Introduction

Food insecurity and malnutrition are rampant in developing nations, predominantly in sub-Saharan Africa and South Asia. Approximately 98% of the world’s population with malnutrition is found in sub-Saharan Africa and South Asia (Berman et al. 2013). The use of biotechnology can be an effective way to decrease food insecurity in developing countries (Farre et al. 2011), and also provides micronutrients for human health (Beyer 2010).

Approximately 6.3 million children younger than the age of five lost their lives in 2013 (Liu et al. 2012). Fortunately, this is down from almost 9 million deaths in 2008 (Black et al. 2010). The most devastated areas are in sub-Saharan Africa and South Asia, where four out of every five deaths of children occur. However, there is hope as more than half of these children die from preventable or treatable diseases.

Of the 6.3 million deaths in 2013, 51.8% were caused by infectious diseases (Liu et al. 2012). Diarrhoea is considered to be one of the primary infectious diseases leading to childhood morbidity and mortality. Approximately 2.5 billion cases of diarrhoea are reported each year (UNICEF & WHO 2009) and diarrhoea is estimated to kill at least 800,000 young children worldwide annually (Kotloff et al. 2013; Patel et al. 2011). Table 1 (over page) shows the burden associated with diarrhoea for World Health Organization (WHO) regions. As shown, more than 80% of the deaths due to diarrhoea in WHO regions occurred in Africa and South-East Asia. Thus, there are opportunities to make substantial difference in these developing areas.

While diarrhoea is a primary infectious disease causing death for children under the age of five, second only to pneumonia, malnutrition is the underlying cause of more than 50% of deaths (Chen 2012). Vitamin A deficiency is prevalent in developing areas and has significant consequences (Luo et al. 2010; WHO 2009; Sherwin et al. 2012). The consequences of vitamin A deficiency includes anaemia, immune dysfunction and increased vulnerability to respiratory infections, poor growth, mortality, visual problems, diarrhoea and measles (Jr and Darnton-Hill 2008; Tang et al. 2009; Farham 2011).

Malnutrition is the most common cause of death for young children and pregnant women in developing countries. Regions like sub-Saharan Africa and South Asia contain 98% of the world’s malnourished population. About 67% and 63% of the total population in South Asia and sub-Saharan Africa, respectively, reside in rural areas where agriculture is their main source of food and income. Adoption of biotechnology such as genetically engineered crops and transgenic livestock provides an alternative solution against malnutrition in these regions since most consumers are also producers of agricultural products. However, the potential positive impacts of biotechnology can be limited by public acceptance. Education coupled with a more relaxed regulation, in both developing areas and by trade partners, will help these technologies reach full potential.
Table 2 shows the prevalence of vitamin A deficiency in WHO regions. The WHO (2009) estimated that approximately 33% of the world’s preschool age children are vitamin A deficient. The situation is worse in Africa and South-East Asia where 44–50% of preschool children are vitamin A deficient. Additionally, the incidence of night blindness in pregnant women, a consequence of vitamin A deficiency, is also higher in African and Asian regions than the rest of the world (WHO 2009; Imdad et al. 2010).

In 2000, the Millennium Declaration established targets for reducing disease and child mortality. The efforts to reduce the child mortality rate has had some success as the number of deaths for children under the age of five years has declined by 49% between 1990 and 2013 (WHO 2015), and there has been a 4% global annual decrease in diarrhoea mortality (Kotloff et al. 2013). However, further steps are needed in order to further reduce vitamin A deficiency and diarrheal diseases in Africa and Asia. Vitamin A deficiency can be reduced by consuming a diverse diet, fortification of staple foods, and high-potency supplements. Diarrhoea can exacerbate vitamin A deficiency due to dehydration. Thus, it is important to promote hydration therapy and breastfeeding to minimise the effects of diarrhoea.

Fortification of staple foods and high-potency supplements are being adopted in many developing areas to reduce vitamin A deficiency. Unfortunately, these interventions have not eradicated vitamin A deficiency and both interventions have limitations. Industrial fortification does not effectively reach poor people in rural areas, while supplements are costly and likely not sustainable; Edejer et al. (2005) estimate that vitamin A supplementation costs $10.84 per child per year, implying a cost of at least $2.8 billion per year to alleviate vitamin A deficiency through supplementation (Jones & De Brauw 2015).

