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Short- and Long-term Effects of Drought on Human Health

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Nearly all of the countries in sub-Saharan Africa (SSA), especially those in the Horn of Africa, are struggling to meet the Millennium Development Goals (MDGs) five of which are related to health.

These include:

- (1) Eradication of extreme poverty and hunger
- (2) Reduction of infant mortality
- (3) Improvement in maternal health
- (4) Combating HIV/AIDS, malaria, tuberculosis, and other diseases with access to essential medicines
- (5) Reduction of the proportion of people without access to safe water and improved sanitation

These health goals are becoming even more difficult to achieve with the threat of climate change and increasing drought. Especially vulnerable to climatic disruption are the health and well-being of populations in arid and semi-arid lands (ASALs).

Some countries of SSA as well as donors are developing initiatives to address climate challenges. For example, the Kenyan adoption of the African Adaptation Program for Climate Change seeks to strengthen national institutional, systemic capacity and leadership to address climate change risks. If successfully implemented, initiatives like this should help build resilience among SSA populations.

Unfortunately, the proportion of land that ASALs occupy in the Horn of Africa is steadily increasing as a result of dwindling water resources and the increasing frequency and duration of droughts. Furthermore, population pressure allied with climate change contributes to growing desertification and the destruction of vegetation in water catchment areas.

Drought and desertification contribute not only to water and food shortages and often famine, but also to energy shortages that occur as

rivers dry up, and to civil strife, often as a result of competition for resources, forcing mass migrations. These effects are intensified by problems of gender inequity, lack of basic infrastructure in these areas, and rapid environmental degradation, all of which have direct and indirect detrimental effects on human health.

As the health of agricultural resources (crops and animals) becomes compromised, so does access to nutritious food and clean water for people, increasing their susceptibility to malnutrition and disease. Recently studies on epigenetics have shown that these detrimental health effects are not only short-term or life-long problems, but trans-generational in that they can carry over to subsequent generations – to our children, grandchildren and beyond.

Effects of Drought and Malnutrition on Human Health

On the basis of available data, the **short-term effects** of drought on human health are those caused by water shortages and concomitant food shortages, and those caused by contaminated water, which people resort to when water is scarce. Dehydration, caused by insufficient liquid intake, and diarrhea caused by microorganisms and contaminants in water, are major causes of infant mortality; in pregnant women inadequate caloric intake and micronutrient malnutrition, resulting from food and mineral shortages, compromise maternal health and hence the development of the fetus. In both children and adults, malnutrition compromises the immune system and thereby increases the likelihood of predisposition to a multitude of infections caused by viruses, bacteria, fungi, and worm and other parasitic infestations.

The potential **life-long effects** of malnutrition *in utero* and early childhood include stunting, a physical manifestation of malnutrition; poorly characterized cognitive deficiencies; psychiatric illnesses (Rutten and Mill); and a variety of metabolic diseases, some of which have been shown to be **trans-generational**, such as diabetes, breast cancer and hypertension.

Synergy between malnutrition and disease

The burdens of disease and malnutrition, each reinforcing the other, continually conspire to weaken African populations. They are at the core of SSA's perennial dilemma of a vicious circle of poverty and underdevelopment. Malnutrition, both caloric and micronutrient, is considered the major cause of SSA's high prevalence of acquired immunodeficiency syndrome (AIDS) from both undernourishment and HIV. AIDS from either etiology predisposes people to a multitude of diseases caused by many infectious agents. These infections stimulate agent-specific and nonspecific host defense mechanisms.

The capacity to mount these molecular and cellular self-defense pathways is directly influenced by the host's macro- and micronutrient status. Observations in populations, even those with adequate caloric intake, have shown that micronutrient malnutrition is associated with alterations in tissue integrity at the organs bearing the portals of entry that protect the body from the external environment. These include the lungs, gastrointestinal tract, the skin, eyes and ears. In human beings death often occurs from infections that arise because of malnutrition and compromised immunological defense systems.

The better characterized of these immunological deficiencies include reduction or lack of mucous secretions that trap and remove foreign agents and loss of ciliated respiratory tract epithelium in the lung and nasal mucosa, alterations in normal intestinal flora and a diminution in the capacity to kill invading organisms by phagocytic cells, such as macrophages (Grimble, 1994).

The synergism between infection and malnutrition is especially clear in areas of poor basic sanitation where bacterial infections and worm infestations are common causes of diarrhea, which is often associated with blood loss and malabsorption of nutrients. Generalized infection with fever causes hyper-catabolism, which is often aggravated by poor appetite, with a resultant loss and ultimately depletion of the body's nutrient reserves (Filteau and Tomkins, 1994).

