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Edited by Dawn Berkelaar and Tim Motis

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Biofortified crops: What are they, how do they work and why should we grow them?

by Dr. Brian Hilton

Dr. Brian Hilton researched and promoted biofortified crops for over 20 years. Brian worked as part of a team testing the first orange sweet potato varieties in Mozambique in 2002. He has 25 years of experience working with farmers in Indonesia, Chad and Mozambique. Brian now works with World Vision Australia, coordinating World Vision's biofortification networks with CGIAR institutions that are breeding biofortified crops and with HarvestPlus whose mandate is to reach 1 billion people with biofortified foods by 2030.

Introduction: Micronutrient Deficiencies

An estimated two billion or more people suffer from 'hidden hunger', the deprivation of micronutrients necessary for growth and good health. In young children, micronutrient deficiency causes malnutrition that results in permanent cognitive damage. Malnourished children never catch up with their better-nourished peers resulting in a lifetime of poorer health and lower productivity. That's a big worry.

The most common micronutrient deficiency is iron. More than 30% of the world's population—about two billion people—are anaemic (a condition symptomatic of iron deficiency). Anaemia contributes to 20% of maternal deaths (WHO 2017a). Another common micronutrient deficiency is vitamin A deficiency, a common cause of preventable blindness and a risk factor for increased severity of infectious disease and mortality. An estimated 250 million children are deficient in vitamin A and each year, an estimated 250,000 to 500,000 children go blind because of it. More than half of these children die within one year after losing their sight (WHO 2017b). Zinc deficiency is another concern; more than 116,000 children die each year because of it, and an estimated 17% of the global population is at risk of inadequate zinc intake (HarvestPlus 2017).

Scientists and governments have addressed micronutrient deficiencies with vitamin and mineral supplementation programs, and with

Figure 1. Zambian farmer showing provitamin A hybrid maize on left vs conventional hybrid on right. *Source: Brian Hilton*

food fortification programs where millers and processors put vitamins and minerals into food. These programs have been cheap and effective, but there can be coverage gaps. Food fortification programs have decent coverage in urban areas where people purchase processed fortified food, but they are less effective in rural areas where families don't purchase much food.

Diet diversity is the ideal mechanism for addressing micronutrient deficiencies, but is very difficult to achieve in the countries we work in because of poverty, long dry seasons, or tiny land areas. For example, haem iron (derived from animal sources) is easier to absorb than non-haem iron (plant based). This is problematic, because the poorer the population, the less meat is eaten and the less diverse the diet. For all these reasons, most favour a combined approach of vitamin supplementation, fortification, diet diversity and biofortification, rather than using a single approach to address micronutrient deficiency.

Biofortification

Biofortification is the process of breeding crops for increased nutritional content or increased nutrient density. In economic crisis, poor people tend to cut down on purchases of expensive non-staples, such as meat, fruit and vegetables (Bouis 2011). This makes staples like wheat, rice, maize, beans, and cassava good targets of biofortification programs, because we know the poorest and most malnourished will be eating these foods even in hard times.

Conventional breeders have used two pathways to biofortify crops: 1) finding varieties of plants that exhibit β carotene pigments and 2) finding strong roots that are more efficient in taking up iron and zinc. When seeking to address vitamin A

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Figure 2. Seven high iron bean types in Burundi, including both bush beans and pole beans. Different colours are preferred in different regions. *Source: Brian Hilton*

deficiencies, breeders cross with varieties expressing orange plant pigments (β carotene) such as those found in Indian corn or in orange sweet potatoes. In selecting for stronger roots, plant breeders can screen varieties for high iron and zinc content and then cross those varieties with plants having high yield characteristics. When breeders investigate why the former crops accumulate more iron and zinc, they usually find that the roots are better able to extract minerals from the soil. Plants improve their ability to extract nutrients by pumping organic acids into the rhizophere to dissolve and increase the uptake of iron and zinc by plant roots. Because of the similarity between cations Fe^{2+} and Zn^{2+}, crops that are biofortified for zinc are often also biofortified for iron (though to a lesser degree) and vice versa. High iron beans being promoted in Burundi are 70% higher in iron, but also 40% higher in zinc than normal beans. The high zinc wheat in Pakistan is also higher in iron.

That brings me to standards. When looking at micronutrient content in a crop, one can often see a large range that is further widened by different soil types, locations and climates. HarvestPlus is an international organization in the CGIAR system that sets the target standards for biofortified crops (that is, the increase in concentration of a particular nutrient must be above a certain threshold to meet the target standards). For example, the baseline iron content of beans is 50 ppm, with a target of 94 ppm for biofortified beans. A couple of years ago I was enthusiastic about supporting a project to promote a new higher-iron bean in one African country, when members of HarvestPlus gently reminded me that the bean variety in my proposal had only 63 ppm iron and did not meet their targets for biofortification. It was a good point. To really make a difference in nutrition, biofortified crops need to be much higher in micronutrients—usually over 70% higher.