### Table 1: Burden of diarrhoea by WHO regions in 2010.

<table>
<thead>
<tr>
<th>WHO Regions</th>
<th>Population (0–4 years)</th>
<th>Incidence (%)</th>
<th>Total deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>133,340,762</td>
<td>3.3</td>
<td>353,300</td>
</tr>
<tr>
<td>South-East Asia</td>
<td>179,956,087</td>
<td>2.4</td>
<td>277,700</td>
</tr>
<tr>
<td>America</td>
<td>76,995,700</td>
<td>3.2</td>
<td>11,000</td>
</tr>
<tr>
<td>Eastern Mediterranean</td>
<td>72,151,965</td>
<td>2.9</td>
<td>96,600</td>
</tr>
<tr>
<td>Western Pacific</td>
<td>116,411,580</td>
<td>2.2</td>
<td>16,900</td>
</tr>
<tr>
<td>Europe</td>
<td>54,605,243</td>
<td>2.8</td>
<td>6,300</td>
</tr>
<tr>
<td>Global</td>
<td>633,461,337</td>
<td>2.7</td>
<td>761,800</td>
</tr>
</tbody>
</table>

**Source:** Walker et al. (2013).

### Table 2: Burden of vitamin A deficiency by WHO regions from 1995–2005.

<table>
<thead>
<tr>
<th>WHO Regions</th>
<th>Preschool age children</th>
<th>Pregnant women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prevalence (%)</td>
<td># of people affected (millions)</td>
</tr>
<tr>
<td>Africa</td>
<td>44.4</td>
<td>56.4</td>
</tr>
<tr>
<td>South-East Asia</td>
<td>49.9</td>
<td>91.5</td>
</tr>
<tr>
<td>America</td>
<td>15.6</td>
<td>8.68</td>
</tr>
<tr>
<td>Eastern Mediterranean</td>
<td>20.4</td>
<td>13.2</td>
</tr>
<tr>
<td>Western Pacific</td>
<td>12.9</td>
<td>14.3</td>
</tr>
<tr>
<td>Europe</td>
<td>19.7</td>
<td>5.81</td>
</tr>
<tr>
<td>Global</td>
<td>33.3</td>
<td>189.89</td>
</tr>
</tbody>
</table>

**Source:** WHO (2009).
Practically all current applications of biotechnology on the market were developed to assist commercial farmers. However, an increasing number of biotechnology applications are being developed for the direct benefit of consumers, including commodity producers in developing countries who are net consumers of agricultural products. Some applications have been developed to minimise the effects of malnutrition and disease in developing areas. Improved nutrition profiles of staple foods is an example of consumer based benefits possible from biotechnology innovation in agriculture. Currently, there are biotechnological solutions developed with hopes to reduce the number of deaths associated with vitamin A deficiency and diarrhoea that have yet to reach the market.

**Biotechnology Solutions**

Adoption of genetically engineered (GE) crops in developing countries has resulted in higher yields, increased farm income, and health benefits (James 2010; Adenle 2011). In addition to decreasing food insecurity, poor farmers in South Africa, Burkina Faso, and Egypt have benefited from increased farm income from GE crops. Economically, South Africa gained a total of US$809 million between 1998 and 2010, and US$133 million in 2010 alone due to GE crops (James 2010). Likewise, expansion of GE cotton production in Burkina Faso has resulted in an annually economic gain of more than US$100 million due to 30% increase in yield in 2010 (Adenle 2011). Biotechnology has the power to limit damage from pests and insects. GE crops can reduce by up to 50% the volume of insecticides that is applied on farms (Adenle 2011). Due to the benefits of GE crops, there has been an annual double digit adoption growth rate of GE technology by farmers in both developed and developing countries since 1996 (James 2010). However, the ability of biotechnology to decrease food insecurity and malnutrition is dependent on acceptance by governments and consumers in developing nations.

