state from a liquid to a gas, it draws heat as energy from the surrounding environment. An insulated chamber keeps fruits and vegetables cooler and with more humidity than the surrounding ambient air.

Evaporative cooling works best in dry climates. [6] Defraeye *et al.* (2023) provided an excellent and thorough analysis of evaporative coolers and where they work best. Researchers mentioned that evaporative coolers typically reduce temperature by 3 to 10°C. They found that, during dry months in a northwestern part of India, evaporative cooling reduced temperature by as much as 14°C, extending the postharvest life of bananas by up to 7 days. They pointed out that evaporative cooling will have the most impact, and best chance of acceptance by farmers, in locations and times of year when > 5°C reductions in temperature are achieved. Horticultural areas in tropical countries often are found at higher altitudes with cooler climates and more humid conditions. Evaporative coolers may not work in such areas.

[6] Theoretically, the cooling temperature will not go below the wet-bulb temperature. You can measure wet-bulb temperature by wrapping the bulb of a thermometer with moistened cloth. Dry-bulb temperature is the temperature reached without the moistened cloth. The difference between wet- and dry-bulb temperature is an indicator of humidity. The drier the air, the greater the difference between wet- and dry-bulb temperatures. Conversely, the more humid the air, the lower the difference will be between wet-and dry-bulb temperatures. At 100% humidity, wet- and dry-bulb temperatures are the same. The drier the air, the faster water will evaporate. Cooling potential increases as the rate of evaporation increases, which is why evaporative cooling works best in dry weather. As explained by Basediya et al. (2013), an evaporative cooling system that is 100% efficient will reduce the temperature by the number of degrees between wet- and dry-bulb temperature, with the wet-bulb temperature being the lowest temperature reached in the cooling chamber. Practically, 1 or 2 °C above wet-bulb temperature is possible.

One example of an evaporative cooling approach is the ZECC (Zero Energy Cooling Chamber). Postharvest Innovations Plan Series (no. 6 and 7, 2012) give designs for 100 kg and 1 MT sizes. A Practical Action guide entitled "Evaporative Cooling" (http://edn.link/ywj3t3), by Noble (n.d), contains additional designs.

Reducing water loss

Most fruits and vegetables, like the human body, are mostly water. Water loss by transpiration is one of the largest losses of produce weight after harvest. This loss of weight is especially economically important to the small-scale farmer, causing wilting and reducing market quality.

Water loss is a complex relationship between the temperature, relative humidity, and the tendency of a fruit or vegetable to transpire. A small transpiration coefficient (onion or potato) means it does not lose much water to the air, while a large coefficient (lettuce) means it wilts or loses water rapidly.

Table 5. Water loss factors for common crops (Holcroft, 2015).

Crop	Water Content (%)	Max. Permitted Weight Loss (%)	Transpiration Coefficient K (mg/kg/sec/MPa)
Onion (*Allium cepa*)	88	10	60
Carrot (*Daucus carota*)	88	8	1207
Lettuce (*Lactuca sativa*)	95	3-5	7400
Tomato (*Solanum lycopersicum*)	94	4-7	140
Potato (*Solanum tuberosum*)	78	7	44
Cabbage (*Brassica oleracea*)	92	6-11	223

Table 5 shows lettuce needs more postharvest care because of its higher water content, low permitted weight loss, and high transpiration rate. A crop like potatoes, with low water content, higher permitted weight loss, and a low transpiration coefficient, is simpler for small farmers to manage postharvest. Farmers or intermediaries often add water to a harvested crop to maintain relative humidity. This water creates other problems, such as the propagation of disease (Wagner *et al.*, 2000).

Ideal storage temperature for many vegetables requires refrigeration, which is beyond the means of most small-scale farmers and is available mostly to agroexporters/retailers for these crops. Nevertheless, there are storage conditions and practices that can be achieved without refrigeration, as shown in table 6 for selected crops.

Table 6. Recommended storage conditions for common crops.