To break this vicious circle of malnutrition, infection, and immunological dysfunction, disease control measures need to be instituted alongside appropriate nutritional interventions. Therapeutic efforts based on food enrichment, such as adding vitamins to staple foods, have had appreciable success. A more recent approach, which will be discussed in more detail, is the biofortification of major staples eaten by populations in the developing world. This novel strategy employs recent advances in the biological sciences to speed up the selection and propagation of crops with desirable traits, such as enrichment in major micronutrients for which deficiencies are common.

Infectious disease in young children

The combination of malnutrition and disease is responsible for sub-Saharan Africa's high mortality rates for infants (9.5 percent) and children under age five (16 percent). Although these rates are gradually decreasing, they are still far above those of the rest of the world, including South Asia (UNICEF 2008). The two-way links between disease and poverty in the adult population, which are such a prominent feature of HIV/AIDS and agricultural under-productivity need to be emphasized.

As a single disease entity, malaria is still the leading cause of morbidity and mortality, especially in SSA. Malaria and intestinal helminthic infestations often coexist and are both exacerbated by and are in a vicious cycle with major contributors to caloric and micronutrient malnutrition. The most vulnerable populations are pregnant women, infants, and children. Anemic pregnant women with malaria and intestinal infestations are at a high risk of giving premature birth and of bearing infants with low birth weight (LBW), while at the same time, premature and LBW infants are at a higher risk of early childhood mortality and impaired growth, as well as impaired cognitive development (Stephenson, Latham, and Ottesen, 2000; Steketee, 2003).

Of the causes of the under-five mortality, infections are thus the leading etiology: pneumonia (18%), diarrheal diseases (15%), and malaria (16%).

As more and more pathophysiologic mechanisms of malnutrition are being defined at both at the molecular and cellular levels, the disease entity called “Dietary Acquired Immunodeficiency Syndrome” or Dietary AIDS is being increasingly recognized.

In assessing the progress being made to attain Millennium Development Goal 2, the UN Interagency Group for Child Mortality Estimation reports a drop of 37%, globally, in the under-five mortality in the 20 year period between 1990 and 2010. Of the 7.6 million deaths of the under-fives that occurred in the 20 years, 3.7 million (49%) were in SSA and 2.5 million (39%) in Southern Asia. The global burden of the under-five mortality is thus increasingly concentrated in SSA. Of the factors studied that contributed the most to the diminution of under-five year-old mortality are the mother’s education, wealth quintile and residence – urban versus rural.

Fluid and electrolyte malnutrition

Diarrhea causes losses of water and electrolytes with resultant fluid and electrolyte malnutrition (FEM). Intestinal worm infestations contribute to iron, nutrient, and micronutrient losses, either directly or by induction of anorexia and malabsorption. Diarrheal diseases caused by rotavirus or bacteria, such as shigellosis and salmonellosis, are associated with malabsorption of amino acids, sugars, and lipids as well as losses of zinc, iron, and vitamin A (R. Glass, 2006). Vitamin A deficiency worsens lesions in the digestive tract, exacerbating malabsorption.

Malnutrition and helminthic infections

Intestinal worms are a major cause of morbidity and contributors to child mortality in the developing world. Unlike the therapy of many other tropical diseases, highly effective, relatively inexpensive, and safe broad-spectrum anthelmintics, such as albendazole and

mebendazole, are available. It has been recommended that routine mass deworming should be introduced where parasitic infections are prevalent and where protein–energy malnutrition (PEM) and anemia are prevalent in humans. The WHO has recommended five anthelmintic drugs for use in controlling intestinal nematodes. These drugs include albendazole, levamisole, mebendazole, pyrantel, and praziquantel, which can be used to improve the health, developmental, and nutritional status of girls and women. It has been recommended that after the first trimester of pregnancy, pregnant and lactating women can ingest single oral doses of these drugs (WHO, 1996, 1998, 1999).

Similarly, routine efforts to treat children with schistosomiasis (kalazar) using metrifonate or praziquantel seem highly desirable, both to rid children of potential serious pathology and to improve their nutritional status. More attention needs to be given to population–based chemotherapy for these infections, along with intensification of public health and other measures to reduce their transmission, including improved sanitation and safer water supplies. Although the logistics may prove challenging and vary from one region of the world to another, such efforts would improve the health and nutritional status of millions of the world’s children (MacLeod, 1988).

Malnutrition and infection–induced molecular and cellular metabolic aberrations

In some cases, infection–associated metabolic alterations are defensive responses by the host attempting to cope with the infectious agents. In other cases, they are driven by parasite factors, and in still others, the reactions are appropriate, but sometimes excessive. These changes may influence protein, carbohydrate, and lipid metabolism and thus the host’s nutritional status, and worsening the condition of an already malnourished individual.