While industrial fortification may not be viable in rural areas, biofortification may be a feasible option. Vitamin A biofortified seeds for maize and planting material for cassava and sweet potato have been developed through conventional breeding practices and the sweet potato varieties have the ability to significantly reduce the burden of vitamin A deficiency (Meenakshi et al. 2010). Additionally, unlike industrially fortified rice, golden rice has the potential to sustainably reach the poor population in urban and rural areas (Albabili & Beyer 2005; Dawe & Unnevehr 2008; Tang et al. 2009). Golden rice is a genetically engineered variety of rice which contains up to approximately 30 micrograms of beta-carotene per gram of dry rice that can be converted to vitamin A (Dawe et al. 2002; Albabili & Beyer 2005; Tang et al. 2009, 2012). The added beta-carotene causes the rice grain to have a yellow colour when milled, hence the name golden rice (Schaub 2005; Albabili & Beyer 2005).

In areas where vitamin A deficiency is rampant, like South-East Asia, consumption of golden rice could have great impact (Dawe & Unnevehr 2008). Tang et al. (2012) found that consuming 50 grams of dry golden rice can provide approximately 60% of the vitamin A intake for a seven year old child. To put that amount of rice in perspective, the per capita calorie intake of rice is 1245 Kcal/day in South-East Asia and 234 Kcal/day in Africa (IRRI 2015). There is approximately 4 Kcal in a gram of dry rice, thus, the average person in South-East Asia and Africa is consuming more than 50 grams of dry rice per day.

The Artemis line of transgenic goats was established in 1999 to produce milk containing human lysozyme (for more details read Maga et al. 2003). The goal of this application of biotechnology is to provide agriculturally relevant animals to developing areas that include targeted novel traits to minimise the growth of pathogens within the gut and subsequent diarrhoeal diseases. Goats were chosen over cows because of a shorter generation interval and the ability to thrive in adverse conditions common in developing areas.

Lysozyme is an enzyme and an important antimicrobial factor that can directly attack a variety of bacteria and thus control their growth, and modulate the gastrointestinal bacterial composition. High quantities of lysozyme are
found in human breast milk, and the incidence, prevalence, and duration of diarrhoea episodes have been found to be lower for breastfed infants (López-Alarcón, Villalpando & Fajardo 1997). Unfortunately, there is little lysozyme in the milk of ruminants like cows and goats.

Lysozyme concentration in transgenic goat milk is 68% of that found in human milk (Maga et al. 2006). A recent study by Cooper et al. (2013) used two groups of pigs, a treatment group and a control group, to determine the effectiveness of transgenic goat milk containing lysozyme compared to non-transgenic goat milk. The study concluded that transgenic goat milk was an effective treatment for diarrhoea caused by enterotoxigenic E. coli, a common cause for bacterial diarrhoea. Pigs consuming transgenic goat milk had significantly increased recovery time from clinical signs of infection, improved faecal consistency, and activity levels compared to pigs that consumed non-transgenic goat milk.

Acceptance of Biotechnology in Developed Areas

Adoption of herbicide-tolerant and insect-resistant crops by growers has been widespread in the United States (US). In 2014, 93% of corn planted, 96% of cotton planted, and 94% of soybeans planted in the US were genetically engineered (GE) varieties (USDA 2014). Despite the widespread adoption by growers, consumer perceptions about GE food has not been as positive. In fact, less than 40% of US consumers believe GE food is safe to eat (McFadden & Lusk 2015; Pew Research Center 2015).

While the majority of US consumers do not believe GE food is safe to eat, 88% of scientists connected to the American Association for the Advancement of Science (AAAS) believe it is safe to eat GE foods. Thus, there is a large gap in opinions between the public and scientists. It appears that better science communication about GE foods is necessary. However, it is not obvious that scientific communication alone will be fruitful.

Figure 1, borrowed from McFadden and Lusk (2015), shows the effect of scientific information on beliefs about the safety of GE foods. Each line represents a belief category prior to receiving scientific information. Believers were people who thought GE foods were safe to eat, deniers were people who thought GE foods were unsafe, and neutrals were people who were unsure about the safety. The horizontal axis in Figure 1 measures how people assimilated scientific information. The conservative group were people whose beliefs were unchanged after receiving scientific information, convergent were people whose beliefs converged to scientific information and now believe that GE foods are safer to eat, and divergent were people whose beliefs diverged from scientific information and now believe that GE foods are less safe to eat. Interestingly, people in the denier category were more likely to diverge from information rather than converge, although the difference was not significant.

