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FOOD SECURITY IN THE FACE OF SALINITY, DROUGHT, CLIMATE CHANGE, AND POPULATION GROWTH

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7.1 Introduction

At this point in human history, the problem of food security is larger than it has ever been, with more than 800 million people chronically hungry and millions more at risk (FAO, 2013). Despite progress in some parts of the world to reduce hunger, in other areas, particularly in Africa and the Middle East, the hungry population is growing.

The problem will not get better by itself. Global climate change, including rising average temperatures, more severe droughts and more extreme weather variability will present ever-increasing challenges in marginal, already-stressed agricultural ecosystems. Moreover, no efforts to reduce hunger will be made easier by rapid population growth. In the next 35 years, the population of Earth is projected to increase by more than the current populations of China and India combined (FAO, 2011b). Most of this growth will be in developing countries, especially concentrated in the poorest communities in urban areas.

The contributions included in this volume represent a diversity of topics associated with halophyte physiology, molecular biology, and potential agricultural uses, largely focusing on dry lands including Bangladesh, Pakistan, the Arabian peninsula and across northern Africa to Morocco. These are areas affected by salinity, either because they are coastal or because inappropriate irrigation schemes have degraded soil and depleted or salinized groundwater. The world's major crops are proving

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inadequate to supply the calories, proteins, fats, and nutrients people need in these areas. New crops are needed, specifically appropriate to the myriad of ecological conditions in the region. The central question around which this volume is organized is whether halophytes can be a useful or important tool for assuring food security to people living in this region and under these conditions.

In this chapter, I will concentrate on the food security issue itself, especially contrasting the problems in Pakistan, one of the more at-risk countries in the region and in the world, and the oil-rich countries of the Arabian peninsula, especially Saudi Arabia and Qatar. I will also consider the potential for modifying old crops or developing new ones, particularly for Pakistan, recognizing the limitations imposed by local climate, societal instability, and the global economic environment.

7.2 The Problem of Food Security

Even among plant scientists, there is a well-ingrained perception that there is enough food in the world, but that the problem is distribution. If one takes the total production of grain (as the major food source by weight) and divides it by the total world population, this is perhaps true, although it is difficult to maintain confidence even at this level if one also projects future production and future population. But even at this level, it is clear that "distribution" is complicated by the fact that most suppliers have little apparent interest in distributing food to the more than 800 million hungry people in the world (FAO, 2013). This includes, in particular, commodity speculators who, in the 2007–2008 food price crisis, demonstrated their primary interest in creating and maintaining high prices, thus greatly reducing accessibility to those in poorer countries who were already spending two-thirds of their income or more on food (Ghosh, 2009; Rapsomanikis, 2009; Wahl, 2009). The problem is exacerbated by the increasing competition for nonfood uses of crops, for example, biofuels (Pimentel et al., 2009), and by rising standards of living, especially increased meat consumption, that alter global market structure.

With this in mind, it is worthwhile to examine the problem of food security more wholly. The broadest and most widely accepted definition of food security is that provided by the FAO, that is, as a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2013). Neither the status of food security nor its achievability is uniform throughout the world, within individual countries, or over time.

There are four key dimensions to the problem (FAO, 2013):

- Availability—there must be adequate quantities for everyone, and the food must provide adequate amounts of calories, protein, fat, and micronutrients
- Accessibility—people must have both sufficient resources to obtain the food and physical access to it. Infrastructural components, such as roads and safe water supplies, are important factors affecting accessibility
- Usability—this includes having the resources for proper handling, storage and preparation, including safe and adequate water and sanitation
- Stability—supplies must be consistently available over time. Global climate change, including such immediate variables as temperature and precipitation, will affect both land suitability (including salinization) and crop yields (Battisti and Naylor, 2009; Schmidhuber and Tubiello, 2007), especially in poorer, drier nations at low latitudes.

