Strategien zur Behebung von Mikronährstoffdefiziten:

Wie gut sind neue Ansätze der Pflanzenzüchtung im Vergleich und was sind die Hürden für eine erfolgreiche Umsetzung?

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Dezember 2009

Gutachten für das
Büro für Technikfolgen-
Abschätzung,
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TA-Projekt »Welchen Beitrag kann die Forschung zur Lösung des Welternährungsproblems leisten?«

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Hinweis: Das Gutachten ist eine Materialie neben weiteren Studien und Materialien im Rahmen des TA-Projektes "Welchen Beitrag kann die Forschung zur Lösung des Welternährungsproblems leisten?" im Auftrag des Deutschen Bundestages.

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Zusammenfassung

Weltweit leidet eine Milliarde Menschen an Hunger und mehrere Milliarden Menschen leiden an "verdecktem" Hunger, d.h. an einem Mangel lebenswichtiger Vitamine und Mineralstoffe. Dieser Mangel ist weniger augenscheinlich als direkter Hunger, doch stellen Vitamin- und Mineralstoffdefizite nach Unterernährung weltweit das größte Gesundheitsrisiko dar, vor allem in den Entwicklungsländern. Die mit den Defiziten dieser Mikronährstoffe einhergehenden Krankheitsfolgen führen sowohl zu menschlichem Leiden bei den Betroffenen wie auch zu erheblichen gesamtwirtschaftlichen Wohlfahrtsverlusten. Mikronährstoffmangel stellt daher eine weitere Dimension des komplexen Welternährungsproblems dar.

Da sich das Ideal einer ausreichenden und ausgewogenen Ernährung aller Voraussicht nach kurz- und mittelfristig kaum erreichen lässt, gibt es verschiedene Ansätze, um Mikronährstoffmangel vorzubeugen oder zu lindern. Während die bisherigen Maßnahmen – wie die Verteilung pharmazeutischer Ergänzungspräparate, die industrielle Anreicherung von Lebensmitteln oder Ernährungsaufklärung mit dem Ziel einer Verhaltensänderung – alle ihre Stärken haben, so stoßen sie bei der Umsetzung auch auf praktische und finanzielle Probleme, die ihren Wirkungskreis einschränken. Vor diesem Hintergrund wird seit wenigen Jahren ein neuer Ansatz, die "biologische Anreicherung", entwickelt. Unter biologischer Anreicherung werden im Allgemeinen alle landwirtschaftlichen Maßnahmen verstanden, die dazu dienen, die Bioverfügbarkeit oder Nährstoffdichte in Nutzpflanzen zu erhöhen, um Mangelernährung vorzubeugen. Im Einzelnen wird darunter vor allem die entsprechende Züchtung der Pflanzen verstanden, wobei biologische Anreicherung aber auch durch den Einsatz von Düngemitteln erreicht werden kann.

Die biologische Anreicherung ergänzt die bisherigen Maßnahmen hinsichtlich der anvisierten Zielgruppen und des Zeithorizonts, d.h., durch biologische Anreicherung können insbesondere auch ländliche Arme erreicht werden und im Gegensatz zu kurzfristiger pharmazeutischer Ergänzung und industrieller Anreicherung, stellen biologisch angereicherte Pflanzen (BAP) eine mittelfristige Maßnahme dar. Darüber hinaus versprechen biologisch angereicherte Grundnahrungspflanzen sehr kostengünstig zu sein, d.h., Investitionen in biologische Anreicherung können ggf. eine effiziente Verwendung knapper Geldmittel darstellen. Diese zu erwartende Wirtschaftlichkeit der BAP wurde anhand einer Reihe von Vorabstudien untermauert, die insbesondere das tatsächliche Konsumverhalten der Zielgruppen berücksichtigten und auf konservative Annahmen hinsichtlich des Nährstoffgehalts und der Verbreitung der BAP bauten. Denn alle BAP (bis auf eine Ausnahme) befinden sich noch in der Entwicklungsphase und das Ausmaß ihrer Wirksamkeit muss genauer erforscht bzw. ggf. weiter erhöht werden. Außerdem gilt es, noch bestehende Hindernisse für eine erfolgreiche Einführung der BAP aus dem Weg zu räumen. Eine besondere Herausforderung stellen dabei diejenigen BAP dar, die (aus Sachzwängen heraus) mit Hilfe der Gentechnik gezüchtet werden; hier ist auch von politischer Seite aus eine rationale und faktenbasierte Auseinandersetzung mit den tatsächlichen Potenzialen neuer Agrartechnologien nötig, um der Landwirtschaft auch ganz allgemein zu ermöglichen, die anstehenden Herausforderungen zu meistern: Während in der Vergangenheit das Ziel in Ertragssteigerungen bestand, so vervielfältigen sich die Ansprüche an die Landwirtschaft immer mehr, soll sie doch nicht nur bei der Bewältigung des Hungers, sondern z.B. auch bei Klimawandel und Ressourcenknappheit helfen. Ohne zusätzliche finanzielle Unterstützung und ohne Ausschöpfung der wissenschaftlichen Möglichkeiten ist dies kaum möglich.

Aufbauend auf eine umfassende Literaturübersicht und die Auswertung einer Expertenbefragung werden in diesem Gutachten diese einzelnen Punkte diskutiert, und es werden die Bereiche in Forschung, Praxis und Politik identifiziert, wo Unterstützung nötig ist. Abschließend werden allgemeine Handlungsempfehlungen abgeleitet.

Inhaltsverzeichnis

Tabellen und Schaubilder

Abkürzungsverzeichnis

CaD - Kalziummangel, bzw. -defizit

CGIAR - Beratungsgruppe für Internationale Agrarforschung (Consultative Group on International Agricultural Research), siehe http://www.cgiar.org/languages/lang-german.html

BAP - biologisch angereicherte Pflanzen

BIP - Bruttoinlandsprodukt

Engl. - auf Englisch

FAO - Welternährungsorganisation (Food and Agriculture Organization), siehe http://www.fao.org/

FeD - Eisenmangel, bzw. -defizit

GV - gentechnisch verändert

ID - Jodmangel, bzw. -defizit

MN - Mikronährstoff

SeD - Seleniummangel, bzw. -defizit

TAB - Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, siehe http://www.tab.fzk.de/

VAD - Vitamin A-Mangel, bzw. -defizit

VMD - Vitamin- und Mineralstoffdefizite

WHO - Weltgesundheitsorganisation (World Health Organization), siehe http://www.euro.who.int/?language=german

ZnD - Zinkmangel, bzw. -defizit

Hintergrund – das Projekt zum Welternährungsproblem

Im Folgenden werden die auf den Webseiten des TAB gegebenen Projekt-Informationen in Auszügen wiedergegeben, um das Gutachten in seinen weiteren Zusammenhang zu stellen.

Thematischer Hintergrund

(http://www.tab.fzk.de/de/gutachter/welternaehrung.htm)

Das vom Ausschuss für Bildung, Forschung und Technikfolgenabschätzung beauftragte Projekt »Welchen Beitrag kann die Forschung zur Lösung des Welternährungsproblems leisten?« umfasst zwei wesentliche Problembereiche: Zum einen das derzeitige Problem der Unterernährung, das weltweit rund eine Milliarde Menschen betrifft und das nach Ansicht des überwiegenden Teils der Experten in erster Linie ein Armuts- und Verteilungsproblem darstellt; zum anderen – in einer auf die nächsten Jahrzehnte gerichteten Perspektive – die Erwartung, dass aktuelle Entwicklungstendenzen sowohl auf der Nachfrageseite (Bevölkerungswachstum, überproportional zunehmender Konsum tierischer Nahrungsmittel) als auch auf der Angebotsseite (Degradierung fruchtbarer Böden durch Erosion, Versalzung usw.; Ernteausfälle infolge des Klimawandels; Nutzungskonkurrenzen) dazu führen können, dass die Ernährung der Weltbevölkerung sich künftig sowohl als Verteilungs- als auch als »Mengenproblem« darstellt.

Vor diesem Hintergrund ist es Ziel des TAB-Projekts zu untersuchen, welche Forschungsansätze besonders große Beiträge zur Lösung der verschiedenen Dimensionen der Welternährungsproblematik zu leisten vermögen. Dabei strebt das Projekt nicht an, eine umfassende Analyse und Darstellung der globalen Unter- und Mangelernährungsproblematik zu leisten. Vielmehr konzentriert es sich auf den Stand von einschlägiger Forschung und Entwicklung sowie zukünftige Forschungsaufgaben, wobei der Schwerpunkt der Untersuchung auf der Forschungslandschaft in Deutschland liegt. Gefragt wird insbesondere, in welchen Bereichen besonderer Forschungsbedarf besteht, wo spezifische Restriktionen zu überwinden und neue Formen der inter- und transdisziplinären Forschung zu entwickeln sind. Die Auswahl der Forschungsfelder richtet sich danach, ob relevante Beiträge zu den zahlreichen, heterogenen Einflussgrößen auf die Welternährungssituation zu erwarten sind; dementsprechend breit ist das Spektrum der Forschungsfelder, die in den Blick genommen werden müssen.