Crop breeding is a difficult job. Breeders select for many different traits, including high yield, pest resistance, drought tolerance, grain size and taste. These scientists are often under intense pressure, especially to increase drought tolerance of crops. Adding an additional parameter like nutrition increases their work load exponentially, so you can imagine that not every breeder is excited by this new challenge. In my experience, the women scientists that I have worked with are much more supportive of biofortification than are the men, because women better understand the importance of nutrition. By contrast, some breeders, when presented with the catalogue of advanced lines from the CGIAR centres, simply pick the highest yielders or biggest seeds without any thought to the nutrition. HarvestPlus is trying to change this by winning the hearts and minds of plant breeders in this great debate, through workshops, conferences and support for national breeding programs testing biofortified crops.

Biofortification can increase nutrient levels enough to improve human nutrition without reducing yield. I work mostly in very poor countries such as Burundi, Mozambique, Bangladesh, and East Timor, where there haven't been many new varieties released in recent times. In Burundi, new high iron beans are yielding 30% more than conventional beans because there have been so few previous releases. New orange sweet potato varieties are going to be released in Burundi in 2017; the last white sweet potato variety was released in 1988, so there is a good chance the new orange sweet potato varieties (that have been bred for characteristics that include higher yield) will yield much better than local white sweet potato. With hybrid orange provitamin A maize (high in β-carotene, the precursor of vitamin A) in southern Africa, yields are still lower compared to other hybrid maize, but the yield difference is decreasing over time as new provitamin A varieties come out.

Biofortified Crops

Many biofortified crops have been released. I will go over a few of the really exciting ones (also see Table 1). The orange sweet potato, yellow cassava, and orange banana provide provitamin A. High zinc wheat and high zinc rice improve access to that important mineral and are promoted where zinc deficiency is high. High iron millet, high iron beans, and high iron lentils help prevent anaemia from iron deficiency. These crops have come out sporadically across Africa, South America, and Asia, as crop breeders and governments have become interested.

Seed from the varieties listed in Table 1 should be available from the respective national department of agriculture or from seed companies within that country. Many of these varieties are available, but not

Table 1. Biofortified crops that have been or soon will be released. (The crops listed here are all conventionally bred).

Crop	Countries released	Countries testing and close to release	Propagation strategy	Can farmers save their own seed?
Provitamin A maize	Zambia, DRC, Zimbabwe	Many	Seed	No, best to buy new seed yearly
Orange sweet potato	Many		Vegetative (cuttings)	Yes (cuttings)
High zinc rice	India, Bangladesh	At early stages in many Asian countries	Seed	Yes
High zinc wheat	Pakistan	Bangladesh, Afghanistan	Seed	Yes
Yellow cassava	Nigeria, DRC	Ghana, Sierra Leone	Vegetative (cuttings)	Yes (cuttings)
High iron beans	Uganda, Rwanda, Burundi, Mexico	Many countries in East and Southern Africa	Seed	Yes
High iron lentils	Nepal, Bangladesh		Seed	Yes
High iron pearl millet	India	Pakistan, West Africa	Seed	Yes

For a more extensive list of biofortified staple crops, visit http://www.harvestplus.org/sites/default/files/publications/HarvestPlus_BiofortifiedCropMap_2016.pdf well-promoted. Note that several of these (banana, cassava and sweet potato) can be propagated vegetatively, resulting in clones that retain the high-nutrient status of the original plants.

Most row crops seem to be self-pollinated or only partly cross-pollinated, making it easier for farmers to maintain their varieties through seed-saving. Farmers in our programs are saving wheat, rice, peanuts, beans, sorghum, cowpea, pigeon pea, soybean etc. Wheat is mostly self-pollinated before the flowers open; some could be cross pollinated by wind, but the pollen is so heavy it usually doesn't travel far. Sorghum is only about 5% out-crossed, so that seed maintains its purity for a number of years. Still, for the seed-propagated crops in Table 1, the best way to maintain the high-nutrient trait in each variety is to regularly purchase seed from local suppliers. The investment is usually offset by the higher returns of using quality seed. Even if a variety is known to be self-pollinated, farmers should probably purchase new seed every four or five years. This reduces risks of contamination by seed-transmitted viruses and pollen from non-biofortified varieties; cross-pollinated crops are more susceptible to contamination than self-pollinating crops, but outcrossing (often through insect activity) occurs even in self-pollinated crops. Provitamin A maize is a hybrid and only available from seed companies; it is best to buy hybrid maize seed every year, because cross pollination and breakdown of the variety occurs in subsequent plantings.