However, public acceptance may be more favourable for some applications, and indeed previous research has indicated that consumers in developed countries do not view all applications of biotechnology uniformly (eg He & Bernard 2011; Lusk et al. 2004; Gaskell, Allum & Stares 2003; Hossain et al. 2003). Moreover, a recent study determined that public acceptance of bioengineered food increases when the technology brings tangible benefits to consumers compared to benefits for growers (Lusk, McFadden & Rickard 2015). Figure 2 shows the relative desirability ratings for various biotechnology applications to food. Consumers in the US are concerned about where food is produced, the price of food, and the nutritional value of food. Insect-resistant crops are beneficial to growers as they decrease input costs and boost yields, but consumers also see the reduction in pesticide residues as a direct benefit. Interestingly, consumers desire herbicide-tolerant biotechnology the least, which is the application currently most used.

Acceptance of Biotechnology in Developing Areas

While it is known that consumers in developing countries are generally concerned about GE foods, it is not known from where the concern originates. Furthermore, it is likely that the concern about
**Figure 1:** Assimilation of scientific information about GE foods by proportion of prior beliefs.  

**Figure 2:** Relative desirability ratings for motivations to adopt food and agricultural biotechnologies.  
GE foods have various origins for individual consumers.

Understanding concerns about biotechnology in developing areas is even more convoluted. Attitudes towards biotechnology differ across developing countries. It is difficult to understand concerns in developing areas because many people lack awareness, education, and knowledge on biotechnology applications (Adenle 2011). In addition, limited studies have been conducted to assess awareness and attitudes of African consumers and stakeholders towards GE food (Kimenju et al. 2013). Recent surveys found that 75%, 19%, and 5% of consumers in Ghana, Tanzania, and Bangladesh, respectively, had knowledge about GE rice prior to the survey (Mwaijande et al. 2014; Durand-Morat et al. 2015). Consumers in Ghana were relatively more informed, and more prior knowledge was associated with lower willingness to accept GE rice (Mwaijande et al. 2014). Thus, consumers who were knowledgeable about GE rice did not have favourable beliefs. Furthermore, similar to developing areas, information had little effect on willingness to accept GE rice.

An aspect of the developing countries context that differs from that of wealthier countries is that many potential consumers of GE products are also agricultural producers. In South Asia and sub-Saharan Africa, for example, 67% and 63% of the total population can be found in rural areas where the dominant economic activity is agriculture.\(^1\) This shapes the situation with respect to biotechnology in two ways. Firstly, poverty and malnutrition are disproportionately present in rural areas of developing countries (FAO 2012); to the extent that biotechnology can positively impact nutrition and agricultural output, it would seem that the potential gains from biotechnology are particularly large in rural areas of developing countries. Secondly, the interlinkage of production and consumption within agricultural households in developing countries means that the benefits of biotechnology will only be realised if both consumer awareness and the factors that affect technology adoption on the part of producers are addressed.

On the producer side, farmers in poor countries typically operate in an environment characterised by weak institutions and poorly functioning markets. For example, agricultural producers cannot or will not in general make use of financial instruments like insurance or formal savings accounts that might allow them to maintain a steady level of consumption in the face of income shocks. Farmers may have uncertain property rights, which will weaken incentives to invest in new technologies because of uncertainty over the ability to capture the benefits in the future. The market for knowledge transfer (eg agricultural extension) can fail due to the high costs associated with serving small, remotely located producers. These are but a few of many constraints on decision-making that can make agricultural producers in developing countries more hesitant to adopt new technologies than their counterparts in the developed world.\(^2\) In addition, for agricultural households that are net producers with respect to food production, new crops will only be adopted by producers if they find them agreeable as consumers.