The most prominent of these metabolic changes is perhaps the synthesis of molecules that mediate innate host defenses such as acute phase reactants and cytokines. These inflammatory responses are primarily mediated by tumor necrosis factor (TNF α), interleukin 1

(IL-1), and IL-6. A secondary response occurs with the action of catecholamines, steroid hormones such as cortisol, and glucagon. TNF α induces higher energy consumption and increases protein and lipid metabolism. TNF α is also an inducer of anorexia and weight loss with the inhibition of lipoprotein lipase production and depletion of fat reserves (Starnes et al. 1988).

In full-blown gluconeogenesis, a host process responding to stress glucose deficiency by deaminating amino acids, becomes a source of glucose. Such a state induces the release of pro-inflammatory cytokines, namely IL-1, IL-6 and TNF α . These cytokines induce the synthesis of a multitude of host defense factors, which are mostly proteins. These include acute phase reactants including complement factors, C-reactive protein, α 1-acid glycoprotein, α 1-antitrypsin, α 1-antichymotrypsin, ceruloplasmin, haptoglobin, fibrinogen, α 2 macroglobulin, and serum amyloid (Fleck 1989). The diversion of available amino acids for synthesis of acute phase reactants occurs to the detriment of maintaining optimal levels of housekeeping proteins such as albumin, hemoglobin, immunoglobulin, and transferrin (Kosek, Black, and Keusch, 2006).

Malaria, although to a lesser extent than bacterial endotoxin, induces the release of cytokines including TNF α (which plays a critical role), IL-1, and interferon gamma (IFN γ). In turn these cytokines induce the release of additional pro-inflammatory cytokines such as IL-8, IL-12, and IL-18. A compensatory mechanism balances these reactions with the release of anti-inflammatory cytokines including IL-6 and IL-10 (Hoffman, Campbell, and White 2006). In malaria, cytokines are responsible for fever, malaise, and other signs of disease. It has been established that TNF α (cachectin) causes body wasting directly or indirectly through activation of IL-1. Because of the activation of all these inflammatory mediators, malaria worsens nutritional status and thus increases susceptibility to other diseases.

It is noteworthy that altered levels and activities of TNF α and other cytokines occur in many infections, including amebiasis, leishmaniasis, trichuriasis, and tuberculosis. In these diseases the balances between

cytokine, chemokine, and stimulatory molecules determine the type of immune response mounted by T cells, which can differentiate along a Th1 or Th2 pathway. Th1 cells produce IFN γ and IL-2 and enhance macrophage defense, resulting in parasite killing and delayed-type hypersensitivity reactions. Th2 responses release deactivating cytokines (IL-4, IL-5, IL-6, and IL-10), which favor B cell activation and antibody production (Hoffman, Campbell, and White 2006).

Protein–energy malnutrition (PEM)

The effects of severe protein–energy malnutrition *kwashiorkor*, are well known and include chronic diarrhea, compromised mucosal immunity, and dysfunction of both the classical and alternate complement pathways, thus predisposing the host to gram–negative and other infections (Fresno, Kopf, and Rivas, 1997).

Deficiencies of micronutrients, including iron, zinc, selenium, copper, other minerals, and vitamin A play roles in PEM, and these roles are being better defined. Iron and zinc are required as co–factors in metalloenzymes involved in macrophage phagocytic functions. The zinc and iron deficiencies seen in PEM also contribute to a decrease in T–cell responses and diminution in IL-2, NF κ B, and IFN γ production, with resultant dysfunction of cell–mediated immune responses. Malnourished hosts with PEM are thus predisposed to developing infections caused by bacteria, intracellular parasites, viruses, and pathologic protozoa.

Although the ever–present hazard of combined infections and malnutrition threatens the health of all those living in poverty, the most vulnerable groups are pregnant women, infants, and children. The synergism between malnutrition and infection and their adverse effects on immunological functions has recently been reviewed (Scrimshaw and Sangiovanni, 1997; Beisel, 1996).

Children under the age of five years would appear to be at especially high risk, yet there are few controlled interventional studies. Studies demonstrating the efficacy of improved diets on the frequency and

severity of infections, especially in childhood, are difficult to carry out. However, one study in the Punjab confirms what has been known in the developed world — that combining infectious disease control and provision of adequate nutritional supplements is the best strategy for promoting good health (Taylor and Parker, 1987).