Biofortified crops can have visible or invisible traits. Provitamin A maize is visibly orange, so farmers can identify what they have. The colour of the maize nsima (porridge) is also a light orange; it is a pleasing color, but most cultures will take a while to get used to it. Some sort of behaviour change may be needed. In Mozambique, I could easily follow the spread of orange sweet potatoes into new villages because the traits were visible.

Figure 3. Zincol 2016 wheat in Pakistan. Brian Hilton with HarvestPlus Wheat Breeder Yacub Mujadin. *Source: Brian Hilton*

Crops higher in minerals have invisible traits—it is not obvious that these crops are more nutritious. These crops with invisible traits can scale up very fast, but farmers growing them are often not aware that they are more nutritious. Farmers may instead grow them for higher yield. I call this 'nutrition by stealth.' I personally like to see biofortified crop scale-ups accompanied by nutrition projects where mothers and fathers can gain knowledge about nutrition. Nutritional knowledge is truly empowering.

Measuring Impact

The Biofortification Priority Index (BPI) assesses impacts for seven biofortified crops across 127 countries. The impacts are estimated by the number of people growing and consuming the crop in each country, along with the severity of micronutrient deficiency that the crop is addressing (Asare-Marfo *et al.* 2013).

The 2016 Global Nutrition Report (p. 18) notes that returns on investment in nutritional interventions are 16 times what was invested, because the impacts on mothers and young children are multiplied over their lifetimes. I have been doing agriculture projects for 30 years and have yet to find projects with more impact per dollar than the scale up of biofortified crops. Consider the new high zinc (and high iron) wheat in Pakistan called Zincol 2016 (Figure 3). 200 million bread-eaters live in Pakistan; you can imagine the impact that this crop could have on a population deficient in iron and zinc. This high zinc wheat would rank high on the BPI.

Genetic Engineering

As genetic engineering becomes more widely accepted, more and better biofortified crops will become available. Genetic engineering involves a process of inserting DNA into a plant. Conventional breeding (crossing of two varieties) requires many generations of crossing. Even if the desired gene has been identified in a wild variety of a crop plant within the same species, there is no guarantee that a breeder will be able to bring it over to the domesticated crop by crossing. Genetic engineering offers a faster and more direct approach for bringing that gene across. Genetic modification among plants of the same species is called cisgenisis. Breeders can also introduce new genes in plants by transferring genes from other species; this is called transgenesis.

An example of a transgenic crop is Golden Rice coming out in Bangladesh and the Philippines. Two genes, one from a daffodil and the other from a soil bacterium, have been introduced to enable the rice to synthesize β-carotene in the grain. This is exciting for nutritionists; micronutrient deficiencies are life-threatening in the Philippines, and genetic modification (GM) both increases the range of crops that can be biofortified and reduces the time needed for national breeding programs to release these crops. GM also offers scientists more pathways to biofortify crops. The inserted genes in golden rice activate the mechanism for β-carotene synthesis in the grain. The inserted genes in (forthcoming) high iron rice turn off the plant's mechanism for iron satiation, so that the rice plant is always trying to take up more iron.

After golden rice, high iron rice and high iron wheat will be the next generation of GM biofortified crops; in fact, these crops are at advanced stages in the pipeline. What will delay them in most parts of the world are national government policies regulating the use of GM crops. Transgenesis is a concern for some, who worry about unintended food safety issues and natural crossing of genetically modified crops into conventional crops and wild relatives. Concern about safety of transgenic crops, however, needs to be balanced against the good that those crops could produce in the extremely poor target populations. Herein lies another great debate, about which everyone seems to have a strong opinion. One opinion not generally heard in the debates is that of the malnourished poor who would benefit most from these crops.

[Editors: In keeping with our areas of strength, ECHO seed resources are focused on non-GMO OPVs, primarily of underutilized food plants.]

Conclusion

The list of available biofortified crops is steadily increasing. If you are promoting crops such as beans or lentils, the new high iron biofortified varieties could be available in your country. I use biofortified crops as a focal point to get donors to invest in integrated agriculture and nutrition projects.

Figure 4. Orange sweet potatoes have been introduced into children's diets in Mozambique. *Source: Brian Hilton*

In my early career I was interested in helping farmers in Chad and Mozambique obtain high yields, increase income and get out of poverty. These farmers were mostly entrepreneurial and mostly men. To be sure, those farmers started out very poor and a lot of progress was made. However, now I go deeper into the community and seek families with malnourished children, the types of farmers that do not often show up at community meetings. I work with others to improve their nutritional knowledge and to help mothers increase their skill in child care and feeding practices. In many respects this has been difficult, but as the Global Nutrition Report states, reaching these farmers and helping their children recover from malnutrition can have huge and long-lasting impacts. Promoting biofortified crops can be an important part of improving nutrition.