Availability is more complex than simply something to fill your stomach; grains alone do not constitute "food." In Bangladesh, for example, the percentage of children who are underweight is falling as incomes are rising, and malnutrition is widespread (Ahmed et al., 2012). However, weight alone is not health. Nearly 80% of the calories consumed are cereals. Partly as a result of the poor overall nutritional quality in these seeds, more than 40% of women are anemic (FAO, 2013; Hyder et al., 2007). With CO_2 elevation and the associated reduction of micronutrients in C_3 grains, especially zinc and iron (Myers et al., 2014), this fraction may increase.

In many regions, food security, if it exists, is fragile. All four dimensions of food security are negatively impacted by political instability (Jenkins and Scanlan, 2001). Poverty, poor health, and malnutrition, in turn, are (and always have been) drivers for increasing armed conflict (Paveliuc-Olariu, 2013; Pinstrup-Andersen and Shimokawa, 2008). Moreover, a positive correlation between the occurrence of civil war and temperature suggests that armed conflict incidences may increase by more than 50% by 2030 associated with global climate change in the already hotter, drier and under-nourished regions of the world (Burke et al., 2009). This will further increase food insecurity.

Shabaz et al. (2012a) noted that conflict, along with the massive monsoon flooding in 2010 in Khyber Pakhtunkhwa province in north-west Pakistan, compounded the food security crisis in an area that was already one of the poorest in the country. The situation, however, is hardly better in the southern Sindh province where 72% of households are food insecure, and half the population suffers from nutritionally related stunting (Fazal et al., 2013), again exacerbated by conflict and flooding.

The issue of food security is not limited to poor countries, however. This was brought into clear focus in oil-rich countries of the Arabian peninsula during the food price crisis of 2007–2008. These countries were able to weather the crisis only because of their financial ability to buffer their local markets. One result of that has been their accelerating acquisition of farmland in developing countries. This is both a means of circumventing the water-limited agricultural systems of the investing countries (essentially importing water already processed through plants into food), and an expression of their distrust of the function of the global market place (Von Braun and Meinzen-Dick, 2009). Saudi Arabia, for example, has been reported to have removed its subsidy on water use for irrigation, much of it derived from desalination of seawater or over-pumping of groundwater, substituting instead food grown in Pakistan specifically for their consumption (Allouche, 2011). Qatar has similarly been in negotiations with Ghana to grow crops specifically for Qatar (Laessing, 2010). Von Braun and Meinzen-Dick (2009) present a table of 57 instances of such "land grabbing" [sic] between 2006 and 2009, the target countries being poor and with serious hunger issues of their own. They note that while these projects can inject much needed funds into the poorest areas of poor countries, they also threaten local access to and control of land and food resources by people in those areas.

Because of their wealth, had the investor countries the land and water resources themselves, they would technically be able to be highly efficient, although the history of their forays into agriculture using groundwater or desalinization of seawater does not reflect this possibility (Brown, 2009; Postel, 1998). Their oil-based economies could well support highly efficient planting, irrigating, fertilizing, and harvesting of crops. Whether this technology and investment can or will be made available to the targets of their investment is unclear, but I have found little reason to be optimistic in the near term.

At the same time, it should be noted that the capacities of the oil producers for outsourcing their food production and purchasing food security are highly dependent upon the world maintaining its dependence on fossil fuels, and hence on continued CO_2 emissions, warming, and climate change. If the world as a whole were to curb emissions, or if the Gulf countries' oil reserves were to be depleted, the economies and sustainability of these countries would be in question. This is not the problem for today, however, as no serious efforts to curb emissions have been taken by any country. Alternately, if warming is not curbed, the associated political, economic and social instability (Ulrichsen, 2009, 2011) may also overwhelm their short-term successes at buying food. Again, population promises to make all aspects of these relationships more difficult.