At the micro level, successful policy interventions designed to promote the adoption of biotechnology must therefore simultaneously address market and institutional failures as well as consumer preferences. One example of a program taking this approach is HarvestPlus, an initiative seeking to improve nutrition in developing countries through the introduction of biofortified crops. The HarvestPlus program addresses failures in the market for knowledge by training farmers to produce bio-fortified crops, addresses input market failures by distributing planting material, and targets consumer preferences by training household members (almost exclusively women) to incorporate biofortified crops into their diet. In a recent study of the impact of the introduction of biofortified orange-flesh sweet potato (OSP) in Mozambique, Jones and De Brauw (2015) estimate that access to OSP vines as well as training on production and consumption of OSP caused a 11.4 % reduction in the prevalence of diarrhoea among children under five years of age, and a reduction of 18.9 % among children under three years of age.

\(^1\) See http://data.worldbank.org/topic/agriculture-and-rural-development

\(^2\) See Jack (2011) for a survey of the evidence on how constraints can affect technology adoption by farmers in poor countries.
Biotechnology also has the potential to affect commercial agricultural production in developing countries. However, the potential positive impacts of biotechnology can be limited by the unwillingness of trading partners to accept GE crops. For example, due to political relationships, many African countries are bound by a European regulatory framework that is hostile to GE crops (Kimenju et al. 2013; Adenle 2011). Although not explicitly related to biotechnology, an anecdotal example of the unfortunate consequences of the interconnectedness of African agriculture and the European regulatory framework is found in a paper by Ashraf, Giné and Karlan (2009). The authors of the study measure the impact of an agricultural development program called ‘DrumNet’ offering credit, agricultural extension, and marketing services to Kenyan horticultural producers in order to promote export to Europe. The authors estimate that the program increased income by 39% for producers with no prior experience in export markets. Unfortunately, the program collapsed a year later when participants could not meet new requirements for certification needed to export to Europe; the authors estimate that the cost of compliance with certification requirements were equal to twice annual net gain from program participation. These high participation costs are likely too much to bear for producers in poor countries, where access to finance is low. The story of DrumNet is a cautionary one for agricultural producers seeking to benefit from biotechnology, as the benefits of adoption must be weighed against the potential cost of exclusion from some markets.

Applications of biotechnology and biofortification have the potential to go beyond what supplementation and industrial fortification can provide by further reducing malnutrition. Reductions in malnutrition will result in improved household food security and household welfare. These methods, however, should not be viewed as the only methods to decrease malnutrition, but rather complements to industrial food fortification and supplementation programs.

Nevertheless, the potential of biotechnology and biofortification may be limited by public acceptance. There is a need for better education for producers and consumers in developing areas to inform the public both to the source of malnutrition and how it can be minimised. Education coupled with a more relaxed regulation, in both developing areas and by trade partners, will help these technologies reach full potential.

## Conclusion

Agriculture is an important sector in developing areas, particularly in sub-Saharan Africa and South Asia. A large proportion of the population is found in rural areas and the labour force is mainly committed to agriculture. The amount and type of food available often does not contain the needed micronutrients. Treatable or preventable diseases, such as diarrhoea and vitamin A deficiency, are the leading cause of death for children and pregnant women in developing areas. Supplementation and food fortification programs may be less likely to reach rural areas and are expensive.

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## References


Lusk, JL, House, LO, Valli, C, Jaeger, SR, Moore, M, Morrow, JL & Traill, WB (2004), Effect of information about benefits of biotechnology on consumer acceptance of genetically modified...


About the Authors

Emmanuel S Domonko is a Graduate Student on an iAGRI Fellowship in the Department of Food and Resource Economics at the University of Florida. He received his Master of Business Administration in Agribusiness and Bachelor of Science in Agricultural Economics and Agribusiness from the Sokoine University of Agriculture-Tanzania. His current research thesis focus on consumer preference and willingness to pay for rice attributes in Tanzania.

Brandon R McFadden is Assistant Professor of Food and Resource Economics at the University of Florida. He received his PhD in Agricultural Economics with a minor in Statistics from Oklahoma State University and a Master of Science in Agricultural Economics from the University of Arkansas. His current research interests focus on understanding consumer attitudes towards contemporary agricultural production and the effects of information on attitudes.

Conner Mullally is Assistant Professor of Food and Resource Economics at the University of Florida. He received his PhD in Agricultural and Resource Economics from the University of California, Davis. His research interests include impact evaluation in developing countries with a focus on agricultural extension and technology adoption.