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The cheers and challenges of Conservation Agriculture programs

by Angela Boss and Stephan Lutz, summarized by ECHO staff

Angela Boss and Stephan Lutz, both working with World Renew, spoke at ECHO's November 2015 International Agriculture Conference about Conservation Agriculture (CA). CA is an ecological, resource-saving approach to farming in which soils are maintained through the application of three main principles: 1) minimum tillage; 2) permanent organic soil cover; and 3) diversification of crop species.

Angela and Stephan emphasized the difference between CA principles (the "why") and practices (the "how"). CA does not include a prescribed set of practices; rather, experimentation and adaptation are encouraged. Some practices for small farmers that are consistent with the principles of CA include: 1) planting into basins and/or permanent ridges; 2) mulching the ground with crop residues and/or green manure/cover crops (gm/cc); and 3) interplanting and/or crop rotation. CA can even include the judicious use of herbicides and fertilizer, and the use of appropriate tools.

The system referred to as Foundations for Farming (FfF) or Farming God's Way (FGW) presents very specific practices to fulfill CA principles, and adds the use of permanent planting stations. Sometimes this system can be a good starting point for small-scale farmers. However, this is not always the case. Angela and Stephan shared several situations in which the introduction of CA has been particularly challenging, for a variety of reasons.

Eastern Zambia

With FfF as the model, CA was introduced in an area of Eastern Zambia characterized by low rainfall, poor soils, and recurring drought. Adoption of the system was poor, with farmers generally having no more than a quarter acre (1/10 of a hectare) of land planted using FfF.

Angela suggested that part of the reason for low adoption might have been the initial "all or nothing" approach. Other constraints included a limited supply of manure; lack of mulch; and a high requirement for labour in the form of hoeing/weeding, especially for women.

Factors that helped to drive adoption included increased yield and soil moisture; availability of CA technologies (e.g. the chakka hoe, a relatively wide and heavy hoe designed by farmers to create planting basins; also the Magoye ripper, used for minimum tillage and helpful for breaking through the hard/plough pan); a supportive policy environment; and heavy promotion by multiple organizations.

Mozambique - Niassa Province

Niassa Province in Mozambique has good rainfall but poor soil fertility. CA was introduced there (via FGW), but with

Figure 5. Niassa province in Mosambioque: Traditional maize cultivation (left) and CA maize cultivation (right). *Source: Juvencio Mataria*

improper spacing/density. As a result, basins flooded. The area has a strong tradition of ridging and intercropping. People fear that mulch will attract termites.

Angela encourages change promoters to emphasize "why" rather than "how" when it comes to CA. In Niassa Province, farmer groups are designing and experimenting on 10 m X 10 m or 20 m X 20 m plots (e.g. one plot with traditional methods, one using CA with traditional seed, and one using CA with improved seed; see Figure 5). They are building on traditional systems and incorporating minimum tillage.

Kenya

In Kenya, chronic food insecurity has led to a growing dependence on food aid. Incidences of drought and flooding are occurring with increasing frequency, and 93% of land is degraded (according to an FAO report).

World Renew partners with Anglican Development Services (ADS), the relief and development arm of the Anglican Church of Kenya. World Renew also works through champion farmers.

For lasting change, Stephan commented that the community needs to be empowered, to create an environment in which farmers can succeed with CA. He described the characteristics of an empowered community in which members do the following:

- discuss their issues without fear
- implement what they have learned
- identify, mobilize and use their local resources to the fullest extent
- organize themselves and work together to achieve their own community plans
- confidently speak out against injustices that are encountered
- hold themselves and stakeholders mutually accountable.

Participatory rural appraisal is an important tool used within communities in Kenya to identify the crops that are grown and to prioritize them according to use, yield, taste, marketability and other criteria the community has identified. Where CA is used in Kenya, it often results in a better product and more marketable food crop, which typically translates into more income.

A Few More Principles

A document from the Canadian Foodgrains Bank, "Principles to Guide Conservation Agriculture Programming," shares principles that include but are not limited to agronomic aspects of CA. The principles include the following:

1. Recognize that CA works better in some contexts than in others
2. Adapt CA to the local context
3. Invest in developing a good project design
4. Invest in project participant selection
5. Pay attention to gender issues
6. Emphasize good staffing
7. Have effective extension/promotion strategies in place
8. Use inputs judiciously

Conclusion

CA has much to offer. Where it is implemented, farmers' crops are more likely to produce a harvest, with improvements in both quantity and quality of yields. These yield gains, as well as improvements to the soil, can be achieved using local resources, with savings in cost (of inputs) and time (through reductions in tillage and weeding).

