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Biofortification of Foods

Breeding crops to enhance their nutritional composition, known as biofortification, is one potential strategy for addressing certain forms of undernutrition. This approach may be useful where there is a dependence on calorie-rich but nutrient-poor staple foods. This briefing describes developments in biofortification, examines its potential impact, and the implications for policy makers in the UK and abroad.

Overview

- Undernutrition is a significant global health burden.
- Biofortification uses selective breeding and/or genetic modification to increase the nutritional value of staple crops.
- Biofortified crop varieties may help to alleviate certain forms of undernutrition.
- However, biofortification is not the sole solution as it does not address the underlying social, economic and political causes of undernutrition.
- Engagement with local communities is crucial for the acceptance of biofortified crops.
- The risks and potential benefits of a genetic modification approach are disputed.

Background

Good nutrition is essential for health, survival and reproduction. Consequently, nutrition is fundamental to achieving the Millennium Development Goals for hunger, education, gender inequality and child/maternal health.[1] The United Nations' (UN) Food and Agriculture Organisation (FAO) estimates that 925 million people worldwide are undernourished.[2] In developing countries, one in four children under the age of five is underweight and malnutrition is directly responsible for 3.5- 5.5 million deaths in this age group.[3] Although overnutrition and obesity also contribute significantly to the global burden of malnutrition, this POSTnote focuses on undernutrition as this is the area in which biofortification is most likely to have an impact.

Causes of Undernutrition

Undernutrition is a common form of malnutrition caused by an inadequate diet, or diseases leading to an excessive loss of nutrients or an inability to absorb nutrients (Box 1). There are many complex underlying causes of undernutrition. They include the lack of access, both physical and economic, to an adequate diet, often compounded by an associated higher burden of disease and a lower ability to cope with disease. The long-term causes include poverty, government instability, lack of employment, lack of access to education and health services, and lack of national food security (the physical and economic availability of food; see also Food Security in the Developing World, POSTnote 274). Undernutrition and other forms of malnutrition often co-exist.

Box 1. Undernutrition and its Various Forms[4]

Undernutrition
Inadequate diet, inability to absorb nutrients or excessive loss of nutrients leading to wasting (thinness), stunting (shortness), and susceptibility to disease. Chronic undernutrition is associated with food insecurity and is prevalent in the developing world. Acute malnutrition can be highly prevalent in emergency settings.

Micronutrient Malnutrition
A deficiency in one or more vitamins and/or minerals. These are required in the diet in small amounts but deficiencies can result in serious health consequences. Deficiencies are common in both the developed and the developing world but at varying degrees and due to deficiencies in a range of different micronutrients.

Protein-energy Malnutrition (PEM)
Malnutrition caused by an inadequate dietary intake of protein leading to stunting, wasting and kwashiorkor (a childhood condition in which lack of dietary protein is a significant factor). An estimated 1 in 4 children worldwide suffers from PEM, particularly in Asia and Africa.

Short-term consequences of undernutrition are increased susceptibility to disease and death. Long-term consequences include cognitive impairment, reduced life-time productivity and increased risk of chronic disease.

Ways of Tackling Undernutrition
In addition to providing food aid in emergency settings, the main ways of tackling undernutrition are shown below.

Short-term Measures
- Ready-to-use foods – energy and nutrient-rich foods, not requiring any form of preparation, used to treat severe malnutrition (e.g. peanut-based "Plumpy'nut®").
- Pharmaceutical supplementation – the administering of supplements to treat micronutrient deficiency.

Medium to Long-term Measures
- Food fortification – the addition of nutritional value, such as minerals and vitamins, during food processing.
- Biofortification – breeding for increased nutritional value.
- Dietary diversification – production, promotion and consumption of locally-available and affordable foods

Short term measures are effective and relatively quick to implement but they rely on effective infrastructure for delivery and recurring costs can be high. Medium to long-term measures take longer to implement and require initial investment but have the potential to be more enduring. While a diverse diet is widely regarded to be the preferred approach to a balance diet, biofortification has the potential to be a cost effective measure for controlling undernutrition in areas where diversity is unavailable or unaffordable.[5]

Biofortification of Food Crops
Biofortified crop varieties are developed by plant breeding using selective breeding and/or genetic modification.