Life-long and Transgenerational Effects of Malnutrition

Many of the children who live beyond the age of five years in the developing world are those who have been exposed to both malnutrition and disease and have survived. But these children are seldom left without some form of permanent adverse effect. Given the difficulties inherent in setting up comparative studies, assessing the long-term impact of PEM is a challenge.

The consequences of micronutrient malnutrition and PEM over a lifetime may include physical, psychological, and cognitive deficits that may not allow affected children to achieve their optimal potential in adult life. Stunted growth, behavioral alterations, and learning disabilities may all have adverse lifelong impact. For instance, chronic iron-deficiency anemia and iodine deficiency may cause mental retardation and poor psychomotor development, even if some of the underlying causes are corrected (Scrimshaw and Sangiovanni, 1997).

Trans-generational Effects of Malnutrition: Genomics and Epigenetics Studies

For the past fifty years, progress in the biological sciences and technology has been explosive and continues to pick up speed. The **genomics revolution**, which led to the sequencing of a large number of microbial, protozoan and mammalian genomes has facilitated, in an unprecedented way, our understanding of evolution and vital life processes across many species. This is leading to the development of better-targeted drugs and vaccines against microbes and other disease-causing agents in mammals and crops, and also a better understanding of metabolic diseases in human beings.

The unfolding recognition of the interaction of heredity and the environment underscores the importance of the influence of drought on life-long and trans-generational health. For example, the ongoing epigenetic studies¹ on the drought and famine that occurred in the Netherlands during World War II suggest that there is a direct link between the nutritional status of mothers and that of their offspring's children.

Epigenetic case studies: Sweden and the Netherlands, long-term and trans-generational effects of drought and subsequent famine in human beings

By the time the 150th Anniversary Celebration of Charles Darwin's publication, *On the Origin of Species by Natural Selection* was taking place in November 2008, a significant body of epigenetic evidence had been collected to show that, under certain powerful environmental conditions, acquired characteristics can be passed onto future generations. Charles Darwin had argued that changes in evolution occur over many generations in the course of millions of years. The first epigenetic study to provide evidence for this form of non-Darwinian inheritance was a retrospective epidemiological study carried out by Lars Bygren, who is now a member of the Karolinska Institute, on populations that lived in Norrbotten in the extreme northern part of Sweden in the 19th Century (Kaati and Bygren).

Church records were meticulously kept so that the dates of births and deaths of all family members could be traced. Norrbotten suffered extremes of gluttonous periods and famine in the winter, so that by

¹ Epigenetics refers to the potentially inheritable phenomena above the level of genes, and without altering the underlying DNA sequence. Over the past 20 years, studies by Bygren in Sweden and his associates, and Smith and his associates at Harvard Medical School, have given rise to the new science of epigenetics. As the name implies, epigenetics means a form of non-Darwinian inheritance determined by factors surrounding or above the genome. These epigenetic elements are important determinants of gene expression – instructing genes to be switched on or off. It is through these epigenetic elements that environmental factors such as pollutants, dietary content, stress and prenatal nutrition can make an imprint on genes causing disease. Some of these epigenetic changes can be passed from one generation to the next.

studying the health status of individuals born during either of these periods one could deduce whether periods of glut or near-starvation had an effect on health and lifespan.

These studies revealed that both gluttony and starvation have adverse effects on the health of offspring as well as grandchildren. The studies also showed that sons who went from eating normal to gluttonous diets during winters of plenty gave rise to sons and grandsons whose lives were shorter by as much as 32 years, compared to an age matched cohort who endured a winter of a poor harvest. Later studies, using more cohorts from Norrbotten revealed that this phenomenon also applied to the female line. Women who went from eating normally to eating gluttonous diets, in a single winter during pregnancy, gave rise to daughters and granddaughters who lived shorter lives by decades, compared to a control group matched for age and socioeconomic factors.

Similar findings have been reported for the so-called “Dutch Famine” of 1944–45 (R Francis, 2011; C Smith, 1947). Towards the end of World War II, as the allied forces were approaching from the south the exiled Dutch government ordered a railway workers’ strike. The Nazis retaliated by instituting a food embargo against the most populous areas of northwestern Holland beyond the city of Arnhem. This embargo coincided with a particularly harsh winter of 1944–1945 (R Francis, 2011). The transportation infrastructure was destroyed, canals were frozen, and the retreating German army had flooded the agricultural fields. From November 1944 to May 1945, when Germany surrendered, it is estimated that 22,000 people had died of starvation in western Holland.

Clement Smith and others initiated a study of children who were *in utero* during this tragedy – often referred to as a “natural experiment” to determine the effects of maternal malnutrition on fetal development.

Timing of exposure to malnutrition determines outcomes

At the three trimesters of pregnancy, embryonic development of different tissues and organs are at different stages of tissue and organ maturity. Hence these studies revealed that the timing of exposure to malnutrition determines the health outcomes that ultimately appear during adult life.