However, the challenges are real. CA requires behaviour change. Mulch can be extremely difficult to come by, and technical support is often lacking.

Some interventions/introductions compliment the introduction of CA. These include animal husbandry (especially of indigenous poultry, goats, rabbits and bees); water and irrigation; and community participation, ownership and adoption of technology. As an example of community participation, Figure 6 shows a gm/cc decision tree developed in a participatory process in Mozambique to meet needs in one specific context.

Cornell University's CA web page (CA: Global Research and Resources) summarizes a flexible approach to CA as follows: "Rather than being a fixed technology to be adopted in blueprint-like fashion, CA should be seen as a set of sound agricultural principles and practices that can be applied either individually or together, based on resource availability and other factors. For this reason, farmers are encouraged to experiment with the methods and to evaluate the results for themselves-not just to "adopt" CA technologies."

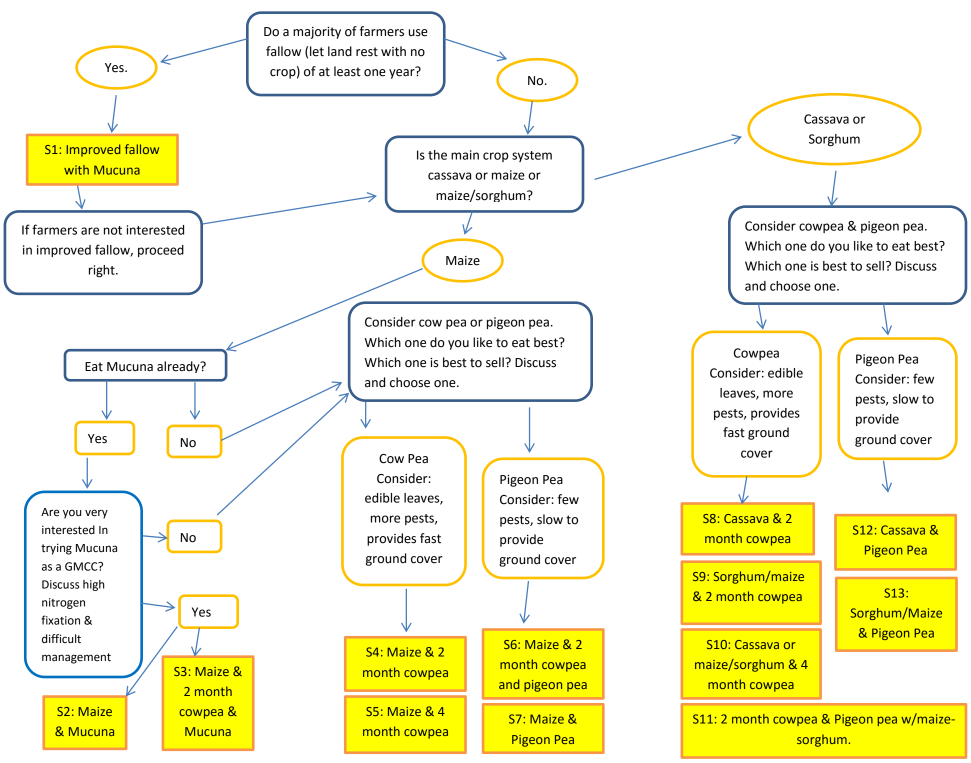

Figure 6. Gm/cc decision tree developed through a participatory process with farmers to meet the needs of a particular context. This is an example of what can be developed in participation with farmers to help guide decision making. *Source: Angela Boss*

Helpful Resources

Designing and implementing conservation agriculture in sub-Saharan Africa: Environment and climate change

- Teaser (8 pages)
- How to Do (24 pages)
- Lessons Learned (24 pages)

Conservation Agriculture Facilitators' Guidebook

Principles to Guide Conservation Agriculture Programming

Conservation Agriculture: A manual for farmers and extension workers in Africa (the full version of this book is available for purchase on Amazon)

Tools helpful for Conservation Agriculture:

- The Chakka hoe, a wide, heavy hoe used to make planting basins. See page 18 in the guide titled "Conservation Farming and Conservation Agriculture Handbook for HOE Farmers in Agro-Ecological Regions I & IIa-Flat Culture."
- The Magoye ripper, a tool used for minimum tillage, that helps break through the hard pan (plough pan). See an article titled "The Magoye Ripper: Preliminary Findings on Adoption, Benefits and Constraints" for details on its use in Zambia.
- In Mali, a ripper called the Kassine is use to ease the creation of zai holes.