Selective Breeding
These programmes search for variation in the characteristic of interest, for example higher iron content, within existing varieties of the crop. This characteristic is then bred into cultivated varieties by crossing (deliberately inter-breeding) and selecting those individual plants with the desired characteristics. In selective breeding, scientists use:
- seed banks - collections of seeds usually collected in the past, which may have greater genetic variation than current varieties;
- mutagenesis - a chemical or physical induction of genetic mutations used to generate new variation;
- wide crosses – inter-breeding between a cultivated species and another, normally closely-related, species.

Genetic Modification
Genetic modification (GM) technology is used to transfer a single gene or several genes, from any species into another. Researchers can control both when (at what point in development) and where a gene is switched on (expressed) in the plant to alter desired characteristics of a crop (see also GM Insects, POSTnote 360).

Targets in Biofortification
Plants provide the bulk of human dietary calories and contain many essential nutrients. This provides a large number of potential targets for improving nutritional value.

Micronutrients
Micronutrient biofortification is the most active area of research as a means of alleviating micronutrient malnutrition, particularly in the developing world (Box 2).

Box 2. Micronutrient Malnutrition
- **Iron** deficiency is a significant cause of anaemia and is a global public health problem, affecting as many as two billion people. It occurs at all stages of life, but is most prevalent in pregnant women and young children.
- **Zinc** is vital for a number of enzymes essential for normal growth and development. Estimates suggest that more than 25% of the world population is at risk from zinc deficiency. Dietary zinc availability varies by geographical region and diet.
- **Vitamin A** deficiency is the leading cause of preventable blindness in children and compromises the immune system leading to increased risk of infection. Between 100 and 140 million children are deficient, leading to an estimated 250,000 to 500,000 becoming blind, half of whom die within a year of becoming blind. Dietary beta-carotene, a natural plant product found in many vegetables, can be converted into vitamin A in the body.

HarvestPlus
HarvestPlus was launched in 2004 with funding from the Bill and Melinda Gates Foundation (Box 3), the UK Department for International Development (DFID) and others. The project is coordinated through the Consultative Group for International Agricultural Research (CGIAR) and involves more than 200 agriculture and nutrition scientists around the world as well as national agriculture research institutes in countries where the varieties will be released.

Box 3. Bill and Melinda Gates Foundation
The Bill and Melinda Gates Foundation, a major charitable donor, launched the Grand Challenges in Global Health programme in 2003. Grand Challenge 9 is to create a full range of nutrients in a single staple crop using all available technologies. In addition to funding HarvestPlus, the foundation has funded biofortification work on cassava (BiocassavaPlus programme), banana (through the National Banana Research Program, Uganda), sorghum (Africa Biofortified Sorghum project) and rice (ProVitaMinRice project).

HarvestPlus is focusing on increasing levels of iron, zinc and beta-carotene in seven staple crops, grown in areas of high subsistence farming, namely sweet potato, bean, pearl millet, cassava, maize, rice and wheat. HarvestPlus sets target levels based on usual portion size, taking into account processing losses, and uses selective breeding, where possible, to achieve these levels. Countries in sub-Saharan Africa and the Indian subcontinent, where micronutrient malnutrition is prevalent, have been identified as targets for biofortified varieties. Orange-fleshed sweet potato varieties, designed to alleviate vitamin A deficiency (Box 4), are already available in two target countries.

Golden Rice Project
Golden Rice is a GM-derived variety of beta-carotene-rich rice. Golden Rice 1 was developed with only moderate amounts of beta-carotene in the grain. More recently Golden Rice 2 was developed containing higher levels and this

variety is being prepared for release, pending regulatory approval (Box 4).

Box 4. Beta-carotene Enrichment

HarvestPlus – Orange-fleshed Sweet Potato

Sweet potato is widely grown in Africa where an estimated one third of the population is vitamin A deficient, although white-fleshed varieties are usually consumed.

- Selective breeding for high beta-carotene, along with other traits such as resistance to local pests, was used to produce locally-adapted, high beta-carotene sweet potato varieties. (The orange colour is a consequence of the enrichment in beta-carotene).
- These biofortified sweet potato varieties were released in 2007 in Uganda and Mozambique.
- In collaboration with local partners, agriculture and nutrition promoters were trained to engage with local groups of farmers and mothers.
- Local traders were involved in the scheme and demand was created using local radio and community drama as part of an 'eat orange' campaign.
- Evaluation of preferences, willingness to pay for plants, product pricing, market chains, consumer sensory perception and effect on vitamin A status in the target communities is on-going.