Most of the children born of malnourished mothers have a low birth weight (LBW) and poor neonatal health. Neonates exposed to malnutrition during the 1st Trimester are prone to obesity and coronary artery disease as adults. Those exposed to famine during the 2nd and 3rd trimesters also developed obesity, had a higher risk for developing schizophrenia, antisocial personality disorders, high blood pressure, coronary artery disease and, in women, breast cancer. Those offspring who were exposed to starvation only during the third trimester had a higher likelihood of developing type-2 diabetes.

These two studies provide compelling evidence for long-term and trans-generational effects of prenatal starvation, but the details of the mechanisms, both at the molecular and cellular levels need to be elucidated.

Genomics and disease

The completion of the sequencing of the human genome in 2002, as well as genomes of many other organisms, ranging from viruses, bacteria, protozoa, agents of disease and those of staple crops was one of the most remarkable landmarks of the Twentieth Century Science. It was hoped that such a towering achievement would open doors for our understanding of all heredity. This turns out not to be the case. Specifically, our understanding of the connection between gene expression and disease turns out to be more incomplete than previously imagined.

Gene silencing: Epigenetics and cell differentiation

What is already emerging from scattered pieces of information such as cellular pathways of differentiation traversed by stem cells to become cells of different organs each of which evolves highly specialized functions, retrograde differentiation of mature cells of any organ that become cancerous and the silencing of one of the **female X** chromosomes in each cell in mammals, disparate phenomena that did not appear to have any apparent relationship, is the fact that gene expression is strongly influenced by environmental factors. It is also becoming clear that because of exogenous factors, identical twins are, in fact, not identical.

Inheritance is thus not merely the transmission of genetic information, but also of patterns emerging from the expression of these genes through interactions with the environment, epigenetics: a complex phenomenon that has loosely been termed the **Triple Helix**. So far the molecular basis of epigenetic changes appears to be mediated by alterations of the density of methyl groups ($-CH_3$) on specific bases of gene sequences, or those changes that occur in elements surrounding DNA in the genome, such as histones, all of which modulate the levels of gene expression (Francis, 2011).

Developmental biology, which is perhaps one of the fastest growing fields in the biological sciences, has gene silencing as its driving force. This field of biology is multidisciplinary in scope and has created a framework that integrates molecular biology, physiology, immunology, cell biology, neurobiology, anatomy, cancer, ecology, evolutionary biology and environmental science.

All the cells in an individual have the same genetic constitution. However, organ development during embryogenesis through early adult life occurs because, for each organ, groups of genes are sequentially silenced thus conferring each tissue or organ its unique functions. For instance, neuronal cells process, store and retrieve information; nodal tissue cells in the heart generate an electric current

that induces the heart muscle cells to contract in a coordinated, rhythmic manner thus pumping blood around the body; the liver cells function as factories, making many of molecules essential for the body's house-keeping functions; and cells in the skin, lungs and the digestive system function to protect the body from harmful infectious agents, toxins and other environmental factors, including UV light.

From stem cells, the development of organs comprises a series of normal physiological gene silencing events, which are mediated by introduction of methyl groups to specific sites of genes. The study of development has thus become essential for understanding any other area of biology, in particular the development of cancer and many other diseases in which epigenetic methylation of DNA appears to be the dominant feature.

There is a major, ongoing research initiative, the **Human Epigenome Project (HEP)**, which seeks to identify, catalogue, and interpret genome-wide methylation patterns in all body organs. Introduction of non-physiological methyl groups (epigenetic methylation) into gene sequences is thought to be a modification of genes that forms the missing link between genetics, the environment and disease. At the molecular level, epigenetic methylation of DNA appears to be the major factor that predisposes the organism to exogenous factor influences that modulate gene expression and may well be the basis of carcinogenesis, certain types of neuropathology and many other diseases, including susceptibility to infectious agents. To develop a better understanding of the epigenetic phenomena will require interdisciplinary, large-scale and long-term longitudinal studies of populations.

Epigenetics and the fetal-placental environment

An adverse fetal-placental environment is associated with increased risk of metabolic, neuroendocrine and psychological disorders in adult life (Dunn et al., 2011). Maternal exposure to stress causes hormonal disturbances. For instance, excess excretion of glucocorticoid hormones, which induce maternal stress, is associated with

“developmental programming” effects resulting in epigenetic changes in target gene promoters in some cases affecting the level of expression of receptor proteins that modulate a variety of important physiological functions in many organs including the heart, endocrine system, adipose tissue and the brain. These changes persist into adult life and, as mentioned, predispose the individual to a variety of diseases of the cardiovascular, glandular, lipid storage, neurological and psychiatric disorders.