ECHOES FROM OUR NETWORK

Joel Matthews, professor of Engineering Technology at Diablo Valley College, shared some comments after reading *EDN* 134. "Thank you for your excellent and timely article on women's agricultural participation in *EDN* 134. I have a few comments that I would like to share. First, I highlight what Laura Meitzner Yoder said regarding no absolutes in terms of gendered behavior. This truth is reinforced by the contrast between Laura's experiences of men and women working together in Asia, and Stacy Reader's experiences of separation between men and women [in one context] in Tanzania.

"As a cultural anthropologist I must remind people that, if we subscribe to the concept of cultural relativity (no single culture has the objective ability to interpret and critique the values of other societies.), then we must acknowledge that this concept cuts both ways. In other words, even our supposedly superior egalitarian ideals must not be considered absolutes. This means that we should always be careful of imposing our ideals, however well-intentioned, on others. This imposition occurs when we organize 'village meetings' where we insist that men and women join forces. Clearly, as Reader noted, such meetings are considered inappropriate [in one context] in Tanzania.

"I have observed many well-intentioned development facilitators imposing mixed meetings in contexts where such mixing is inappropriate, but this 'steamrolling' over community values is allowed, or even encouraged, when we believe that our values are superior to theirs. It is easy to imagine that if the Tanzanians would follow our lead, they could achieve the type of egalitarian society that we envision for them. This is a difficult area to sort out, especially when women are oppressed, which they often are. However, my experience in West Africa has shown me that forcing men and women to attend meetings together may ultimately harm the very women we hope to assist. This is particularly true in regions of West Africa where men and women operate in separate, parallel organizations.

"In Niger, where I did much of my research, successful men and women conduct social relations and business operations in the context of small voluntary associations. Among the Hausa women of Niger, these are often much more successful than men's associations. One of the dangers of forcing mixed development planning meetings in this context is that men can easily take control of what had previously been highly successful women's enterprises.

"Thus, I suggest that in some contexts, men and women may function in separate societies, not because women have been denied joint control over resources with men, but rather because women do not want to risk losing control of the resources that they already manage. One of the most important pre-cursors to sustainable and equitable development is to understand what already exists, and why things are the way they are. Once this is understood, it may be discovered that, rather than being haphazard, customs are based on informed decisions.

"I address these very issues in a recent article published by Taylor and Francis."

FROM ECHO'S SEED BANK

Gac: A colorful and health-promoting fruit

By Tim Motis

What is special about gac?

Perennial leafy greens, such as moringa and chaya, have been featured quite extensively in *EDN*. Here we focus on the bright orange-to-red fruit (Figure 7) of a tropical vining plant called gac (*Momordica cochinchinensis*). Belonging to the Cucurbitaceae family, other names for gac are cochin gourd, spiny bitter cucumber, and sweet gourd. Gac fruit has a mild flavor. Like moringa, it can be consumed in a variety of ways; it can be eaten fresh, cooked, or as a powder. Incorporated into traditional foods, gac adds both color and nutrition.

Figure 7. Immature (left) and ripe (right) gac fruit. *Source: Stacy Reader*

Gac fruits are best known for their high concentration of carotenoids, natural chemicals that protect against cell damage and are the source of yellow, orange, or red coloring in fruits and vegetables. By weight, beta-carotene is more concentrated in gac fruit than carrots. Similarly, gac fruit has a higher concentration of lycopene than tomato. Much more detail about these and other health-enhancing properties of gac are available in the literature (Chuyen *et al.* 2015, Minh 2014).

Where does it grow?

In South and Southeast Asia, where gac originates, its long (up to 6 m) perennial vines are often seen climbing on fences or into trees. Gac occurs naturally on edges of forests or rivers at 400 to 1,100 m elevation (Ecocrop 1993). It prefers full sun and a well-drained soil with good air circulation and pH near neutral (7.0). Gac is best adapted to warm, moist conditions (20-30 °C with 1,500-2,500 mm annual rainfall). However, it can also be grown in areas with dry or cold seasons; in these situations, vines die back until the return of favorable conditions, when new growth is generated from the tuberous roots.

A growing season of about eight months is needed to obtain fruit. Because the fruits become soft when ripe, they are difficult to transport. Gac is well-suited, though, for the household garden.

Figure 8. Foliage of gac vine. *Source: ECHO Staff*

What does it look like?

The vines have large (10-15 cm wide), dark green leaves with three to five lobes (Herklots 1972; Figure 8). Gac is dioecious, meaning that some plants will have female flowers and others will have male flowers (Figure 9). Fruits are round or ovate (egg-shaped), 10-15 cm long X 10 cm wide, and covered in short spines (Figure 7). Green, immature fruits turn bright orange or red when ripe. Just under the spiny skin is a 1-2 cm thick layer of yellow to orange flesh called the mesocarp. Beneath this layer, the inner portion of the fruit is filled with numerous red, oily sacs/membranes called arils (Figure 10). Each aril encloses a nearly flat, brown to black seed that is around 2 cm wide (Figure 11).