The possible solutions to the food security problem depend in large part on where in the world the problem is. In the dry countries from Pakistan and Bangladesh to Morocco, the problem is different from those facing countries in East Asia or sub-Saharan Africa. As noted in the "Introduction", the present discussion is most concerned with the former group, where drought and salinity are critical limitations. These areas may be saline either because they are coastal and have little available freshwater, or because inappropriate irrigation practices and related causes have led to salinization of their groundwater and soils. To solve this, crops will need to be able to integrate their salt management with other aspects of metabolism, especially with producing a product edible by and nutritious to humans or their animals. Whereas the genetic manipulation of crops to improve their nutritional value may be a viable solution to address deficiencies in the nutritional qualities of the plants themselves (Ronald, 2011), no such relatively simple solution is possible in the case of salt tolerance (Cheeseman, 2013).

Even within this region, the food security problems and solutions are not uniform. In countries with financial wealth with soil, water, and agriculture poverty, the problems are likely to grow in the next 35 years. Since the dawn of the petrochemical era, both the indigenous and guest worker populations in the oil-rich countries of the Arabian peninsula have grown well beyond what was previously sustainable. Today, 80% of the people in Qatar are non-Qatari (Qatar Information eXchange, 2014). In the working population, 94% are migrants/guest workers. The total population rose 5.6% in 2013, down from 14% in 2000 (World Bank, 2014). Also in 2013, the population of Saudi Arabia increased by 1.9%, Oman by 9.2%, and Kuwait by 3.6%. The ramifications of this for the whole region are huge; they are at risk of becoming very poor if or when the oil economy fades. Clearly, they will not be able to fall back on their own agricultural resources for food security.

Today's poor countries, on the other hand, and especially the poorest regions within those countries, are already experiencing a worst-case scenario. In a sense, they are prepared or preparing for things to come but, like the rich countries, they also have nothing to fall back on. Moreover, the worst case could get worse. The population of Pakistan, for example, has been growing at 2.2% since the 1980s (Anonymous, 2013), whereas wheat and rice production have been increasing more slowly (2.0% and 1.1% respectively, Khan et al., 2010).

7.3 The Problem of Salinity in Agriculture

Although there has been significant progress in reducing hunger world-wide in the last 25 years and there are promising signs for continued improvements in relatively stable, relatively productive parts of the world (FAO, 2013; Godfray et al., 2010), the outlook is less optimistic in areas affected by both drought and salinity. That salinity is a challenge and a major limitation to agriculture has been recognized for about 6000 years (Jacobsen and Adams, 1958). It has been a significant and recognized limitation to agricultural productivity in countries with industrial agriculture for more than 100 years (Lawton and Weathers, 1989). The relationships between salt and plants (at least one step removed from agriculture itself) have been a major area of study for more than 60 years (e.g., Epstein, 1956). In this latter phase, the salt relations of plants have been approached at the physiological, biochemical, and molecular levels as each sub-discipline emerged and flourished, leading to increasingly reductionist approaches with increasingly tenuous ties to organisms or to agriculture.

In the last roughly 20 years, molecular approaches have come to dominate basic research associated with salt, transport and stress tolerance, and land salinization and agricultural effects have increasingly been invoked as justification for research projects. Unfortunately, this has generally been little more than an invocation, usually at the start of the "Introduction" or "Discussion" section, and frequently as a conclusion (e.g., "our results show gene x is central to increasing salt tolerance in y"). The processes targeted have been quite limited and most often observational (e.g., simple photosynthetic rates, proline concentrations, activities of a few enzymes, sodium "exclusion," or worse, growth of *Arabidopsis* seedlings for 2 weeks in Petri plates with added glucose as a carbon source). The genes targeted have also been limited; although more than a hundred genes have been considered at some level, a few putative transporter genes and transcription factors are most highly represented (Cheeseman, 2013). Efforts to use molecularly based approaches to improve the salt tolerance of existing crops (especially wheat and rice) have made only painfully slow progress; even their successes are not all that impressive (Ashraf, 2010; Colmer et al., 2006; James et al., 2012; Munns, 2005; Munns et al., 2012; Schubert et al., 2009).