Crop	Recommended Storage Conditions
Onion (*Allium cepa*)	Harvest when leaves dry out and topple over. Cure at 32°C with circulating air. Store under low relative humidity after curing. 1-8 months storage life at 65 to 75% relative humidity.
Carrot (*Daucus carota*)	Keep moist, at high relative humidity (98-100%) to reduce incidence of decay. Mist it with water in the final display.
Lettuce (*Lactuca sativa*)	Short storage life. The major cause of postharvest loss is wilting, so store at high humidity (98-100%). Benefits from misting with water. Ethylene sensitive, so display apart from tomatoes and peppers.
Tomato (*Solanum lycopersicum*)	Wash before cooling. Ideal storage temperature of 10-21° C; fruit susceptible to chilling injury at temperatures below 10° C. Bruising hastens spoilage. Store partially ripe at 65%-75% relative humidity; tomatoes at the mature green stage will store longer.
Potato (*Solanum tuberosum*)	Cure at 15-20° C, at 90-95% relative humidity for 5-10 days. Store in darkness to minimize sprouting of tubers; can store outdoors in a shed with ventilation.
Cabbage (*Brassica oleracea*)	Mature when solid and compact. Highly perishable. Do not wash. Control soft-rot. Benefits from misting with water.

To make farming profitable and benefit from the improved postharvest processes available to you, harvest frequently and sell to the consumer for fresh use. This requires knowledge of the time for harvest, like the fruits presented in Motis and Swartz (2022) and others.

Diseases and occupational health

The safety of our food supply has been a topic of justified environmental concern. There is a potential for food borne illness because of microbial contamination of fresh produce. Contamination of fresh produce can occur during production and subsequent postharvest handling. Improper compost handling also increases the risk of contamination (Wagner *et al.*, 2000).

Figure 8. Workers wash carrots in a storm sewer. All water used in postharvest practices should be potable to avoid disease transmission. *Source*: Robert Walle

Figure 9. Interlocking stackable crates. Note the raised corners and ventilation. *Source*: Robert Walle

Human pathogens in fresh produce occur in four categories: soil, feces, parasites, and viruses. These are soil pathogens such as *Clostridium botulinum*, and *Listeria monocytogenes*; fecal pathogens such as *Salmonella* spp., *Shigella* spp., E. coli O157: H7; parasites such as Cryptosporidium and Cyclospora; and viruses such as hepatitis and enterovirus. Most of these pathogens spread through humans (or livestock) to food (Figure 8). Contamination of produce can occur because of infected workers, water, or soil (Kitinoja and Kader, 2015).

Modular plastic containers

Standardized and stackable crates aid post-harvest handling where they are available to farmers (Figure 9). Plastic crates eliminate problems associated with fasteners (staples, nails, screws, bolts), pieces of glass, or wood splinters damaging produce. Strong and ventilated, they protect the crops in them. Workers easily wash off some chemicals from the crates such as pesticides, fungicides, herbicides, and others . Crates are washable and re-usable, helping maintain sanitation in the value chain. Exporters/retailers often pay farmers for the standardized boxes or crates of crops that they produce. Some exporters/retailers provide or facilitate crates to farmers to improve postharvest practices. These containers are easy to stack for transportation and effectively stabilize and ventilate loads.

Coordinating with transport

For most small-scale farmers, transport is the final stage of the harvest. Consider whether transport is for retail or wholesale because selling the produce as fast as possible usually requires a predetermined buyer. Arrange transportation and coordinate with intermediaries and buyers. One does not want to be a farmer with his produce in the shade, looking for a buyer. Refrigerated transport and storage is best for fruits and vegetables.

Coordinate with transport to increase profits and better reach the consumer in a more just value chain. Many small-scale producers sell to intermediaries with refrigerated transport. Cold rooms and electricity-dependent techniques may be too expensive in the global south for small-scale farmers. Simple steps, like cooling, sorting, and direct sales, can assist small-scale farmers in market participation.

Concluding Thoughts

Below is a list of practices that small-scale farmers can implement without having to purchase expensive equipment.

- Careful handling of produce during harvest
- Simple cooling, in the shade, or using the lower temperature of the night air to help maintain product freshness
- Sorting produce by size and ripeness (or other market criteria) to deliver a more salable product and save space where limited
- Protect all produce from moisture loss
- Consider sanitation and always use potable water in all steps within the value chain

Methods described here will help meet UN Millennial Development Goal 12.3 and allow farmers to ask for a just price at the market or field gate.