Strategien zur Behebung von Mikronährstoffdefiziten

(http://www.tab.fzk.de/de/gutachter/welternaehrung.htm)

Neben einer kalorischen Unterversorgung sowie quantitativen und qualitativen Defiziten bei Makronährstoffen (Proteine, Fettsäuren) können Defizite bei sogenannten Mikronährstoffen (Vitamine, Mineralstoffe, Spurenelemente) massive gesundheitliche Probleme hervorrufen. Sie sind das Resultat einseitiger Ernährung, die zum Teil durch mangelndes Ernährungswissen (auch in Industrieländern) hervorgerufen werden kann, vor allem aber armutsbedingt auftritt. Besondere öffentliche Aufmerksamkeit sowie eine gezielte Förderung v.a. durch Einrichtungen in den USA erfahren Ansätze der gentechnischen Anreicherung von Grundnahrungsmittelpflanzen (»Biofortifikation«); zum Teil werden auch konventionelle Züchtungsansätze verfolgt. Eine Anreicherung mit Vitaminen und Mineralien kann auch bei der Lebensmittelverarbeitung geschehen, eine auch in Industrieländern häufig vorkommende Maßnahme ist die Supplementierung als Nahrungsergänzungsmittel. Grundsätzlichere bzw. umfassendere Interventionsansätze sind die Schaffung (oder auch Reaktivierung) von Ernährungswissen und -kompetenz, gerade auch unter prekären Lebensbedingungen, z. B. durch eine Gemüseselbstversorgung in Kleinstgärten oder die Nutzung von Wildpflanzen. Das Forschungsfeld umfasst Forschungsansätze, die sich mit der Effektivität und Effizienz der Einzelmaßnahmen und der Angepasstheit und Nachhaltigkeit von Gesamtstrategien befasst.

Hintergrund, zentrale Aspekte des Themas

(http://www.tab.fzk.de/de/gutachter/welternaehrung.htm)

Fehl- und Unterernährung aus Armutsgründen sind ein Problem, das zum großen Teil in Entwicklungs- und Schwellenländern auftritt und einen Kern der im Frühjahr 2008 aufgeflammten Debatte über die Zukunft der weltweiten Landwirtschaft repräsentiert. Das trotz aller Bemühungen der vergangenen Jahrzehnte immer noch vorhandene Welternährungsproblem betrifft weltweit derzeit ca. 1 Milliarde Menschen, entgegen den Hoffnungen früherer Jahre wird angesichts stark schwankender Nahrungsmittelpreise (u.a. aufgrund von Produktionsproblemen als Folge der negativen Auswirkungen des Klimawandels, der wachsenden Nachfrage nach Agrarrohstoffen für die stoffliche und energetische Nutzung sowie einen überproportional steigenden Fleischkonsum bei weiter wachsender Weltbevölkerung) mittlerweile wieder mit steigenden Zahlen betroffener Menschen gerechnet.

Weil die Ursachen so vielfältig sind (von der Welthandelspolitik als Bedingungsfaktor der wirtschaftlichen Entwicklung allgemein sowie der Absatzmärkte für landwirtschaftliche Produkte aus Entwicklungsländern über Fragen der Migration bis zur Wasserverfügbarkeit) und sich gegenseitig beeinflussen, fällt es schwer, all diejenigen Disziplinen der Agrar-, Bio- und Umweltwissenschaften, der Ökonomie, der Sozial- und Politikwissenschaften zu benennen, deren Forschung besondere Beiträge zur Lösung des Welternährungsproblems leisten können. In allen einschlägigen neueren Stellungnahmen und Berichten, u.a. des G8-Gipfels im Juli 2008, des International Assessment of Agricultural Knowledge, Science and Technology (IAASTD), der Weltbank und auch der deutschen Bundesregierung, wird Wissenschaft und Technik – und damit auch einer zukünftigen intensiv(er)en Forschung – eine wichtige Rolle zugesprochen. So fordert der Bericht der Bundesregierung "Globale Ernährungssicherung durch nachhaltige Entwicklung und Agrarwirtschaft" vom Juni 2008 eine Intensivierung der Agarforschung sowohl grundsätzlich als auch spezifisch mit Blick auf das Problem der Nutzungskonkurrenzen beim Ausbau der Bioenergienutzung. Um Ertragssteigerungen erreichen zu können, seien Forschungsanstrengungen entlang der gesamten landwirtschaftlichen Produktionskette inklusive der Zulieferindustrien notwendig.

Ziel und Vorgehensweise

(http://www.tab.fzk.de/de/projekt/skizze/welternaehrung.htm)

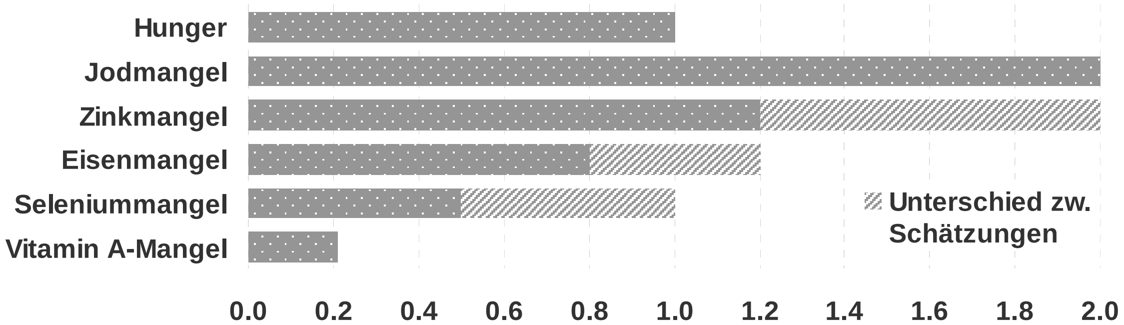
Im Projekt des TAB soll vor allem untersucht werden, von welchen Disziplinen der deutschen Wissenschaft bzw. FuE besonders relevante und weiterführende große Fortschritte und Lösungsbeiträge zu erwarten sind, sodass eine intensivere Unterstützung naheliegt. Gefragt werden soll, wo spezifische Restriktionen zu überwinden und neue Formen der inter- und transdisziplinären Forschung und Wissenschaft zu erkunden und zu entwickeln sind.

1 Einleitung – Welternährungsproblem und Mikronährstoffmangel

Den neuesten Schätzungen der Welternährungsorganisation zufolge leiden derzeit über eine Milliarde Menschen an Hunger, soviel wie seit fast 40 Jahren nicht mehr; anders ausgedrückt ist weltweit jeder sechste Mensch unterernährt (FAO 2009a). Diese Situation ist moralisch nicht vertretbar, sie widerspricht grundsätzlichen Menschenrechten und internationalen Verpflichtungen der Staaten, und sie ist ökonomisch kontraproduktiv. Entsprechend einer Studie der Weltgesundheitsorganisation stellt Untergewicht weltweit überdies das größte Gesundheitsrisiko dar (WHO 2002). Es ist somit unbestreitbar, dass direkter Hunger, d.h. unzureichende Energiezufuhr über die Nahrung, einen dominierenden Bestandteil des Welternährungsproblems darstellt. Nichtsdestotrotz gibt es einen weiteren wichtigen Faktor des Welternährungsproblems: Mikronährstoffmangel.

Mikronährstoffmangel wird auch als "verdeckter" Hunger (Engl. "hidden hunger") bezeichnet, da die Betroffenen es nicht spüren, wenn ihrem Körper Vitamine und Mineralstoffe fehlen (im Gegensatz zum herkömmlichen Hunger, der sich innerhalb kurzer Zeit bemerkbar macht). Überdies treten negative Gesundheitsfolgen von Mikronährstoffmangel zeitversetzt auf und der Zusammenhang zwischen diesen Wirkungen und der eigentlichen Ursache, d.h. der Unterversorgung mit lebenswichtigen Vitaminen und Mineralstoffen, ist oftmals nicht offensichtlich. Gleichwohl können diese Gesundheitsfolgen schwerwiegend sein und direkt sowie indirekt (z.B. über eine Schwächung des Immunsystems) bis hin zu erhöhter Sterblichkeit reichen. Die Zahlen der von Mikronährstoffmangel Betroffenen sind enorm: Weltweit gibt es geschätzte zwei Milliarden Fälle von Zinkmangel (ZnD), bis zu zwei Milliarden Fälle von Jodmangel (ID), ungefähr eine Milliarde Fälle von Eisenmangel (FeD), bis zu einer Milliarde Fälle von Seleniummangel (SeD) sowie Millionen von Fällen von Kalziummangel (CaD), Vitamin A-Mangel (VAD), Vitamin D-Mangel und Folsäuremangel (*Abb. 1*, Borwankar et al. 2007, Allen et al. 2006, Bereket 2003, Ramakrishnan 2002). Werden diese Zahlen addiert so ist leicht ersichtlich, dass es womöglich mehr Fälle von Mikronährstoffmangel als Menschen auf dieser Erde gibt, d.h. viele Mitmenschen leiden an multiplen Vitamin- und Mineralstoffdefiziten (VMD) (Ramakrishnan und Huffman 2008).