Prenatal programming of the epigenome is an important determinant of offspring health and forms the inter-phase between genetic heredity and the environment. Maternal exposure to stresses such as caloric or micronutrient malnutrition or obesity is associated with a multiplicity of metabolic and neurodevelopmental diseases affecting the offspring in adult life. It is known that some of these diseases are passed onto the second or third generation. The placental environment and maternal diets thus contribute to the epigenetic programming of the embryo that appears to have adverse long-term health outcomes during adult life.

Because primordial germ cells, which contribute both genetic and epigenetic information to future generations, are exposed to such stress in this period of fetal development, they are also reprogrammed during embryonic development. It is believed that epigenetic changes in germ cells are usually reversed in the process of sperm and egg formation. It is apparent that such reversals do not always occur and may be especially erratic in states of malnutrition, which include both food excess and starvation. This is thus the likely basis for trans-generational epigenetic transmission of predispositions to disease.

Plant and Animal Health: Resilience in Times of Drought

A substantial part of SSA comprising the Sahel, the Horn of Africa and Northern Kenya is prone to frequent droughts that are the main cause of suffering, massive social disruption and conflict. It is thus essential to develop technologies and crop varieties that will increase social,

economic and ecological resilience in such regions and others that will be similarly affected as effects of climate change intensify.

Drought tolerant plants for food safety

It has been argued that the Genomics Revolution is different from all other previous revolutions as it has enormous potential for helping to alleviate the enduring problems of hunger, disease and environmental degradation in the developing world, especially drought. It is well known that genome sequences of all the major cereals including those of maize, wheat and rice have been completed by CGIAR centres in collaboration with other institutions. The availability of this information provides molecular markers and the genetic basis for drought tolerance and other important traits, all of which will improve the efficiency of animal and crop breeding programs.

There are many varieties of staple crops that have been selected for tolerance to drought, salinity as well as many pests. Using conventional breeding technologies, several of the CGIAR centres and their partners have developed drought, salinity and pest tolerant varieties.

By comparative genomics, the major African cereals are being studied by CGIAR centres including the International Crops Research Institute for Semi-arid Areas (ICRISAT) in India, the International Centre for Research in the Dry Areas (ICARDA) in Aleppo, Syria, the International Institute for Tropical Agriculture (IITA) in Nigeria, the International Maize and Wheat Improvement Centre in Mexico (CIMMYT) and the International Centre for Tropical Agriculture (CIAT) in Cali, Colombia and the West African Rice Development A (WARDA). Thus improved varieties of millet and sorghum, rain-fed rice such as NERICA, multipurpose grain legumes such as cowpea, barley, and drought-tolerant maize have all been developed in this way.

Lessons from resurrection plants

In spite of the continuing success in breeding plant varieties that have drought tolerance and other desirable traits, there is still a need to

have a better understanding on the mechanisms that these plants employ to survive extreme drought and other abiotic and biotic adverse conditions.

Although much less is known in plants compared to animals, there is every reason to believe that for most plants prolonged drought with attendant malnutrition adversely affects plant defense mechanisms at both the molecular and cellular levels. Because of immunodeficiency, plants thus become more susceptible not only to abiotic stresses, but also to a variety of diseases caused by viruses, bacteria, fungi and nematodes. However, the pathways and mechanisms of progression from desiccation to death are still ill defined.

An exception is some plant species growing in arid areas. A series of studies on such desiccation-tolerant plant species growing in arid areas of South Africa has identified several enzymatic pathways that mediate the process of survival at near-total desiccation. In some of these species, drought tolerance is mediated by sequestration of certain sugars such as sucrose and complex polysaccharides. Other pathways involving metalloenzymes have also been identified and are being further characterized. Such plants can tolerate up to 95% water loss for months and even years, but revive completely within 48 hours after exposure to water. Some of the most dramatic species include *Myrothamnus flabellifolia*, *Xerophyta humilis* and *Selaginella lepidophylla* (Farrant JM, Cooper K, Nell H, 2011).

The latter recovers from months of extreme drought within three hours of exposure to water. The genes encoding the elements of these pathways have been termed “resurrection genes”. The holy grail of these types of studies is to make possible the development of drought-resistant crops.

It is very timely that with the threat of climate change, sensitive molecular selection techniques are now becoming available. These include Marker Assisted Selection and Intussuception (MASAI), which has greatly improved the efficiency of identifying markers for drought

tolerance and other traits in crops. These are being developed and applied to a wide variety of crops.