Today, more than 34 MHa are salt-affected and the area is increasing rapidly, with Pakistan being one of the most affected countries (FAO, 2011b). Food security puts a different spin and different urgency on the problem; once it is invoked, it is no longer sufficient to say that salinity is a growing problem. At stake are the lives of millions of people, and they are not winning.

7.4 Fitting Crops to the Environment—A Place for Halophytes?

Having dismissed molecular- or laboratory-based approaches to improving the salt tolerance of plants, I will briefly discuss what I consider to be four more viable options for improving or developing crops to meet the food security needs of dry and saline regions.

7.4.1 Option 1

Develop local cultivars of existing crops for local use; for example, wheat and rice, the two most important of the world's grains, are already major crops in Pakistan. In the sense that a large fraction of the literature on salinity and agriculture focuses on this approach, it is the obvious alternative. Such efforts have been underway in Pakistan, for example, for more than 45 years (Mahar et al., 2003; Shah et al., 1969), and more than 100 wheat landraces from Nepal and Pakistan have shown unexpectedly high salt tolerance (Martin et al., 1994). More recently, Shahzad et al. (2012) analyzed 190 landraces of wheat, including 130 from Pakistan, correlating molecular and morphological markers. They identified 12 SSR markers associated with tolerance to NaCl up to 250 mM, five of which were identified with four or more selectable traits. However, if these have been deployed in Pakistan (or countries with similar climatic conditions), they have not resulted in the yield increments needed to grow food production at the rate of population growth, or reduce under-nutrition. Because of the freshwater limitations on the Arabian peninsula, the costs of desalinization and the water use inefficiencies of C_3 crops, this is not an option for those countries.

7.4.2 Option 2

Expand efforts to cross crop species (especially wheat) with naturally salt-resistant relatives. Even within the Triticeae, there are more than 30 species that could be used for this (Colmer et al., 2006). In Pakistan, studies to improve wheat in this way have included efforts to cross it with *Aegilops ovata* (Poaceae) (Shafqat, 2002). Such efforts, particularly in wheat and rice, have a long history but have had only moderate success (Colmer et al., 2006). Perhaps most important for the present discussion, they have also not led to cultivars that can be deployed successfully in the poorest and most saline areas of the world, nor does a concerted effort appear to be pointed in that direction.

7.4.3 Option 3

Expand the species used in agriculture beyond the major grain crops. The premise here is that there are significant potential food crops lurking in diets around the world that could be expanded to new regions and contribute to local food security. Identifying them, moving them, establishing their cultivation (especially under drought and saline conditions) and developing local acceptance would be important aspects of exercising this option.

In Pakistan, for example, Shahbaz et al. (2012b), noted the importance of vegetables, not just grains, in providing calories, vitamins, proteins, and nutrients, and their importance to the diets of poor people there and in other parts of the developing world. Therefore, they studied the salt tolerance of pea, okra, tomato, eggplant, pepper, carrot, broccoli, cauliflower, and potato, and the strategies that were being used to enhance their salt tolerance. Such crops would also be important contributors in reducing the micronutrient limitations already in place and destined to increase as C_3 grains are subjected to higher atmospheric CO_2 levels (Myers et al., 2014).

Indeed, the number of plants which have served and are still serving as foods throughout the world is quite large even though they are poorly represented in the biological and agronomic literature. For example, Harlan (1992) provides a list of 88 genera harvested for food by native Australians, most of which are also represented in other countries as domesticated species (including *Chenopodium*, *Glycine*, *Ipomoea*, *Musa*, *Oryza*, *Solanum*, *Vigna*, and *Vitis*). In addition, he documented more than 250 plants cultivated in other regions of the world.