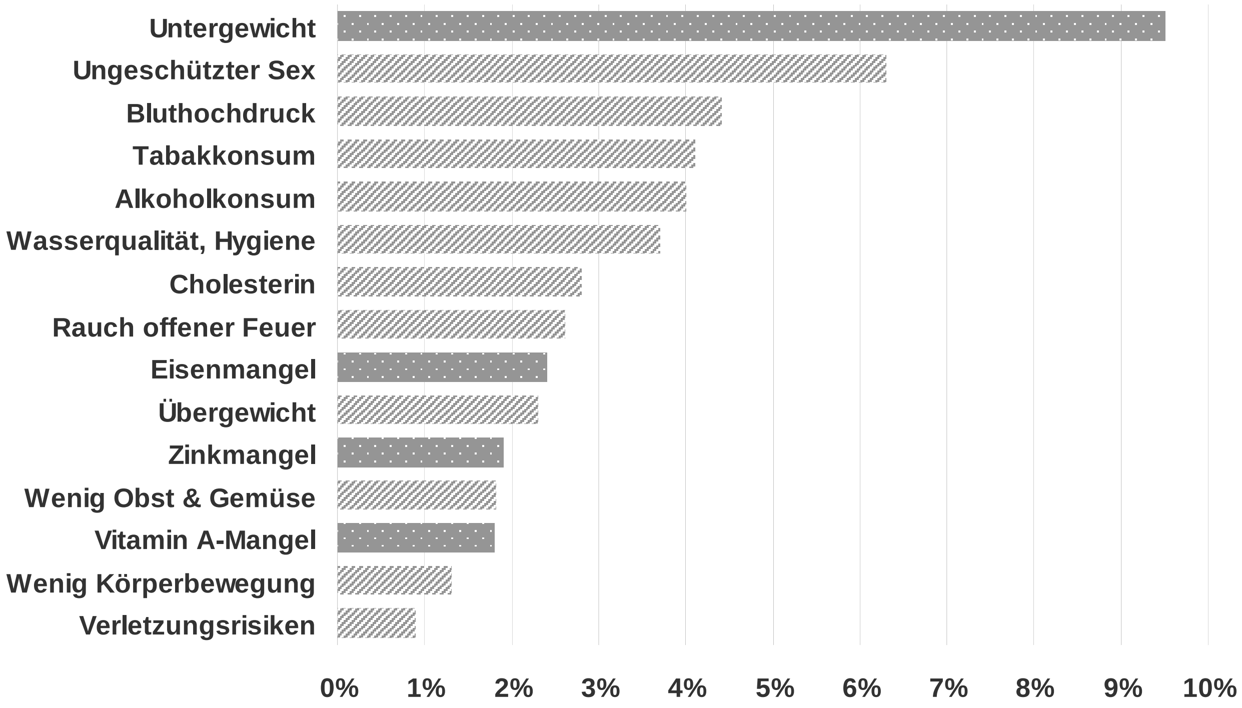
Abb. 1: Anzahl der Fälle der wichtigsten Formen von Mangelernährung (Milliarden)



Quellen: FAO (2009a), de Benoist et al. (2004), WHO (2002), Hotz and Brown (2004), de Benoist et al. (2008), WHO (2009a), Stein et al. (2005), WHO (2009b), Combs (2001).

In der eingangs bereits erwähnten Studie hat die Weltgesundheitsorganisation auch das Gesundheitsrisiko einzelner VMD bewertet. Während Untergewicht als das größte Gesundheitsrisiko weltweit 10 Prozent der globalen Krankheitslast ausmacht, sind auch drei VMD (FeD, ZnD und VAD) unter den 15 größten Gesundheitsrisiken zu finden – zusammen mit ID, der auch von der WHO erfasst wurde, macht Mikronährstoffmangel über sechs Prozent der globalen Krankheitslast aus und rangiert damit auf Platz zwei (*Abb. 2*). Darüber hinaus sind in dieser Liste weitere ernährungs- und konsumbedingte Gesundheitsrisiken zu finden, wie Tabakkonsum, Alkoholkonsum, Cholesterin, Übergewicht, sowie geringer Obst- und Gemüsekonsum. (Teilweise sind dies Gesundheitsrisiken die sich durch einfache Verhaltensänderungen weitestgehend ausschalten ließen, doch selbst in Industrieländern – wo diese Risiken sowie die "Gegenmaßnahmen" bekannt sind – handeln viele Menschen wider besseren Wissens.)

Abb. 2: Die weltweit größten Gesundheitsrisiken (Anteil an der globalen Krankheitslast)



Quelle: WHO (2002).

Neben der Quantifizierung der Krankheitslast von Mikronährstoffmangel wurden in der Vergangenheit in verschiedenen Studien auch die wirtschaftlichen Auswirkungen von Mikronährstoffmangel geschätzt. So fand die Weltbank, dass Eisen-, Jod- und Vitamin A-Mangel das Bruttoinlandsprodukt (BIP) in Entwicklungsländern um bis zu fünf Prozent verringert (World Bank 1994); Horton und Ross (2003) fanden für eine Auswahl von Entwicklungsländern, dass deren Bruttoinlandsprodukt ohne Eisenmangel um bis zu vier Prozent größer sein könnte; und eine gemeinsamen Studie von UNICEF und der Micronutrient Initiative (MI/UNICEF 2004) kam zu dem Ergebnis, dass Eisen-, Jod-, Folsäure- und Vitamin A-Mangel in einigen Entwicklungsländern bis zu zwei Prozentpunkten des Bruttoinlandsprodukts kosten. In einer Studie zu VMD in Indien berechneten wir selbst, dass die von Eisen-, Zink- und Vitamin A-Mangel verursachten Kosten bis zu 2,5 Prozent des indischen Bruttoinlandsprodukts entsprechen (Stein und Qaim 2007). Und in einer historischen Analyse des Wirtschaftswachstums in Großbritannien fand der Nobelpreisträger Robert Fogel (2004), dass bessere Ernährung – inklusive einer verbesserten Versorgung mit Vitaminen und Mineralstoffen – 30 Prozent zum Wachstum des britischen Pro-Kopf-Einkommens in den letzten 200 Jahren beitrug.

Die Wirtschaftskraft einer Gesellschaft ist jedoch kein Ziel an sich, sondern sie dient lediglich als Maßstab, um den Fortschritt menschlicher Entwicklung zu messen. Da die Wirtschaftskraft hierfür jedoch nur bedingt geeignet ist, berücksichtigt z.B. das Entwicklungsprogramm der Vereinten Nationen in seinen Statistiken Größen wie Lebenserwartung, Bildung, Lebensstandards oder gesellschaftliche Teilhabe (UNDP 2009). Kürzer und prägnanter ist die dem König von Bhutan zugeschriebene Formulierung "Gross National Happiness is more important than Gross National Product" (Thinley 1999: 12-13), mit der unterstrichen wird, dass neben wirtschaftlichem Wohlstand vor allem die Steigerung der Glückseligkeit Ziel der Politik sein sollte. Die Vereinten Nationen haben diese Mehrschichtigkeit menschlicher Entwicklung bei der Formulierung der "Millennium-Entwicklungsziele" ebenfalls berücksichtigt, als sie die Vorsätze fassten, bis zum Jahr 2015 den Anteil der Armen und Hungernden zu halbieren, mindestens die Grundschulbildung für alle Kinder sicherzustellen, die Gleichstellung der Geschlechter sowie die Beteiligung von Frauen zu fördern, die Mütter- und Kindersterblichkeit dramatisch zu senken, die Verbreitung ansteckender Krankheiten zurückzudrängen, den Schutz der Umwelt zu verbessern und eine nachhaltige Entwicklung zu unterstützen, sowie eine weltweite Entwicklungspartnerschaft aufzubauen (BMZ 2009, UN 2000).

Die Bekämpfung von Mikronährstoffmangel kann zur Erreichung vieler dieser Ziele einen Beitrag leisten: Mangelernährung, Sterblichkeit, Krankheitsanfälligkeit, verringerte geistige und somit schulische Leistungsfähigkeit, geringere körperliche Leistungsfähigkeit und damit eingeschränkte Verdienstmöglichkeiten, oder auch die überproportionale Krankheitslast, die auf Frauen und Kindern ruht und diese somit benachteiligt, sind alles Konsequenzen von Mikronährstoffmangel die den Millennium-Entwicklungszielen entgegenstehen.

2 Fragestellung – Die mögliche Rolle biologischer Anreicherung

Wie im vorigen Kapitel kurz dargelegt stellt Mikronährstoffmangel ein ernsthaftes Problem der Welternährung dar. Dementsprechend wurden in der Vergangenheit schon verschiedene Ansätze verfolgt, um Vitamin- und Mineralstoffdefizite einzudämmen. Diese Maßnahmen lassen sich grob in drei Gruppen einteilen: die Verteilung von Ergänzungspräparaten, die Anreicherung von Lebensmitteln mit Mikronährstoffen und Bemühungen um Nahrungserweiterung bzw. -diversifizierung und Wissensvermittlung bei den Zielgruppen. Diese Maßnahmen – Ergänzung, Anreicherung und Diversifizierung – wurden und werden mit unterschiedlichem Erfolg umgesetzt; insbesondere in Entwicklungsländern gibt es oftmals Hindernisse wie den geringen Konsum industriell verarbeiteter Lebensmittel, Schwierigkeiten bei der Bereitstellung, Verteilung, Akzeptanz und Einnahme von Ergänzungspräparaten, die Notwendigkeit einer weitergehenden Verhaltensänderung, versteckte Kosten für die Nutznießer oder ein begrenzter Wirkungskreis der Projekte. Diese Maßnahmen stellen außerdem größere, jährlich wiederkehrende Ausgaben dar, die von vielen Entwicklungsländern nur schwer oder nicht mit der nötigen Regelmäßigkeit getätigt werden können. Vor diesem Hintergrund wurde im Laufe der letzten Jahre ein neuer Ansatz entwickelt, die sogenannte "biologische" Anreicherung (Engl. "biofortification") (Tanumihardjo et al. 2008, Bouis 2008, Nestel et al. 2006, Welch und Graham 2005, Bouis 2002, Welch und Graham 2000, Bouis et al. 2000). Unter biologischer Anreicherung im weitesten Sinn versteht man die Verbesserung des Nährwerts einer Nahrungspflanze (Montagnac et al. 2009). Im Allgemeinen wird versucht, diesen Ernährungsmehrwert zu erzielen, indem Pflanzen auf höheren Mikronährstoffgehalt hin gezüchtet werden. Bisher sind außer konventionell gezüchteten orange-farbenen Süßkartoffeln jedoch noch keine biologisch angereicherten Pflanzen (BAP) in Umlauf gebracht worden.[1] Diese ersten BAP helfen zur Vorbeugung gegen VAD, da sie eine erhöhte Konzentration von Betakarotin bzw. Provitamin A aufweisen (der menschliche Körper kann Betakarotin in Vitamin A umwandeln). Aufgrund des Karotins haben die Süßkartoffeln auch eine dunklere, orangene Färbung gegenüber herkömmlichen Sorten. Gegenwärtig gibt es jedoch schon mehrere internationale Programme, die biologische Anreicherung verschiedener Nahrungspflanzen (parallel) mit verschiedenen Mikronährstoffen durchführen:

- Zum einen gibt es das HarvestPlus-Programm der Beratungsgruppe für Internationale Agrarforschung (CGIAR). HarvestPlus hat diejenigen Grundnahrungspflanzen identifiziert, die in der Ernährung der Armen und Mangelernährten in Entwicklungsländern die größte Rolle spielen: Reis, Weizen, Mais, Maniok, Süßkartoffeln und Bohnen. HarvestPlus arbeitet nun daran, diese Pflanzen mit Hilfe klassischer Züchtung mit Eisen, Zink und Betakarotin anzureichern (siehe http://www.harvestplus.org/).
- Zum anderen gibt es das "Grand Challenges in Global Health"-Programm der Bill & Melinda Gates Stiftung das als eines seiner Ziele die Verbesserung der Ernährung in Entwicklungsländern hat. Hierfür werden vier Projekte finanziert, die insbesondere auch mit Hilfe der Gentechnik Reis, Maniok, Sorghum und Bananen mit Eisen, Zink, Betakarotin, Vitamin E, aber auch Protein anreichern sollen (siehe http://www.grandchallenges.org/ImproveNutrition/). Eines dieser Projekte besteht in der Weiterentwicklung des betakarotinreichen "Goldenen Reis", der unter maßgeblicher Beteiligung deutscher Forscher (der Universität Freiburg) entwickelt wurde (siehe http://www.goldenrice.org/).

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[1] Mohrrüben werden schon seit Jahrzehnten auf ihren Karotingehalt hin gezüchtet (Sun et al. 2009), doch das ist ein Einzelfall der zudem nicht als Beitrag zur Lösung des Welternährungsproblems gedacht ist.

- Weitere, kleinere Projekte befassen sich mit der Anreicherung von Getreide mit Zink und Selenium, vor allem durch Mineraldünger (für das HarvestZinc-Projekt der Sabanci Universität in Istanbul siehe http://www.harvestzinc.org/; für das Bagels-Projekt der Universität Nottingham siehe http://bagels.ukcrop.net/). Seit 2008 gibt es außerdem das im Siebten Rahmenprogramm der Europäischen Kommission geförderte Instapa-Projekt an der Universität von Wageningen (siehe http://www.instapa.org/), und auch die EU Projekte "COST 859" und PHIME befassen sich mit Fragestellungen die für biologische Anreicherung relevant sind. Darüber hinaus gibt es unseren Wissens nur vereinzelte und eher akademisch geprägte Forschungsprojekte (siehe auch "Bibliographie und Literaturverzeichnis").

Für eine allgemeine Übersicht verschiedener Mikronährstoffmaßnahmen sowie ihre Eingruppierung siehe *Tabelle 1*; die Kategorisierung dient jedoch nur der Orientierung, überschneiden sich die Gruppen doch teilweise. So kann z.B. die Einnahme von Lebertran sowohl als Einnahme eines Ergänzungspräparats zählen wie auch als Erweiterung der Nahrung (insofern Lebertran als Lebensmittel zählt), oder der Konsum orange-farbener statt weißer Süßkartoffeln kann sowohl als Bio-Anreicherung zählen (selbes Nahrungsmittel mit höherem Nährwert) wie auch als Diversifizierung der Ernährung (mit einer neuen Pflanzensorte). Andererseits zählt die Einnahme eines Mikronährstoffpräparats beim Essen als Ergänzung, während die Zusetzung von Mikronährstoffpulver bei der Zubereitung des Essens als Anreicherung gilt.

Tabelle 1: Beispiele für Mikronährstoffmaßnahmen und ihre mögliche Eingruppierung

Nahrungsergänzung:
- Pharmazeutische Präparate (z.B. Eisentabletten für Schwangere)
- Synthetische Präparate (z.B. Vitamintabletten)
- Natürliche Präparate (z.B. Fischölkapseln)
- Natürliche Mikronährstoffquellen (z.B. Lebertran)

Anreicherung der Nahrung:
- Obligatorisch anreicherte Lebensmittel (in vielen Ländern z.B. jodiertes Speisesalz)
- Kommerziell angereicherte Lebensmittel (z.B. Multivitaminsäfte)
- Mikronährstoffpulver zur Beimengung bei der Nahrungszubereitung
- Natürliche Mikronährstoffquellen als Zusatz beim Kochen (z.B. rotes Palmöl)

Biologische Anreicherung:
- Rückzüchtung des früher üblichen Mikronährstoffgehalts in Nutzpflanzen (z.B. Eisen in Getreide)
- Erhöhung des üblichen Mikronährstoffgehalts in Pflanzen durch Züchtung (z.B. Betakarotin in Mais)
- Anpassung neuer, ortsfremder Sorten (z.B. orange-farbene statt weiße Süßkartoffeln)
- Schaffung von Pflanzen mit neuem Mikronährstoffgehalt (z.B. Betakarotin in Reis)
- Erhöhung des Mikronährstoffgehalts in Pflanzen durch Düngung (z.B. Zink in Getreide)

Nahrungserweiterung:
- Wissensvermittlung (z.B. nährstoffschonende Lagerung und Zubereitung)
- Anbau zusätzlichen Gemüses in Küchengärten
- Bekannte Nahrungsmittel in neuer Kombination (z.B. Getreide mit Vitamin C-Quellen)
- Wiedereinführung traditioneller Nahrungsmittel mit hohem Mikronährstoffgehalt
- Konsum neuer Nahrungsmittel mit hohem Mikronährstoffgehalt

Darüber hinaus unterscheiden sich die einzelnen Maßnahmen in Bezug auf ihre Wirksamkeit (d.h. auf die zusätzliche Mikronährstoffmenge die die Nutznießer aufnehmen), auf die Kosten die den Nutznießern entstehen, auf die Notwendigkeit der Kooperation durch die Nutznießer, auf das Maß an Selbstbestimmung, das sie den Nutznießern gewähren, auf die Kosten die der

Gemeinschaft entstehen, auf das Maß an notwendiger Technik, etc. So ist z.B. sowohl für Ergänzung wie auch für Diversifizierung die Kooperation der Nutznießer nötig (sie müssen die Präparate einnehmen oder ihr Ernährungsverhalten umstellen), während die verschiedenen Formen der Anreicherung z.T. gänzlich ohne Mithilfe der Nutznießer durchgeführt werden können, andererseits können über vom Arzt verschriebene Ergänzungspräparate individuell bemessene Dosen von Mikronährstoffen verabreicht werden und innerhalb kurzer Zeit eine Besserung von VMD erzielen, während durch die Erweiterung der Ernährung eine graduellere Verbesserung des Mikronährstoffstatus der Nutznießer erreicht wird. Für Ergänzungsmaßnahmen fallen jedoch fortwährend Kosten an (für die Herstellung und Verteilung der Präparate), und auch die industrielle Anreicherung von Lebensmitteln verursacht fortlaufend Kosten (für die zugesetzten Mikronährstoffe). Auch die Erweiterung der Ernährung kann Kosten verursachen, wenn die neue Ernährungsweise teurer ist als die herkömmliche, oder wenn z.B. für die Pflege des Küchengartens Zeit aufgewandt und Saatgut gekauft werden muss. Demgegenüber fallen z.B. bei der Anreicherung durch Züchtung kaum fortlaufende Kosten an, wenn die mikronährstoffreichen Nahrungspflanzen erst einmal entwickelt sind.

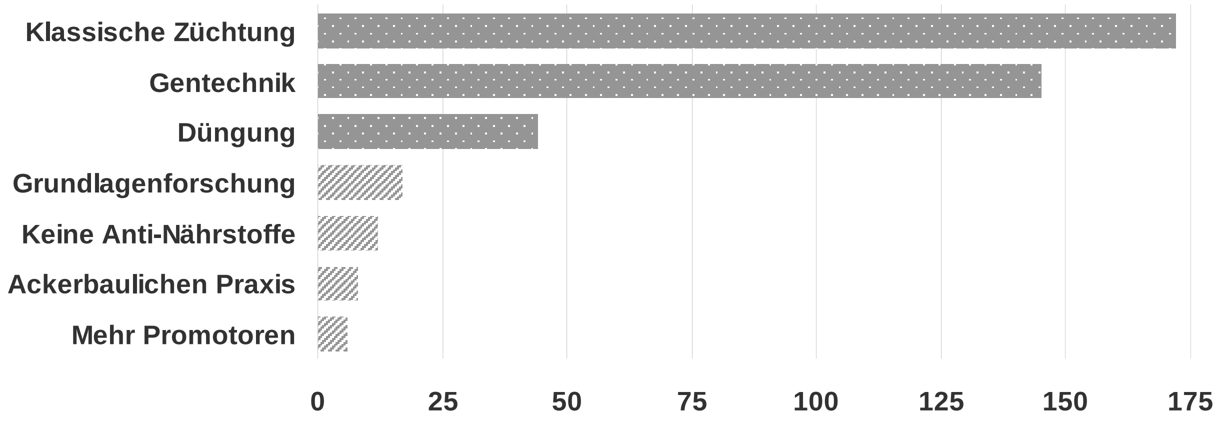
Es ist in diesem Zusammenhang kaum möglich einzelne Maßnahmen grundsätzlich abzulehnen oder die Maßnahmen einer Kategorie als Allheilmittel zu propagieren, da jede der Maßnahmen ihre Stärken und Schwächen hat und fallweise der eine oder andere Ansatz zielführender sein kann – es gilt also vielmehr, das für die jeweilige Situation passende Maßnahmenpaket zusammenzustellen. Und selbst wenn es langfristig das unbestrittene Ziel ist, dass sich alle Menschen ausreichend und ausgewogen ernähren können – d.h. die derzeitige (armutsbedingte) unzureichende und einseitige Ernährung der Hungernden und Mangelernährten zu erweitern – so ist es nicht realistisch davon auszugehen, dass dieses Ziel kurz- bis mittelfristig erreicht werden kann (Meenakshi et al. 2009, Hoekenga et al. 2009, Islam und Hotz 2009, White and Broadley 2009, Baulcombe et al. 2009, Tanumihardjo et al. 2008, Mayer et al. 2008, Stein et al. 2008, Shekhar 2008, Tanumihardjo 2007, Ramaswami 2007, Zimmermann und Hurrell 2007, Zhu 2007, Unnevehr et al. 2007, Haas und Miller 2006, Gibson 2006, MI 2005, Hunt 2005, Schneeman 2005, Stein et al. 2005). Anstrengungen dennoch (nur) auf das ferne Ideal einer Diversifizierung zu konzentrieren würde bedeuten, dass vielen Menschen die hier und heute an Mikronährstoffmangel leiden nicht geholfen wird. (Wie der Generaldirektor der Welternährungsorganisation, Jacques Diouf, beim Welternährungsgipfel im November jedoch sagte: "The poor and the hungry cannot wait" (FAO 2009b).) Daher werden gegenwärtig als ergänzende oder alternative Maßnahmen oftmals die industrielle Anreicherung von Lebensmitteln oder die Verteilung synthetischer Ergänzungspräparate durchgeführt – jedoch nicht immer mit Erfolg, aber oft mit erheblichen Kosten. Es gilt nun die biologische Anreicherung in diesem Zusammenhang zu verorten, ihre Stärken und Schwächen aufzuzeigen und die Hindernisse für eine erfolgreiche Umsetzung zu identifizieren. Dabei soll dieses Gutachten helfen. Im folgenden Kapitel wird zunächst der Stand der Forschung anhand einer Literaturübersicht wiedergegeben, im vierten Kapitel wird die Erfahrung aus der Praxis mittels den Ergebnissen einer Expertenbefragung dargestellt, anschließend wird in den Schlussfolgerungen der mögliche Beitrag der biologischen Anreicherung zur Lösung des Welternährungsproblems dargestellt und in einem Ausblick werden die entsprechenden Fördermöglichkeiten aufgezeigt. Es folgen dann noch eine umfangreiche Bibliographie sowie im Anhang die Ergebnisse der Expertenbefragung im Detail.