Figure 9. Male (left) and female (right) gac flowers. *Source: Stacy Reader and Holly Sobetski*

Which parts of the plant are eaten?

The arils in ripe fruits can be eaten fresh or cooked. For example, in Vietnam, gac arils are cooked with rice to make a traditional dish called xôi gac.

Although the fruits are only available for a short time each year, the nutritional benefits of the arils can be preserved by drying and powdering them (see an entire thesis on this by Tran 2007), or by extracting oil with a screw-type press (Vuong and King 2003). It takes about 100 kg of fresh fruit to obtain 1 liter of gac oil.

Immature/green fruits and young leaves are boiled and used in curries. The spiny outer peel, pulp (mesocarp) and seeds are not eaten, though the pulp and peel can be used for fertilizer or to feed cattle (Chuyen *et al.* 2015).

How to grow gac?

Propagation and cultivation

Gac can be propagated by seed, vine cuttings or root tubers. Gac seed typically germinates in one to four weeks. However, forty percent or more of seed-grown plants may be male, as indicated by the absence of a swollen structure [ovary/immature fruit] at the base of the flowers (Wimalasiri 2015; see Figure 9). By using tubers or cuttings, a farmer can control the number and ratio of male and female plants. For maximum insect-pollination, aim to establish about 1 male for every 10 female plants. Vine cuttings 15 to 20 cm long and 3 to 6 mm wide can be rooted in water or in well-aerated, moist potting media before transplanting to a final location (Parks *et al.* 2013).

Since gac is a vigorous climber, able to cover entire trees if allowed, give vines adequate space (e.g. 1.5 m within and between rows) and consider pruning them. Support the vines with a lattice or trellis, 2 to 2.5 m in height, to minimize spoilage of the soft, ripe fruits. When the main stem reaches the top of the trellis, its growing tip can be removed; then laterals can be selected and trained as desired.

Pollination by hand is not difficult, and may be necessary if insect pollination is not sufficient.

Gac responds well to fertility inputs. Consider using similar rates as for bitter melon (*Momordica charantia*; as described by Palada and Chang [2003]).

Little information is available about pests and diseases of gac. Rats and birds can damage the fruits. Bitter melon, a relative of gac, is susceptible to leaf spot (caused by *Pseudoperonospora cubensis*), bacterial wilt (caused by *Pseudomonas solanacearum*), melon fruit fly (*Dacus cucurbitae*) and nematodes (*Meloidogyne incognita*) (Nguyen and Widodo 1999).

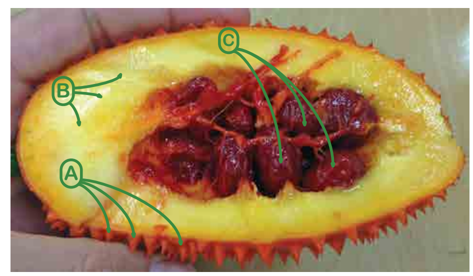

Figure 10. Outer peel (A), pulp/mesocarp (B) and red arils (C) of a ripe gac fruit. *Source: Stacy Reader*

Harvesting

Gac will usually flower 2 to 3 months after seeds or tubers are planted. Fruits are ready for harvest about 5 months after flowering. Some plants may not produce fruit until the second year after planting. A vine produces fruit once per year, over a 2- to 3-month season that depends on the region (in Southeast Asia, the season falls between September and February). Expect to harvest 30 to 60 fruits per plant, with each fruit weighing 1 to 3 kg.

Seed saving

To save seeds for planting, collect them from fully ripe, dark orange or red fruits. Seeds are more easily separated from the arils after soaking in water overnight or in a 1:10 bleach and water solution for just a few minutes. (In the latter case, the thick seed coat will protect the seed from any bleach damage.) Seeds should then be air-dried on a counter and stored under cool, dry conditions.

Figure 11. Gac seeds, after removal from surrounding seed sacs (arils). *Source: Tim Motis*

Closing thoughts

Gac fruit arils are an excellent source of important vitamins and antioxidants. Though gac has a short fruiting season and the ripe fruits spoil quickly, these limitations are counterbalanced by the multiple ways it can be consumed and utilized. This summary primarily describes the fruit, but several of the references below mention uses for and/or medicinal qualities of the leaves and seeds. If you live in an area where gac is grown, much more could be learned from the farmers and gardeners who are growing it. Those registered with ECHOcommunity (see www.ECHOcommunity.org for information) and actively working with farmers internationally may request a trial packet of gac seed from our Global Seed Bank. If you have experience in growing this unique crop, please share your insights on vine management (to control plant size and maximize fruit production) and on fruit preparation (any favorite recipes or suggestions for making aril powder or oil).