The Way Forward: Holistic Interventions for Mitigation of Effects of Drought

Regional proactive programs are required for the mitigation of the adverse effects of climate change, drought and food insecurity. At the community level, integrated solutions are needed to control the threats of drought on human, animal, crop and environmental health. Such solutions should incorporate effective strategies with synergistic components, enabling partner organizations to work together to achieve the goal of reducing the burden of disease and malnutrition.

Synergistic components must include:

- recognition of country and regional priorities for socioeconomic development and donor agency coordination
- commitment and support by sub-Saharan African governments to increase agricultural productivity
- holistic approaches to mitigate the effects of drought that recognize the interplay between disease and malnutrition
- improving nutritional status through agricultural interventions, better animal husbandry and crop improvements
- application of innovative and appropriate technologies including biofortification
- community involvement in policy formulation, project planning, implementation, and evaluation

According to the *World Development Report* (World Bank 2008), the overarching global challenges of the 21st century, including ending hunger and poverty, sustaining the environment, providing security, and managing global health, will be difficult to achieve without significant improvements in agricultural productivity. Both agricultural productivity and animal and human health will be adversely affected if insufficient attention is paid to holistic strategies to mitigate malnutrition and the spread of infectious diseases.

The importance of collaboration between national, regional and international institutions

All countries across SSA have research institutions conducting work on agriculture productivity, human and animal health and the environment. Unfortunately, a feature that many of these institutions share is that they work in isolation – commonly known as silo operations – that are very reminiscent of the Myth of Sisyphus where progress is often elusive. If research organizations, SSA governments and development agencies are to facilitate the attainment of MDGs in SSA, then it is imperative to apply the best that science can offer in **collaborative** institutional, regional and international efforts.

There is abundant evidence in support of coordinated programs that use a holistic approach, which concurrently aim at improving nutritional status and controlling infectious diseases.

Improving nutritional status: animal husbandry

Investing in animal productivity is the most obvious way to control PEM. Although reducing animal production risks requires developing broadly applicable technologies to meet many challenges, the main challenge is to protect animals against endemic and epidemic diseases. The others are to identify and conserve animal genotypes that remain productive under biotic and abiotic stresses and that are most suited for the diverse ecosystems in Sub-Saharan Africa and to develop nutrient-rich feeds that are also suited to varied local environments.

Among the most important diseases that constrain livestock productivity in Sub-Saharan Africa are trypanosomiasis, tick-borne diseases (including theileriosis, or East Coast fever [*Theileria parva*]), tropical theileriosis (*Theileria annulata*), bovine tuberculosis, contagious bovine pleuropneumonia, and African swine fever. Among these diseases, the most widespread and challenging malady is African

trypanosomiasis, which affects human beings, livestock, and wildlife in the communities that are most vulnerable.

Need for improvement in animal feeds

In addition to food crops, the improvements in animal productivity are also needed to combat protein malnutrition, Kwashiorkor and Marasmus in the human populations living in ASALs. One of the biggest challenges to the livestock industry in ASALs is provision of animal feeds during drought. One of the major developments in the provision of animal feeds in recent years is the breeding of *Brachiaria* grasses. The Tropical Forages Project of CIAT in Colombia and EMBRAPA centres in Brazil have produced highly nutritious *Brachiaria* grasses that are also drought and pest resistant.

These grasses are of high interest to the East African Region because they originated from Kenya, Tanzania and Rwanda and were taken to various parts of the world; initially to Australia, during the colonial era and, more recently, through Ethiopia and Montpellier, France, to Latin America. Although these *Brachiaria* grasses are being grown across the whole of South America, Brazil alone grows these grasses in an area of over 140 million hectares of its Cerrados savannah-like region. It might not be common knowledge, but the eastern Africa region has the highest biodiversity in grass species.

Continuation of this breeding for varieties of grasses that are tolerant to biotic and abiotic stresses is needed, in part, because it has been estimated that in the developing world the *per capita* meat consumption leaped from 14 to 21 Kg between 1983 and 1993. With increasing population the trend will continue and it is expected to grow from the current total of 206 million to over 300 million tons per annum by 2020. The demand for dairy products is taking a similar trend.

Food crops for drought tolerance

To improve food security in ASALs, a variety of crops that are tolerant to biotic and abiotic stresses have been developed and are either undergoing demonstration or are being distributed to farming

communities. These include grain legumes, pigeon peas, cowpeas, and mungbeans (Kenya Agriculture Research Institute, Research Program on ASALs, 2012).

Many cereal varieties have also been developed and include sorghums, pearl and finger millets. The largest number of maize hybrids that are drought tolerant and others that are pest resistant have been adapted for low lands and highlands as well. Many of these have either been released or are undergoing farm trials.