3 Stand der Forschung – Zusammenfassung der Literaturübersicht

Als Basis für das Gutachten führten wir zunächst eine Literatursuche durch. Unser Ausgangspunkt hierfür waren die englischen Schlüsselbegriffe "biofortification" und "biofortified", die wir in allgemein zugänglichen wissenschaftlichen Suchmaschinen suchten (Scholar, Scirus, Scopus), sowie in unserer eigenen Literaturdatenbank. Da im Hinblick auf die Identifizierung noch bestehender Hindernisse und Restriktionen für eine erfolgreiche Umsetzung der biologischen Anreicherung die ältere Literatur weniger relevant ist, da viele der darin identifizierten Zweifel und Hindernisse in der Zwischenzeit womöglich schon ausgeräumt werden konnten (und da wir aufgrund unserer eigenen Arbeit zu biologischer Anreicherung einen gewissen Überblick über die "ältere" Literatur haben), schränkten wir unsere Suche auf die letzten fünf Jahre ein (d.h. auf Veröffentlichungen aus den Jahren 2005 bis 2009). Die Treffer der Suche luden wir herunter, sichteten die Beiträge und erstellten eine Bibliographie die über 270 Artikel umfasst (siehe "Bibliographie und Literaturverzeichnis" am Ende des Gutachtens).

Die Durchsicht der Artikel ergab, dass der ursprüngliche Untertitel für unser Gutachten zu Strategien zur Behebung von Mikronährstoffdefiziten – "Wie gut sind neue Ansätze der Pflanzenzüchtung im Vergleich und was sind die Hürden für eine erfolgreiche Umsetzung?" – zu eng gefasst war, denn in der Literatur wird der englische Begriff "biofortification" inzwischen weiter gefasst und nicht nur auf die Züchtung von Grundnahrungspflanzen mit höherem Mikronährstoffgehalt bezogen (*Abb. 3*). Vielmehr ist der Einsatz von Mineraldünger zur Steigerung des Mikronährstoffgehalts in Nahrungspflanzen, oder auch "agronomische Anreicherung", mittlerweile als eine Form der biologischen Anreicherung etabliert (White und Broadley 2009, Cakmak 2009a/b, Welch 2009, Khoshgoftarmanesh et al. 2009, Alloway 2009, Karley und White 2009, Wu et al. 2009, Zapata-Caldas et al. 2009, Zhao und McGrath 2009, Phattarakul et al. 2009, Rose et al. 2009, Singh 2009, Zuo und Zhang 2009, Sands et al, 2009, Jin et al. 2008, Zhang et al. 2008a/b, Cakmak 2008, Palmgren et al. 2008, Ríos et al. 2008a/b, Horton et al. 2008, Adams 2008, Brinch-Pedersen et al. 2007, Hawkesford und Zhao 2007, Yang et al. 2007, Cox und Bastiaans 2007, Hokmabadi et al. 2007, Lyons et al. 2007, Zhao et al. 2007, Ma 2007, Zhu et al. 2007, Broadley et al. 2006, Dai et al. 2006, Popham und Shelby 2006, Gibson 2006, White und Broadley 2005, Cichy et al. 2005, Lyons et al. 2005, Genc et al. 2005, Welch und Graham 2005). Darüber hinaus wird auch die Verminderung von Hemmstoffen (Engl. "antinutrients"), die die Aufnahme von Mikronährstoffen durch den menschlichen Körper stören, als biologische Anreicherung bezeichnet (Hotz 2009, Hirschi 2008, Connolly 2008, Jeong und Guerinot 2008, Sparvoli et al. 2007, Stomph et al. 2006), ebenso wie die Erhöhung der Konzentration von Promotoren, welche die Aufnahme von Mikronährstoffen fördern (Yasuda et al. 2006, Welch 2005). Auch die Ausrichtung der Anbausysteme (z.B. Fruchtwechsel) sowie die Bewirtschaftung des Bodens auf das Ziel eines höheren Mikronährstoffgehalts in Nahrungspflanzen zählt als biologische Anreicherung (Zuo und Zhang 2009, Cakmak 2009, Welch 2009, Singh 2009, Stomph et al. 2006, Welch und Graham 2005). Weitere Autoren schließen auch die Anreicherung von Viehfutter (Singh 2009, Chassy et al. 2008, Palmgren et al. 2008, Johns und Eyzaguirre 2007, Campos-Bowers und Wittenmyer 2007, Cox und Bastiaans 2007, Pray et al. 2007), die Kontrolle von Pflanzenkrankheiten, die sich negative auf deren Mikronährstoffgehalt auswirken (Darrigues et al. 2008), die Bewirtschaftung der Mykorrhiza (He und Nara 2007), die Verwendung ausgesuchter Mikroorganismen bei der Herstellung von Lebensmitteln (Hjortmo et al. 2008), die Verwendung mikronährstoffreicher Heilpflanzen (Bhat et al. 2009) oder die Verwendung natürlichen, mikronährstoffreichen Düngematerials (Singh et al. 2005) in den Begriff der biologischen Anreicherung mit ein.

Abb. 3: Themen, die von "biofortification" in der gesichteten Literatur abgedeckt werden



Anmerkung: Es wird die Anzahl der in der Bibliographie erfassten Veröffentlichungen gemessen, die das jeweilige Thema nennen; Mehrfachnennungen sind möglich. "Klassische Züchtung" und "Gentechnik" beziehen sich hier auf die Steigerung des Nährstoffgehalts einer Nahrungspflanze.

Selbst wenn nicht alle dieser Definitionen allgemein akzeptiert sein dürften, so deutet diese Vielzahl der Arbeiten doch auf ein großes Interesse an diesem Ansatz hin – und mithin evtl. auch auf sein Potenzial und darauf, dass die Logik, die der biologischen Anreicherung zugrunde liegt, überzeugend ist.[2] Um dieser breiteren Sichtweise von "Biofortification" gerecht zu werden wäre ein passenderer Untertitel für das Gutachten evtl.: "Was kann biologische Anreicherung leisten und was sind die Hürden für eine erfolgreiche Umsetzung?" Was die biologische Anreicherung laut Literatur leisten kann (oder soll), haben wir im folgenden Abschnitt zusammengefasst; die Hürden und Restriktionen, die in der Literatur genannt werden, listen wir im Anschluss auf.

3.1 Stärken und mögliche Anwendungsgebiete der biologischen Anreicherung

Biologische Anreicherung durch Pflanzenzüchtung ist prinzipiell möglich, d.h., mikronährstoffreiche Sorten können gezüchtet werden, der Mikronährstoffreichtum ist stabil über mehrere Pflanzengenerationen und unter verschiedenen Umweltbedingungen, und eine Steigerung des Mikronährstoffgehalts reduziert nicht den Ertrag der Pflanzen (Zhao et al. 2009, Broadley et al. 2009a/b, Khoshgoftarmanesh et al. 2009, Waters und Pedersen 2009, Chen et al. 2009, Šimić et al. 2009, Bóna et al. 2009, Cichy et al. 2009, Salas et al. 2009, Thavarajah et al. 2009, 2008, Wissuwa 2008, Harjest et al. 2008, Shi et al. 2008, White und Broadley 2007, Ssemakula und Dixon 2007, Nestel et al. 2006, Rébeillé et al. 2006, Genc et al. 2005, Cichy et al. 2005, White und Broadley 2005, Welch et al. 2005, Welch und Graham 2005), selbst wenn fallweise aus praktischen Gründen auf den Transfer von Genen aus anderen Quellen zurückgegriffen wird (d.h. Einsatz gentechnischer Methoden), um den Züchtungserfolg zu ermöglichen oder zu beschleunigen und um den Nährstoffgehalt gezielter zu beeinflussen (Hirschi 2009, Nunes et al. 2009, Hotz 2009, Wirth et al. 2009, Naqvi et al. 2009, Tiong et al. 2009, Mayer et al. 2008, Shekhar et al. 2008, Connolly 2008, Aluru et al. 2008, Bekaert et al. 2008, Tuberosa 2008, Zhu et al. 2007, Storozhenko et al. 2007, 2005, Stupak et al. 2006, Graff et al. 2006, Sautter et al. 2006, Basset et al. 2005). Insofern es sich um humanitäre Projekte handelt ist der private Sektor bereit, diese mit der Freigabe geschützten Materials und patentierter Verfahren zu unterstützen, was insbesondere bei Einsatz der Gentechnik nötig ist (Potrykus 2009).