> "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses." (FAO, 2022).

References

Basediya, A.L., D.V.K. Samuel, and V. Beera. 2013. Evaporative cooling system for storage of fruits and vegetables – a review. *Journal of Food Science and Technology* 50(3):429-442.

Defraeye, T., K. Shoji, S. Schudel, D. Onwude, and C. Shrivastava. 2023. Passive evaporative coolers for postharvest storage of fruit and vegetables: where to best deploy them and how well do they perform. *Frontiers* 3. https://doi.org/10.3389/frfst.2023.1100181

FAO. 2004. Manual for the preparation and sale of fruits and vegetables From field to market. FAO AGRICULTURAL SERVICES BULLETIN 151. Rome.

FAO. 2022. Indicator 12.3.1 - Global Food Loss and Waste. https://www.fao.org/sustainable-development-goals/indicators/1231/en/

Holcroft, D. 2015. Water Relations in Harvested Fresh Produce. White Paper No. 15-01. The Postharvest Education Foundation (PEF).

Kitinoja, L. and Kader, A.A. 2015. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (5th Edition). Postharvest Technology Research and Information Center. University of California, Davis.

Motis, T. 2022. Extending Postharvest Life of Fresh Fruit: Harvest for Quality. *ECHO Development Notes* no. 156.

Motis, T. and S. Swartz. 2022. Extending Postharvest Life of Fresh Fruit: Harvest at the Right Time. *ECHO Development Notes* no.154.

Noble, N. non-dated (n.d.). Evaporative cooling. Technical Brief.

Postharvest Innovations Plan Series. 2012. Shade Structure. Post harvest innovation plan series. Number 1. University of California, Davis.

Postharvest Innovations Plan Series. 2012. Sizing Rings. Post harvest innovation plan series. Number 2. University of California, Davis.

Post Harvest Innovations LLC. 2012. Color charts. Post harvest innovation plan series. Number 4. University of California, Davis.

Postharvest Innovations Plan Series. 2012. Zero Energy Cool Chamber (100 kg model). Post harvest innovation plan series. Number 6. University of California, Davis.

Postharvest Innovations Plan Series. 2012. Zero Energy Cool Chamber (1 MT model). Post harvest innovation plan series. Number 7. University of California, Davis.

Wagner, A.B., Dainello, F.J., and Parsons, J.M. 2000. Texas Vegetable Growers Handbook, 4th edition. Texas A&M. College Station, Texas.

Echoes From our Network: Experiments to Control Millipedes with Locally Available Ingredients

by David Uhr, Ph.D. and Galima Mowolo

Introduction

Millipede species can cause severe damage to various crops. We have heard reports of heavy damage from West Africa, but also more recently from Uganda. Many crops are susceptible to feeding at the seedling stage, including maize (*Zea mays*), beans (*Vigna* spp.), pumpkin and melons (Cucurbita) and okra (*Abelmoschus esculentus*). Continuous mulch used to control erosion and conserve moisture seems to provide a good habitat for millipedes. Effective chemical controls are expensive and difficult to obtain for many rural farmers. Thus, we are trying to identify locally available products that might reduce damage. These experiments are just the beginning of this effort, and we are planning to continue investigating local options for millipede control. Students conducted these experiments at the Agriculture Research Center (ARC) on the campus of Liberia International Christian College in Ganta, Liberia in March 2023. Many of these treatments were conceived during a training program on research principles with agriculture students at the ARC. We are very thankful for the partnership of these students and the ARC leadership.

Methods

The first round of experiments conducted in hill plots (planting stations) identified potentially promising treatments. Based on this first screening trial, a second experiment was designed with 10 treatments, 2 replications, and 3 crops (*Zea mays*, *Cucurbita moschata*, and *Vigna unguiculata*). Each plot was a hill plot of 3 seeds. Table 7 explains treatments tested in the second experiment.

Table 7. Treatments corresponding to seed treatments in the second experiment.