Prestcott-Allen and Prestcott-Allen (1990) listed 103 crops contributing 90% of the world's food supply based on FAO data, several of which were agglomerations (e.g., pulses, or roots and tubers). They noted, however, that some countries with unique and rich agricultural histories (e.g., Ethiopia) were not represented in their tables, so the number of globally or locally important crops is actually significantly higher.

Among the "minor crops," one in particular stands out for its transformation since these lists were published: quinoa (*Chenopodium quinoa*). This was an indigenous crop at high elevations in Bolivia, but its acceptance has experienced rapid expansion because it is highly nutritious, it can be substituted for other grains in many uses, and its domestication has not proceeded to the point at which reduced genetic variation compromises the development of new cultivars (FAO, 2011a). It is also naturally salt-tolerant.

7.4.4 Option 4

Localized development of new crops for local consumption. This option may be the only alternative in countries or regions experiencing low political stability (including ethnic disparities), poor infrastructure, or few if any financial resources. Essentially, it involves implementing domestication processes similar to those which led to the world's major grain crops, but in a much shorter period of time and in both biologically and sociologically stressful environments. The efforts would build on local knowledge and traditional uses of plants, and be accomplished largely by relatively uneducated farmers with the assistance (if possible) of extension specialists, but without reliable contributions from governments, universities, or international breeders. Much as the concept of de novo domestication of new crops is daunting, with concerted effort, it could be done in as little as 20–30 plant generations (Hancock, 2012). If perennials were targeted with the idea that they would remain perennials, it is conceivable that appropriate genotypes could be selected even more rapidly, the case of *Aeluropus lagopoides* in Pakistan being an example (Ahmed et al., 2013).

Local salt-tolerant relatives of major grain crops might themselves be such crops of the future. In fact, the development of halophytic crops is not a particularly new idea (e.g., Glenn et al., 1999; Rozema and Flowers, 2008; Yensen, 2006), but progress in accomplishing it has been slow, and in few cases has the intent been to develop food crops. In large part, this reflects the fact that plant biologists, crop scientists, and politicians in the developed world are not hungry, nor are their families, and thus, that funding has been difficult to obtain.

I envision this option as best suited to countries with an agricultural tradition, and question whether the historically non-agricultural oil-producing countries of the Arabian peninsula (for example) could follow this path. They do, however, have an endemic halophytic flora (from Shahina Ghazanfar, unpublished data), although they have managed it poorly; it is often difficult to find, having been subjected to oil spills and overgrazing. Whether this could be developed along with seawater irrigation for food and fodder will depend on the foresight and will of those ruling the countries. In any case, it is unlikely to support the population that has accrued and continues to grow rapidly.

7.5 Concluding Remarks

We are at a point of decision: do we attempt to develop crops to assure food security for saline and dry countries over the next 35 years, or do we let the people in those countries continue to fend for themselves. How we make this decision, or even if we make it, remains to be seen. Whether new crops can be developed rapidly enough to bring food security to all and assure its continuity will depend on many factors, including the will of governments and international organizations to seriously fund the efforts, and the willingness of people, especially poor people in poor countries, to adopt new crops and cropping methods if they are developed by "outsiders."

In 1995, Flowers and Yeo wrote: "although salinity might be of profound local importance, it has not yet had sufficient impact on regional agricultural production to warrant the effort necessary to produce new salt-tolerant cultivars." This is a very telling statement in that "regional agricultural production" largely refers to "regions" in the most developed countries, and the "effort" that has not been expended is effort by large agro-businesses. Without their involvement, what can we expect for dry, saline countries in our lifetimes and those of our children? The rich, now able to buy food without limit, are at peril because of their inability to produce locally. In an era of increasing CO_2, increasing temperatures, more frequent droughts, and population growth that will put ever-increasing pressure on water and land resources, a prosperous future is far from certain. For the poor, and particularly (in this volume) in those countries stretching from Bangladesh across the Arabian Peninsula and North Africa to Morocco, the situation is already dire. It does not seem likely to get better, and there is a very real possibility that they will have to go it alone.

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