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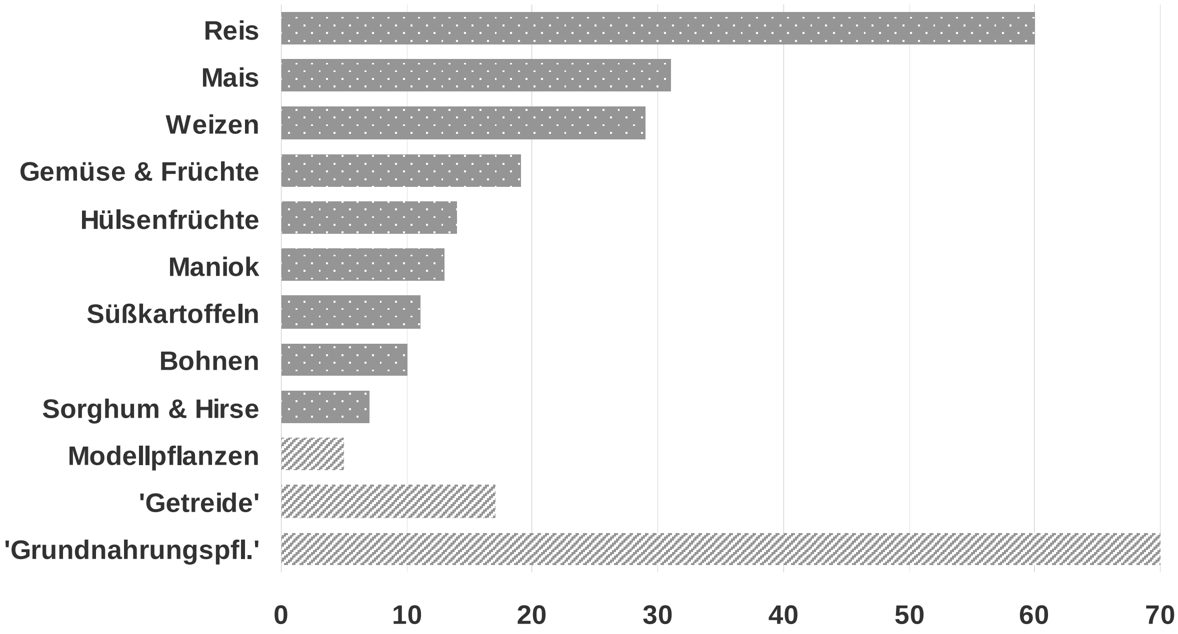
[2] "Biofortification initiatives have led to greatly increased scientific interest in micronutrients, resulting in a rapidly developing field of research comprising and integrating agronomy, breeding, molecular biology, genetics, plant physiology and nutrition" (Brinch-Pedersen et al. 2007).

Agronomische Ansätze wie der Einsatz von Mineraldünger sind ebenfalls geeignet, den Mikronährstoffgehalt von Pflanzen zu erhöhen, und sie können das Ergebnis der Pflanzenzüchtung fallweise weiter verbessern oder als selbstständige – und schneller umsetzbare – Maßnahme eingesetzt werden (White und Broadley 2009, Cakmak 2009a/b, 2008, Phattarakul et al. 2009, Alloway 2009, Jin 2008, Broadley et al. 2006, Ríos et al. 2008a/b, Zhao et al. 2007, Hawkesford und Zhao 2007, Hokmabadi et al. 2007, Dai et al. 2006, Lyons et al. 2005). Erste Fütterungsversuche mit biologisch angereicherten Pflanzen (BAP) haben gezeigt, dass die eingezüchteten Mikronährstoffe nicht nur positive Ergebnisse in Modell- oder Tierversuchen liefern (Lönnerdal 2009, Nyhus et al. 2008, Mills et al. 2008, Tako et al. 2008, Davis et al. 2008, Denova-Gutiérrez et al. 2008, Nyhus 2007, Howe 2007, Howe und Tanumihardjo 2006a/b, Ariza-Nieto et al. 2006), sondern dass sie tatsächlich den Ernährungsstatus menschlicher Testpersonen verbessern bzw. entsprechende Messwerte erhöhen können (Rosado et al. 2009, Tang et al. 2009, Low et al. 2007, Nestel et al. 2006, Haas et al. 2005). Und auch die Anwendung von Mineraldünger hat schon gezeigt, dass dieser Ansatz wirksam ist ZnD, ID und SeD zu reduzieren (White und Broadley 2009, Wu et al. 2009, Cakmak 2008). Ferner haben erste sensorische Analysen gezeigt, dass zumindest bei Mineralstoffen biologische Anreicherung möglich ist, ohne dass die BAP sensorisch wahrnehmbare Unterschiede im Vergleich zu Kontrollpflanzen aufweisen (Park et al. 2009).

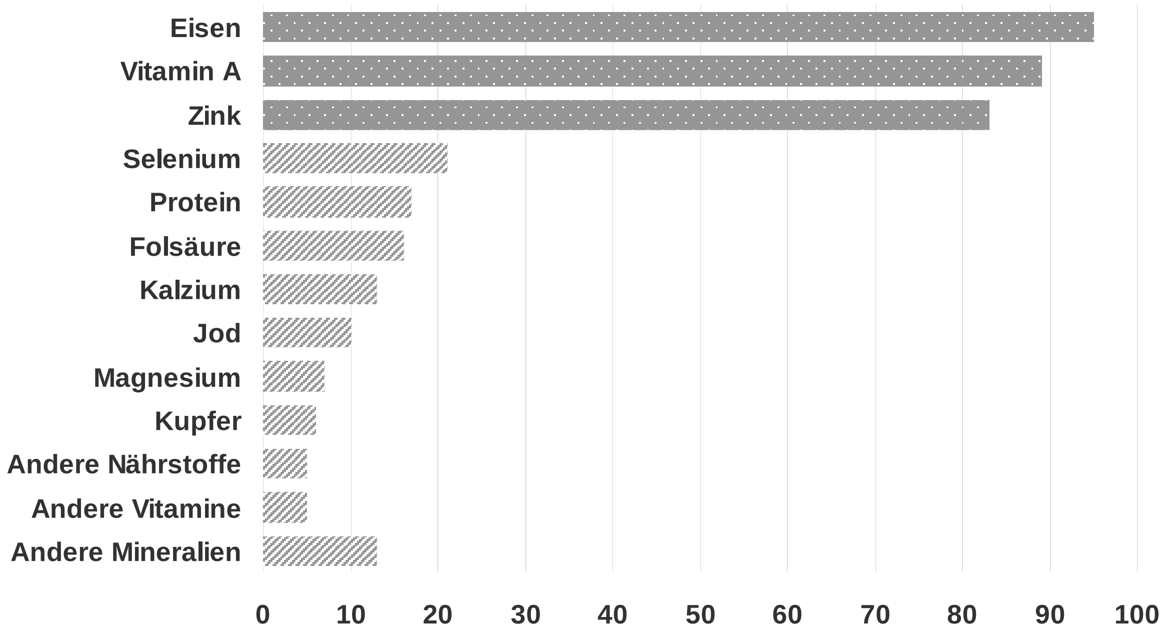
Abb. 4: In der Literatur im Zusammenhang mit "biofortification" genannte Pflanzen



Anmerkung: Es wird die Anzahl der in der Bibliographie erfassten Veröffentlichungen gemessen die die jeweilige Pflanze nennen; Mehrfachnennungen sind möglich.

Biologische Anreicherung baut vor allem auf den regelmäßigen, täglichen Konsum größerer Mengen bestimmter Nahrungsmittel durch alle Mitglieder eines Haushalts auf, daher sind die Zielpflanzen für die biologische Anreicherung auch überwiegend Grundnahrungspflanzen (*Abb. 4*). Da Grundnahrungspflanzen in der Ernährung der Armen dominieren, ist der Ansatz damit unmittelbar auf die Hauptzielgruppe ausgerichtet. Angesichts der durch Eisen-, Zink- und Vitamin A-Mangel verursachten Krankheitslast (*Abb. 2*) ist nur folgerichtig, dass diese Mikronährstoffe in der Forschung auch die ersten Plätze einnehmen (*Abb. 5*). BAP ermöglichen außerdem mangelernährte Bevölkerungsgruppen auch und gerade in unzugänglichen ländlichen Gebieten in Entwicklungsländern zu erreichen – Personengruppen, die kaum Zugang zu industriell verarbeiteten Lebensmitteln oder dem öffentlichen Gesundheitssystem haben, Grundnahrungspflanzen aber selber anbauen (Stein 2009, Meenakshi et al. 2009, Hoekenga et al. 2009, Qaim 2009, Tanumihardjo et al. 2008, Bekaert et al. 2008, Hirschi 2008, Mayer 2007, Ortiz-Monasterio et al. 2007, Nestel et al. 2006, Pinstrup-Andersen 2006, Heyd 2007, Javelosa 2006, Sanchez et al. 2005, Genc et al. 2005). Hierfür gibt es auch Anstrengungen, geeignete Zielgebiete geographisch einzugrenzen, um BAP gezielt zu entwicklen und zu fördern (Zapata-Caldas et al. 2009, Rose et al. 2009). Das heißt anders als z.B. im Falle der funktionellen Lebensmittel (Engl. "functional food"), die auf die Märkte der reichen Industrieländer zielen, ist es das explizite Ziel biologischer Anreicherung, einen Beitrag zur Lösung des Welternährungsproblems in armen Ländern zu leisten.