Treatment	Form	Rate of application
Control	N/A	0
Deltamethrin	Powder	5 ml
Papaya tea - low rate	Liquid	5 ml
Papaya tea - high rate	Liquid	15 ml
Neem tea - low rate	Liquid	5 ml
Neem tea - high rate	Liquid	15 ml
Smoke	Semi-solid	thin layer
Diatomaceous earth - low rate	Powder	5 ml
Diatomaceous earth - high rate	Powder	15 ml
Charcoal dust	Powder	15 ml

We made “tea” treatments from crushed, dried leaves and applied “tea” treatments at a rate of 30 ml dried leaves/250 ml water for both papaya and neem. The other treatments we tested include smoke (greasy grill grime), diatomaceous earth at two rates, charcoal, deltamethrin (a commercial chemical), and a control with no treatment. We placed seeds into the planting station (hill), then applied the treatment directly over the top of seeds. We then covered the seed with soil, added 2.5 cm of fine mulch, and irrigated the field. Three days after emergence, we recorded the number of strong plants, number of weak plants, and number of seeds that did not germinate.

Results and discussion

We calculated averages of data points across treatments to determine which treatments might be most effective. An analysis of variance was conducted treating the three different crop species as replications for a total of 6 replications per treatment.

The most promising local treatments were neem teas (both high and low rates) and smoke (greasy grill grime) (Figure 10). These were significantly different than the untreated control at the P=.01 level. Neem tea treatments were similar to the chemical control, deltamethrin. Papaya tea treatments were significantly better than the untreated control at the P=.05 level. Charcoal dust effectively controlled millipede activity on maize and pumpkin but for an unknown reason, we observed no germination of cowpea in both replications for this treatment. Thanks to Ron Fritz for the statistical analysis.

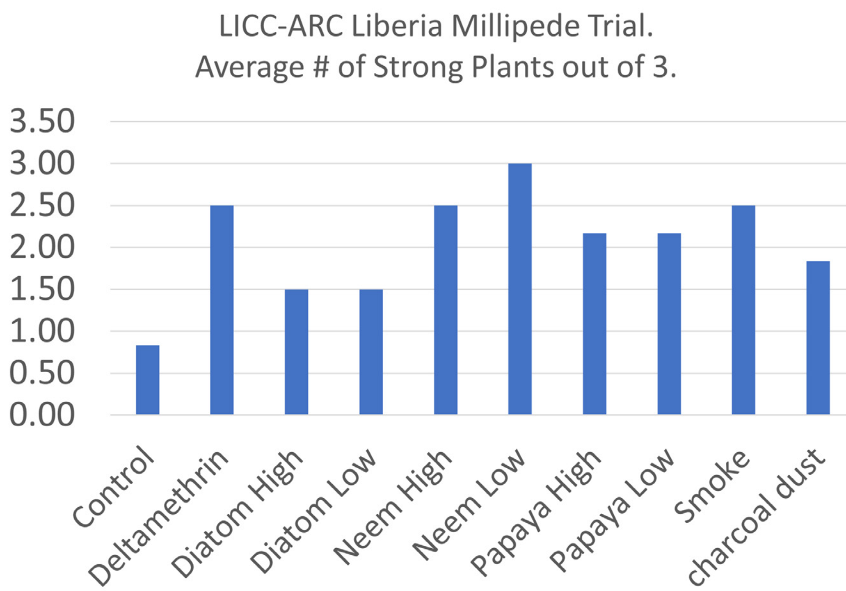

Figure 10. Average number of strong plants out of three seeds in each plot, averaged across 2 replications and 3 crops of maize, cowpea and winter squash for a total of 6 replications per treatment.

We plan to conduct another experiment in Liberia and in Senegal during July 2023. We would love to have others conduct the same treatments or simply try the most promising treatments and report back their results. There is much work left do to develop an effective treatment plan we can be confident in recommending, and the more locations of observations we have, the more confident we can be.

From ECHO's Seed Bank: *Erythrina berteroana*

by Robert Walle

Erythrina berteroana is an agroforestry tree with many uses including animal fodder and soil improvement. Research by Tropical Agricultural Research and Higher Education Center (CATIE) supports its benefits and production in practice. Native to Central America, common names of *E. berteroana* include helequeme, coral bean, and pito.