Amount of crop seeds and root crops cutting distributed to farmers 2011-2012

Crop	Amount-KARI(Tons)
Pigeonpea	8
Dolichos	10
Cowpeas	122.01
Greengram	50.05
Beans	125.42
Maize	74
Sorghum	291.6
Pearlmillet	38.2
FingerMillet	1.4
Soya	5
Cassava	1,995,000.00
Sweetpotatoes	2,080,000.00

Root and tuber crops, which include potatoes, sweet potato, and cassava varieties, have also been developed. In addition to selecting these crop varieties for tolerance to abiotic stresses and pests, high yields were also taken into consideration. One particular variety of cassava was selected for pest resistance and for its yield of upto 76 tons per hectare. A variety of sweet potato known as orange-fleshed sweet potato is especially important as it is enriched in Vitamin A.

Integrated pest control for maize

One particularly successful procedure, employing an integrated pest management (IPM) strategy for the control of stem borers, which are the main pests of maize in SSA, is described. Stem borers lay their eggs in the stems of growing maize and the larvae can destroy more than 80% of a maize crop. The technique involves surrounding the maize field with Napier or other types of grasses and intercropping with a member of a legume family called *Desmodium*. The stem borers appear to prefer laying their eggs in Napier grass, which exudes volatile compounds that attract the parasitoid natural enemies of these moths, which attack the moth's larvae (Khan et al. 2007, International Centre for Insect Physiology and Ecology).

Another group of volatiles released by the *Desmodium* intercrop repel the stem borers. The stem borers are thus attracted into the Napier grass and repelled by the volatile compounds from the intercrop hence the use of the term "push pull" to describe this strategy. A group of compounds belonging to the family of uncinanones are also released by the roots of the *Desmodium* intercrop and induce suicide germination of the main weed of maize Striga. Another member of this family of chemicals also inhibits the attachment of the Striga roots to the roots of maize. In addition to controlling stem borers and Striga, the *Desmodium* intercrop used in "push-pull" also fixes nitrogen and improves soil moisture content with a substantial increase in the nematode biodiversity and crop yields.

Biofortification of Food Crops: Consultative Group of International Agricultural Research (CGIAR), HarvestPlus

A recent approach to improve nutrition for the developing world is the biofortification of major staples consumed by those populations. This novel strategy, the CGIAR HarvestPlus Program, is in its second phase and is funded by the Gates' Foundation.

It has been estimated that more than half of the world's population consumes diets that lack bio-available vitamins and minerals.

Micronutrient malnutrition is therefore rampant. Micronutrient malnutrition especially affects women and pre-school children.

HarvestPlus recognized from the outset of the program that working with farmers, consumers and other end users in evaluating the most nutritious crop varieties would be critical. These varieties needed to have superior agronomic, socioeconomic, and end-user acceptable traits in order to be successfully adopted (HarvestPlus, 2010–2012).

In Phase I of HarvestPlus the program bred nutritionally improved varieties of seven major staple food crops, which are consumed in much of the developing world. It employed recent advances in the biological sciences to speed up the selection and propagation of crops with desirable traits. The selection included plants with demonstrated high levels of major micronutrients, for which deficiencies are common. These include iron, zinc and Vitamin A. The enriched staples include: maize, wheat, rice, cassava, sweet potatoe, common beans, and pearl millet. In Phase II, HarvestPlus has moved from discovery to full-scale production of these fortified staples.

Because bio-availability of micronutrients in the fortified staples goes through complex intra-cellular steps, from synthesis, transport, storage and stability, once harvested it is imperative to carry out studies to ensure that the micronutrient is available in the consumed diet. Developing full-scale production will be carried out in collaboration with national and regional plant-breeding and health programs. The ongoing program includes high-zinc rice for India and Bangladesh, high-zinc for India and Pakistan, pro-vitamin A for DR Congo and Nigeria, high-iron beans for Rwanda and DR Congo, and pro-vitamin A sweet potato (orange sweet potato) for Uganda and Mozambique.

It appears logical and appropriate for National Agricultural Research Systems along with regional and international partners to participate in the propagation of bio-fortified plant breeding and assessment for efficacy of biofortified staples.

There is a need for integrative agriculture for health – an approach that goes beyond crop and livestock production to embrace human health and environmental resilience. To break the vicious circle of malnutrition, infection, and immunological dysfunction, disease control measures need to be instituted alongside appropriate nutritional interventions, such as those based on therapeutic programs on staple-food enrichment. Integrated agriculture for health exploits the interconnectedness of agriculture, health and environmental conservation in producing both regional and global public goods.

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