Abb. 5: In der Literatur im Zusammenhang mit "biofortification" genannte Nährstoffe



Anmerkung: Es wird die Anzahl der in der Bibliographie erfassten Veröffentlichungen gemessen, die den jeweiligen Nährstoff nennen; Mehrfachnennungen sind möglich. Karotin wurde unter Vitamin A erfasst.

BAP stellen eine nachhaltige Maßnahme dar, da die laufenden Kosten gering sind sobald das Saatgut entwickelt und in Umlauf gebracht ist. Und BAP können selbst dann noch von den Landwirten angebaut und nachgebaut werden – und Konsumenten helfen Mikronährstoffmangel zu vermeiden – wenn sich die Prioritäten von Regierungen und internationalen Geldgebern ändern; bei industrieller Anreicherung oder pharmazeutischer Ergänzung führt dies zwangläufig zu einer Reduzierung der Programme (Stein 2009, Mayer et al. 2008, Nestel et al. 2006, Pinstrup-Andersen 2006, Heyd 2007). Sind die BAP erst einmal entwickelt, so kann das entsprechende genetische Material auch über Ländergrenzen hinweg zwischen entsprechenden nationalen Forschungs- und Züchtungsstationen geteilt werden, d.h. (nach Einzüchtung des Mikronährstoffreichtums in lokale Sorten) die BAP können einen großen internationalen Verbreitungsgrad erzielen. Auf diese Weise können die Entwicklungskosten der BAP über Raum und Zeit hinweg aufgeteilt und (hypothetisch auf die Nutznießer umgelegt) dramatisch reduziert werden – während die BAP einen fortlaufenden und sich ausbreitenden Nutzenstrom abgeben können. Das heißt durch biologische Anreicherung können Skaleneffekte genutzt werden die zu einem sehr vorteilhaften Kosten-Nutzen-Verhältnis der BAP führen (Qaim 2009, Tanumihardjo et al. 2008, Nestel et al 2006). Diese potenzielle Wirksamkeit und enorme Wirtschaftlichkeit von BAP wurde bereits in mehreren Vorab-Studien und Analysen bestätigt, sowohl für biologische Anreicherung durch herkömmliche Pflanzenzüchtung wie auch für gentechnische Ansätze, für die Mikronährstoffe Eisen, Zink und Betakarotin und für eine Reihe von Grundnahrungspflanzen (Meenakshi et al. 2009, Qaim und Stein 2009, Horton et al. 2008, Bhagwati et al. 2008, Lemaux 2008, Stein et al. 2008a/b, 2007, 2006, Qaim et al. 2007, Ma et al. 2007, Javelosa 2006, Sandler 2005, Zimmermann and Qaim 2004). Diese Studien weisen auch darauf hin, dass die Entwicklung von BAP einen effizienten Einsatz knapper Ressourcen darstellen kann, gerade auch im Vergleich zu alternativen oder komplementären Maßnahmen wie industrieller Anreicherung oder pharmazeutischer Ergänzung. Denn um das Welternährungsproblem zu lösen, können (leider) nicht alle wirksamen Maßnahmen finanziert werden, sondern es gilt, diejenigen Maßnahmen zu bestimmen, die für ein gegebenes Budget den größten Beitrag zur Problemlösung leisten.

Schließlich ist es möglich, dass biologische Anreicherung (zumindest mit Mineralstoffen) sogar greifbare Vorteile für die Landwirte mit sich bringt, da eine ausreichende Versorgung mit Mineralstoffen auch für Keimlinge und Pflanzen allgemein wichtig ist und ihnen hilft, Krankheiten und anderen Stressfaktoren besser zu widerstehen sowie Erträge zu steigern (Khoshgoftarmanesh et al. 2009, Singh 2009, Krämer 2008, Walker und Connolly 2008, Pfeiffer und McClafferty 2007, Phattarakul et al. 2007, Nestel et al. 2006, Stomph et al. 2006). Das heißt, BAP könnten den Landwirten zumindest auf mineralstoffarmen Standorten sogar Ertragsvorteile bringen – was die Verbreitung des biologisch angereicherten Saatguts deutlich erleichtern würde. Zumindest in Asien wird die Verbreitung neuen, besseren Saatguts aufgrund der bestehenden Infrastruktur (Märke und Kommunikation) jedoch auch allgemein nicht als Problem betrachtet (Nestel et al. 2006). Es gibt bereits mehrere Studien zur Akzeptanz von BAP, insbesondere von BAP, die als solche erkennbar sein werden (aufgrund von farblichen Änderungen oder, weil sie als gentechnisch veränderte (GV) Pflanzen in Umlauf gebracht werden sollen) (González et al. 2009, Chowdhury et al. 2009, Dickinson et al. 2009, De Steur et al. 2009, Stevens and Winter-Nelson 2008, Muzhingi et al. 2008, De Groote und Chege Kimenju 2008, Ezedinma und Nkang 2008, Heyd 2007, Wolson 2007, Pray et al. 2007, Mazuze 2007, Low et al. 2007, Chege Kimenju et al. 2006, Chong 2003, Hagenimana and Low 2000). Diese Studien zeigen, dass BAP, um angebaut zu werden, vor allem Eigenschaften aufweisen müssen, die für Landwirte von Interesse sind (d.h. höhere Erträge, Dürretoleranz, Schädlingsresistenz oder bessere Vermehrungsfähigkeit). Darüber hinaus müssen BAP als lokal-angepasste Sorten zur Verfügung stehen, und Saatgut und Pflanzmaterial müssen leicht zugänglich sein. Da die BAP auch zur Einkommenserzielung geeignet sein müssen, müssen sie auch für Konsumenten akzeptierbar sein, d.h., sie müssen den bekannten Sorten in deren Konsumeigenschaften wie Geschmack, Konsistenz oder Lagerfähigkeit weitestgehend entsprechen. Unter diesen Bedingungen – die auch von den Entwicklern von BAP als essenziell betrachtet werden (z.B. Ortiz-Monasterio et al. 2007) – ist eine Akzeptanz auch erkennbar angereicherter Grundnahrungspflanzen realistisch, bzw. bei entsprechender Einbindung der örtlichen Gemeinwesen und begleitenden Informations- und Aufklärungsmaßnahmen ist selbst eine positive Zahlungsbereitschaft für BAP möglich. In diesem Fall ist es sogar wünschenswert, wenn BAP als solche erkennbar sind (Pray et al. 2007). In Bezug auf GV-BAP besteht strategisch auch die Möglichkeit, auf die positiven Erfahrungen von Landwirten mit bisherigen GV-Pflanzen (insbesondere insektenresistente Baumwolle) aufzubauen (Wolson 2007), bzw. eine höhere Akzeptanz kann national wie regional durch organisierte Interessenvertretung gefördert werden (Pray et al. 2007, Pray und Huang 2007, Birner et al. 2007). Insbesondere in Afrika, wo die formale Infrastruktur für Saatgut schwächer ist, kann die Einbindung von Nichtregierungsorganisationen zudem bei der Verteilung des Saatguts von BAP helfen (Paarlberg und Pray 2007).

Die BAP können jedoch auch den Konsumenten zusätzliche Ernährungsvorteile bringen, z.B. weil durch den Konsum kompletter Nahrungsmittel (im Gegensatz zur Einnahme von Ergänzungspräparaten) Synergien realisiert werden können, wenn die biologische Anreicherung auch zu einer Verbesserung der Ballaststoff- und Proteinversorgung führt, wenn höhere Mikronährstoffkonzentrationen die Aufnahme anderer Nährstoffe erleichtert, wenn BAP eine gleichmäßige und sichere Versorgung mit Mikronährstoffen gewährleisten oder wenn BAP industrieller Anreicherung oder Ergänzung vorgezogen werden (Mills et al. 2008, Stomph et al. 2009, Lyons et al. 2007, Tanumihardjo 2007, Prakash 2006, Cox und Bastiaans 2007). Zudem kann es auch ganz praktische Gründe für BAP geben – z.B. im Fall von Reis ist industrielle Anreicherung sehr viel komplizierter und teurer (Horton 2006).

3.2 Voraussetzungen und Einschränkungen für biologische Anreicherung

Wie im vorigen Abschnitt gesehen, ist biologische Anreicherung prinzipiell möglich und es können dadurch bisher vernachlässigte Zielgruppen der Mangelernährten in Entwicklungsländern erreicht werden; außerdem ist biologische Anreicherung nachhaltig in dem Sinne, dass nach einer gewissen Anfangsinvestition kaum fortlaufende Finanzierung nötig ist, bzw. selbst bei der Anfangsinvestition können Skaleneffekte genutzt und eine hohe Kosteneffizienz erreicht werden. Falls BAP keine für die Konsumenten erkennbaren Veränderungen aufweisen und zusätzlich landwirtschaftliche Vorteile für die Landwirte mit sich bringen, sollte ihre Verbreitung verhältnismäßig einfach möglich sein. Erste Konsumentenstudien deuten an, dass unter den Nutznießern eine Akzeptanz auch von erkennbar angereicherten Pflanzen erreichbar ist. Einzelne Annahmen dieser vorläufigen Studien werden in der Literatur jedoch hinterfragt und mögliche Einschränkungen einer erfolgreichen Einführung von BAP werden diskutiert. Diese Punkte werden im Folgenden zusammengefasst.