Golden Rice Project – Golden Rice 2

Rice is important staple food in many parts of Asia where vitamin A deficiency is prevalent.

- Genetic modification of rice, using one gene from maize and one from a bacterium, has been used to produce two new enzymes in the grain of rice causing the grain to accumulate beta-carotene. This results in the yellow colour seen in the picture on page 1.
- The high beta-carotene trait has been bred into four varieties that are commercially grown in Asia.
- Golden Rice has yet to receive regulatory approval but approval is being sought for release in the Philippines in late 2012.

Selenium Biofortification of UK Wheat

Selenium levels in UK soils are generally low so UK-grown wheat is low in selenium. A Department for Environment, Food and Rural Affairs Link-funded project explored selective breeding and timely application of selenium-containing fertiliser to increase selenium levels in wheat. The project found adding small amounts of selenium to fertiliser increases selenium levels in the grain. The addition of selenium to fertilisers, mandatory in Finland since the 1980s, would therefore increase selenium intake in the UK.

Protein

Quality Protein Maize (QPM) was developed at the International Maize and Wheat Improvement Centre using selective breeding. Compared with regular maize, QPM kernels contain the same amount of total protein but greater amounts of two essential amino acids. Amino acids are the building blocks of proteins; essential amino acids are required for normal growth and must be obtained from dietary protein. Several QPM varieties have been released in sub-Saharan Africa, where maize is a staple food, and studies have shown a beneficial impact on growth (height and weight) in children. Adoption remains relatively low (less than 1% of the 90 million hectares of maize grown in Central America, sub-Saharan Africa and Asia is QPM) but uptake is good when substantial promotion is undertaken.

Fatty Acids

Plant oils, such as rapeseed oil, contain long-chain fatty acids that can be converted into two, health-promoting, long-chain poly-unsaturated fatty acids: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) although conversion rates are low. The FAO recommends dietary consumption of EPA and DHA, particularly for pregnant and lactating women, based on good evidence that EPA and DHA improve cardio-vascular health in adults and play an important role in brain and eye development in the foetus.

EPA and DHA can be obtained from oily fish or algal oils. Biotechnology companies are developing oil crops with novel fatty acids. For example, BASF is developing oilseed rape containing high levels of DHA and EPA which it intends to market as multi-purpose cooking oil, for use in the home and in processed foods. Using GM, multiple genes from a variety of fungal, algal and plant sources, have been introduced into oilseed rape to produce oil containing DHA and EPA and other long chain fatty acids. Regulatory approval is being sought for commercialisation in the next 5-10 years.

Other Targets

Other breeding targets include digestion-resistant starches, as a form of dietary fibre, and antioxidants, which may reduce the risk of developing some forms of cancer (see also Diet and Cancer, POSTnote 330).

UK Policy

The international community is committed to the UN Millennium Development Goals (MDGs) of which food security and malnutrition are major components. The government recently reaffirmed its commitment to the MDGs and pledged to increase government spending on international development in line with UN national spending targets for achieving the MDGs.[6] DFID currently provides funding for a number of agricultural development initiatives including core funding to the CGIAR network of agricultural research stations of which £2 million was directed to the HarvestPlus initiative in the financial year 2008-09.

Food security continues to be high on the political agenda. In 2006, DFID and the Biotechnology and Biological Sciences Research Council (BBSRC) launched the Sustainable Agriculture Research for International Development (SARID) programme, worth £6.9 million. This programme aims to "harness the UK's world class bioscience research base to address the challenges of agriculture and food security in developing countries". DFID has recently announced a new research programme aimed at tackling chronic malnutrition, to begin in 2011, worth £6 million over 5 years.[7]

Issues

Biofortification has the potential to be a useful tool in alleviating undernutrition. However, sceptics are cautious, particularly with GM approaches, and cite a need for greater engagement with the farmers and consumers for whom the varieties are intended.

The potential benefits of biofortification include:

- scope – reaching rural communities without access to pharmaceutical supplements or fortified food and improving life-time nutritional status;
- endurability – less susceptible to social and economic changes than short term interventions;
- cost effectiveness – the potential to impact a large number of people at a low cost per person.