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BOOKS, WEB SITES AND OTHER RESOURCES

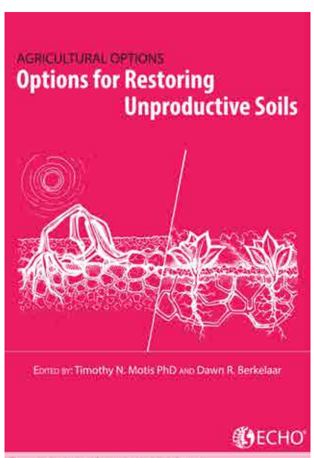
Options for Restoring Unproductive Soils and Options Where Water is Scarce epublication Releases

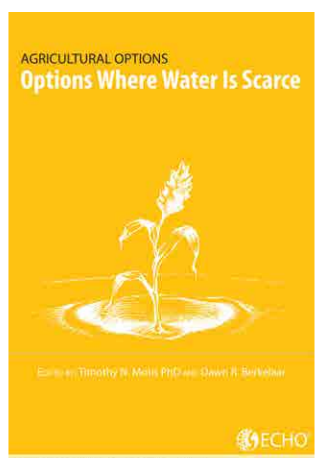
ECHO is pleased to announce availability of the ebooks ***Options for Restoring Unproductive Soils*** and ***Options Where Water is Scarce***. These electronic publications include the content from the second and third chapters of *Agricultural Options for Small-Scale Farmers: A Handbook for Those Who Serve Them* (originally published in 2012 as a sequel to Amaranth to Zai Holes).

Options for Restoring Unproductive Soils builds on the foundational concepts explored in ECHO's previous electronic publication (*Fundamentals of Agricultural Development*), and covers practical, project-oriented options for restoring unproductive soils. Topics discussed in this ebook include lessons and practices in land stewardship; specific farming systems with proven success in soil restoration; and soil amendment options that reduce reliance on mineral fertilizers.

Options Where Water is Scarce also builds on foundational agricultural development concepts. It covers options for coping with scarce rainfall, including rainwater harvesting strategies and irrigation options.

Upcoming ebooks include Chapters 4 and 5, which cover practical, project-oriented options for crop utilization to improve human nutrition (Chapter 4) and for diversifying the smallholder farm (Chapter 5).





The ebooks *Options for Restoring Unproductive Soils* and *Options Where Water is Scarce* are available for purchase from Amazon for $4.99 each.

We hope that the perspective found in these ebooks will help lead to improved livelihoods of smallholder farmers around the world. Please let us know how their content contributes to your efforts to serve the poor.

Chaya

Miracles in Action has brochures about chaya available in English and Spanish. A collection of recipes for chaya, in Spanish, is also available for download. http://miraclesinaction.org/photos-links/links/

Moringa

Strong Harvest International has a peer educator manual to facilitate communication about moringa. The manual is available in seven languages--English, French (for West Africa), Haitian Creole, Spanish, Arabic, Portuguese and Swahili. Though the 20-page section with training illustrations contains almost no words, the manual includes many other sections, including an outline and instructions for conducting a two-day Peer Educator Seminar; information about doing a family and community assessment; basic nutrition information; reproducible forms for record keeping; information about growing and eating moringa; details about water treatment; and an introduction to economic opportunities.

Hard copies of the manual can be purchased for $30 US, or an electronic download can be purchased for $10 US. http://www.strongharvest.org/resources/

UPCOMING EVENTS

ECHO Florida Events:
Location: ECHO Global Farm, USA
Presented by: ECHO

Tropical Agriculture Development Workshops

- Seed Saving: A practical overview for small-scale seed banking
  May 8-12, 2017
- Tropical Agriculture Development 1: The Basics
  July 24-28, 2017
- An Introduction to Community Development
  August 14-18, 2017

ECHO International Agriculture Conference
November 14-16, 2017

ECHO's remaining 2017 training schedule will be posted at ECHOcommunity.org/events.

ECHO Asia Events:

ECHO Nepal Agriculture and Community Development Workshop
May 22-24, 2017
Location: Kathmandu, Nepal

ECHO Asia Agriculture and Community Development Conference
October 3-6, 2017
Location: Chiang Mai, Thailand

Please watch ECHOcommunity for further information. Subscribing to "calendar notifications" will help ensure that you don't miss out. More information and registration details can be found on www.ECHOcommunity.org.

PLEASE NOTE: At ECHO we are always striving to be more effective. Do you have ideas that could help others, or have you experimented with an idea you read about in *EDN*? What did or did not work for you? Please let us know the results!