A 10 m tree or a pruned shrub (for fodder), *E. berteroana* ranges from southern Mexico to Peru and has been introduced to the Caribbean and Tanzania (CABI, 2016). Hummingbirds pollinate its bright red, ornamental flowers. Introduced for coffee shade in Costa Rica, farmers replaced it with other species because it did not offer sufficient shade. It is still found on many farms because of its usefulness for fodder.

Uses

People commonly use *E. berteroana* for live fencing because its spines form an impenetrable barrier. Farmers use it in windbreaks and fodder banks. Horticulturists also use it as a live support for crops such as black

Figure 11. *E. berteroana* seeds.
Source: Holly Sobetski

pepper (*Piper nigrum* L.), granadillo (*Passiflora ligularis*), yam (*Dioscorea alata*), and vanilla (*Vanilla planifolia* Andr.) (Mueschler *et al.*, 1993).

E. berteroana adapts readily into agroforestry systems. Its wood is not a precious hardwood and finds its functional use as stakes and live support for trellised crops.

CATIE (2003) recommends pruning trees every 6 months. *E. berteroana* responds well to pruning, producing 1885 kg of biomass per year and supplying 33.6 kg nitrogen. The pruned material is useful for soil amendment, mulch, and fodder. Fodder is high in protein, which increases the benefit to animals produced.

Propagation

Propagate *E. berteroana* from seed or stem cuttings. Scarify seeds with sandpaper or a knife or treat them by soaking in hot water (40° C) for 12 hours. Small stakes or post- size cuttings for live fences (2.0 to 2.5 m, 5 to 8 cm diameter) sprout readily.

Pests

The Erythrina Stem Borer (*Terastia meticulosalis*) burrows into trees of *Erythrina* spp., causing death. Later infestations affect the pods and seeds (University of Florida, 2021).

Adults of *Phyllophaga menetriesi* feed on young and tender leaves of *Erythrina* spp. The larvae (white grubs) are pests of agroforestry plants like young coffee, causing root damage and facilitating pathogen entry (OFI-CATIE, 2003).

Environmental requirements

- Elevation–300 to 600 m (planted up to 1000 m).
- Rainfall–1500 to 3500 mm per year
- Soil–heavy textured, neutral to acidic, tolerates seasonal waterlogging
- Temperature Range–16 to 28° C, 18 to 26° C ideal

Source: OFI-CATIE, 2003

This useful tree will serve you in your agroforestry system, live fence, or as an ornamental. Active development workers who are ECHOcommunity members may request a trial packet of this or other seed. See the website to register and learn how to order seeds.

References

CABI. 2016. *Erythrina berteroana*. Commonwealth Agriculture Bureau International Compendium. https://doi.org/10.1079/cabicompendium.

OFI-CATIE. 2003. Arboles de Centroamérica. Un Manual para Extensionistas. Cordera, J. and Boshier, D.H. (Editors). OFI (Oxford Forestry Institute) - CATIE (Centro Agronómico Tropical de

Investigación y Enseñanza). Turrialba, Costa Rica.

Muschler, R., P.K. Nair, and L. Meléndez. 1993. Crown development and biomass production of pollarded *Erythrina berteroana*, E. fusca and *Gliricidia sepium* in the humid tropical lowlands of Costa Rica. *Agroforestry Systems* (24) 123-143.

University of Florida. 2021. Erythrina Moths *Terastia meticulosalis* Guenée and Agathodes designalis Guenée. Institute of Food and Agricultural Science (IFAS), University of Florida, Gainesville, Florida.

Upcoming Events

ECHO Asia

Agriculture & Community Development Conference

Chaing Mai, Thailand
October 16 - 20, 2023

ECHO East Africa

Symposium on Appropriate Technology Innovations and Renewable Energy

Arusha, Tanzania
August 9-11, 2023

ECHO Global Farm

North Fort Myers, Florida

Agroecosystems for Smallholder Resilience

September 11-15, 2023

ECHO International Agriculture Conference

November 7-9, 2023