The possible limitations include:

- narrow focus – increasing any single micronutrient in the diet is unlikely to address the whole problem;
- allergenicity and toxicity – increasing the amount or incidence of certain plant products in the diet could have a negative impact on some peoples' health;
- 'top-down' approach – a technological solution alone will not address root causes of the problem, such as social inequality, lack of education and poverty;
- lack of capacity – plant breeding is an ongoing exercise requiring continued effort and financial support, at a regional level, with local farmer engagement.

Technical Considerations

Biofortified crop varieties must be shown to have increased nutritional value in the environments in which they will be grown. These varieties must also perform well for yield and pest resistance to meet with farmers' approval. The nutrients in the crop must withstand post-harvest processing such as milling, storage and cooking and must also be bioavailable (in a form that can be absorbed by the body).

Social and Economic Implications

The introduction of new varieties into countries or regions must take into account the possible impacts on local markets. For example, is there effective infrastructure for delivering improved varieties to local farmers? Are these crops already being grown or will they have an impact on local agricultural systems? Biofortified varieties may attract a market price premium that may encourage farmers to adopt the biofortified variety as a marketable commodity. However, they should not price the poor out of the market.

Regulatory Approval

Biofortified varieties are subject to regulatory approval prior to release (Box 5). Selectively bred varieties require relatively little testing prior to release. GM varieties must undergo compositional, allergenicity and toxicity testing, assessment of the molecular characteristics and potential environmental impact of the crop. GM technology has been used to produce disease-resistant, herbivore-resistant and herbicide-resistant crops that are now being grown in 25 countries in both the developed and developing world.[8] No biofortified GM crops have yet been commercialised.

Box 5. Regulatory Assessment

Selective Breeding Programmes

New varieties are approved under the International Convention for the Protection of New Varieties of Plants. New plant varieties must be shown to be new, distinct, uniform and stable before they can be registered on a national recommended seed list. Breeders are entitled to royalties from sales through Plant Breeder Rights granted by national offices.

Genetic Modification

Release of GM crops into the environment, where there is likely to be transboundary movement or trade, is regulated by the widely-ratified Cartagena Protocol on Biosafety. This protocol assumes that individual countries having their own biosafety frameworks. In the EU, release and commercialisation is regulated by the European Food Safety Authority under Directive 2001/18/EC (see GM Crops in the UK, POSTnote 211).

Biosafety Capacity Building

Developing national biosafety frameworks in developing countries is an area of active capacity building. The largest initiative is the UN Environment Programme's Global Environment Facility. As of July 2009, 111 countries (38 in Africa) have completed draft biosafety frameworks but as many as 100 nations have none.[9]

Public Acceptance of Products

Public acceptance is critical for biofortification to succeed. If flavour or texture is altered consumers must be willing eat the altered variety. If flavour or texture is not altered consumers must be able to identify the product. Early indications are that the selectively bred orange-fleshed sweet potato has good consumer acceptance in Uganda and Mozambique. Whether consumers will accept GM varieties such as Golden Rice is unclear; some NGOs continue to oppose GM products and consumers may regard selectively bred varieties as more acceptable.

Effectiveness of Biofortification

Biofortification is a relatively new technology and its effectiveness is not known. Both the efficacy (biological impact under controlled conditions) and effectiveness (biological impact in real life) need to be evaluated. The latter is influenced by consumer acceptance and also by diet. For example, phenolic compounds in teas are known to inhibit the uptake of iron in the gut. Trials testing effectiveness are difficult to design, costly and time-consuming to undertake.

Endnotes

1 http://www.un.org/millenniumgoals/
2 FAO, *The State of Food Insecurity in the World,* 2010 (2010)
3 USAID, *Global Food Insecurity and Price Increase Update #3*, (2008)
4 WHO, *Turning the Tide on Malnutrition*, (2006)
5 The Royal Society, *Reaping the Benefits*, (2009)
6 Deputy Prime Minister, speech at UN MDG Summit, New York, Sept. 22nd 2010
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8 EC/JRC, *The Global Pipeline of GM Crops*, Stein and Rodriguez-Cerezo (2009)
9 UNU-IAS, *Internationally Funded Training in Biotechnology and Biosafety: Is it Bridging the Divide?*, Johnston, Monagle, Green and Mackenzie (2008)

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