Die Ergebnisse aus Labor- und Gewächshausversuchen müssen im freien Anbau bestätigt werden, d.h. bei BAP muss der Mikronährstoffreichtum über Pflanzengenerationen und Umwelteinflüsse hinweg stabil sein, und sie müssen sich gegenüber Kontrollpflanzen hinsichtlich Ertrag, Stresstoleranz und Umwelteinflüssen (mindestens) als gleichwertig erweisen, um Akzeptanz seitens der Landwirte zu gewährleisten (Connolly 2008, Lyons et al. 2007, Pfeiffer und McClafferty 2007, Ssemakula und Dixon 2007, Abilgos-Ramos et al. 2007, Brinch-Pedersen et al. 2007, Juma et al. 2007, Stein et al. 2006). So müssen z.B. mögliche negative Auswirkungen auf den Ertrag der BAP durch erhöhten Schädlingsbefall ausgeschlossen werden (Popham und Shelby 2006). Ist der Nährstoffreichtum jedoch erst einmal in einer Sorte etabliert, so kann diese Eigenschaft leicht in andere, den örtlichen Gegebenheiten angepasste Sorten eingezüchtet werden (Pardey et al. 2007). Züchtungseinrichtungen vor Ort müssen jedoch die notwendige Kompetenz und Kapazität haben (Harjest et al. 2008, Bekaert et al. 2008); für die markergestützte Selektion ist dies derzeit in vielen Entwicklungsländern nicht gegeben (Johns und Eyzaguirre 2007).

Die Kosten für die Anpassungszüchtung und die Verbreitung von BAP erfordern Investitionen, die eine erhebliche Belastung für die Forschungsbudgets in vielen Entwicklungsländern darstellen, d.h., ohne internationale Unterstützung können BAP nur auf Kosten anderer wichtiger Forschungsprogramme entwickelt werden (Stevens und Winter-Nelson 2008). Insbesondere in Regionen mit heterogenen Anbaubedingungen kann die notwendige Einzüchtung in eine Vielzahl angepasster Sorten die Kosten für biologische Anreicherung erhöhen (Slingerland et al. 2006). Da bei BAP – anders als bei Pflanzen mit agronomischen Vorteilen – zudem Marktanreize für die Entwicklung fehlen, kann dies zu vom gesellschaftlichen Standpunkt aus zu Unterinvestition in diesem Bereich führen, insbesondere beim Einsatz der Gentechnik (Unnevehr et al. 2007). Auf der Seite der reicheren Länder müssen Ressourcen, Forschung und Beratung mit dem Ziel mobilisiert werden, an Anwendungen zu arbeiten, die für die Armen in einkommensschwachen Ländern relevant sind (Graff et al. 2006). Vor Einsatz der Gentechnik muss jedoch überprüft werden, ob andere Maßnahmen wie klassische Züchtung, pharmazeutische Ergänzung oder Diversifizierung der Ernährung nicht einfacher und kostengünstiger sind (Dawson et al. 2009). Zudem müssen die Herausforderungen in Bezug auf die Verbreitung des Pflanz- und Saatguts überwunden werden, vor allem durch die Entwicklung und Anpassung von Saatgut- und Anbausystemen sowie durch Informations- und Sensibilisierungsaktivitäten (Hotz 2009, Stevens und Winter-Nelson 2008, Harjest et al. 2008, Low et al. 2007, Johns und Eyzaguirre 2007, Nestel et al. 2006). Dies ist vor allem in Afrika keine leichte Aufgabe, weil dort in vielen Ländern und für viele wichtige Kulturarten Saatgutmärkte kaum entwickelt sind (Meenakshi et al. 2009, Botha und Viljoen 2008, Birner et al. 2007, Paarlberg und Pray 2007). Andererseits gelten ähnliche Herausforderungen für jede neue Saatguttechnologie, nicht nur für BAP.

Neben der Angebotsseite müssen auch Absatzmärkte für BAP und daraus gewonnene Lebensmittel entwickelt werden, um den Anbau der BAP zu gewährleisten (Low et al. 2007, Nestel et al. 2006), bzw. um eine kontinuierliche Versorgung der Märkte mit BAP zu erreichen, muss ebenfalls sichergestellt werden, dass die örtlichen Landwirte BAP anbauen (Tanumihardjo et al. 2008). Und um die Wirksamkeit biologischer Anreicherung zu maximieren, sollten die BAP zudem dort angebaut werden, wo die Nahrungspflanzen bereits konsumiert werden und wo die entsprechenden Vitamin- und Mineralstoffmängel verbreitet sind. Für eine solch geographische Eingrenzung ist die Datenlage – Produktionsstatistiken und Ernährungsstatus der Bevölkerung – jedoch oftmals unzureichend (Zapata-Caldas et al. 2009); ein besseres Verständnis bevölkerungsweiter Ernährungsmuster ist erforderlich (Rose et al. 2009).

Für größtmögliche Wirksamkeit der BAP muss deren weitreichende Produktion und Konsum (durch die Zielgruppen) erreicht werden (Stein et al. 2008). Um sicherzustellen, dass BAP von Landwirten und Konsumenten akzeptiert werden, ist ihre Einbindung bei der lokalen Anpassungszüchtung der Pflanzen nötig (Nestel et al. 2006), insbesondere auch um ethische Prinzipien wie das Recht auf Selbstbestimmung und Teilhabe zu wahren und um indigenes und geschlechterspezifisches Wissen berücksichtigen zu können (Johns und Eyzaguirre 2007). Außerdem dürfen die BAP für (städtische) Nutznießer nicht teurer sein als herkömmliche Nahrungsmittel. Und um ländlichen Armen zugänglich zu sein, müssen die BAP – insofern sich durch ihren Anbau für die Landwirte keine positiven, unmittelbaren Einkommensvorteile ergeben – frei von geistigen Eigentumsrechten bzw. als fremd- oder selbstbestäubende Sorten erhältlich sein und das Saatgut muss ggf. zu subventionierten oder zumindest gedeckelten Preisen abgegeben werden (Johns und Eyzaguirre 2007, Zhu et al. 2007, Campos-Bowers und Wittenmyer 2007, Haas et al. 2005). Nichtsdestotrotz können gesellschaftliche Einflüsse, Essgewohnheiten und farbliche Veränderungen der BAP zu eingeschränkter Akzeptanz führen (Harjest et al. 2008, Lozano-Alejo et al. 2007), d.h., bei der Entwicklung von BAP müssen auch deren sensorische und Verarbeitungseigenschaften berücksichtigt werden (Baulcombe et al. 2009, Johns und Eyzaguirre 2007, Juma et al. 2007) und insbesondere die Akzeptanz der Verbraucher in Bezug auf andersfarbige BAP muss weiter erforscht werden (Meenakshi et al. 2009, Qaim 2009, Pinstrup-Andersen 2006), bzw. Anstrengungen müssen unternommen werden, um die Nutznießer mit den Vorzügen farbigerer Nahrungspflanzen vertraut zu machen und ihre Präferenzen entsprechend zu ändern (Tanumihardjo et al. 2008, Ezedinma und Nkang 2008, Tanumihardjo 2007, Stein et al. 2006, Sanchez et al. 2005); dies sollte in umfassendere Maßnahmen der Ernährungsaufklärung und -diversifizierung integriert werden (Meyers 2005).

Im Falle von GV-BAP muss die Öffentlichkeit zudem gegenüber GV-Pflanzen offen sein und auch bereit sein, Gelder für aussichtsreiche Projekte zur Verfügung zu stellen (Sautter et al. 2006, Stein 2006). In diesem Zusammenhang besteht die größte Herausforderung in objektiver, wissenschaftlich fundierter Aufklärung (Miller 2009, Cabanilla 2007, Zhu et al. 2007, Storozhenko et al. 2005, Van Montagu 2005), insbesondere der Zielgruppen (De Steur et al. 2009). Allerdings können kommerzielle Interessen – vor allem der befürchtete Verlust der die Gentechnik ablehnenden Exportmärkte in Europa – dazu führen, dass Regierungen der allgemeinen Ernährungssituation ihrer Bürger und dem Wohlergehen ihrer Kleinbauern eine geringere Priorität einräumen (Pray et al. 2007, Pray und Huang 2007). (Selbst wenn solche Befürchtungen oftmals rational weder begründet noch begründbar sind (Gruère und Sengupta 2009).) Jedoch auch bei anderen BAP können Ertragsreichtum und Einkommensgewinnung im Agrarsektor bei politischen Entscheidungen mehr Gewicht haben als Ernährungsfragen (Paarlberg und Pray 2007). Daher müssen die Entscheidungsträger in Entwicklungsländern bei der Gestaltung ihrer Agrarpolitik diese auch auf Auswirkungen auf den Anbau von nährstoffreichen Pflanzen hin überprüfen (Muzhingi et al. 2008). Und die Dringlichkeit von Mikronährstoffmangel als Gesundheitsproblem muss ganz allgemein verdeutlicht werden (Laxminarayan et al. 2008).

Da die gezielte Entwicklung von BAP für Märkte in Entwicklungsländern kommerziell uninteressant is, die BAP aber von hohem gesellschaftlichen Nutzen sind, fällt es primär dem staatlichen Sektor zu, diese Pflanzen zu entwickeln und in Umlauf zu bringen. Für Wissenschaftler im öffentlichen Dienst – die an der Entwicklung solcher Pflanzen arbeiten könnten – sind an erfolgreiche Machbarkeitsstudien anschließende Produktentwicklungen jedoch von geringerem Interesse, weil dies zwar sehr zeit- und kostenintensiv, aber für das wissenschaftliche Renommee irrelevant ist. Was im universitären Umfeld zunehmend zählt, sind die Anzahl und Qualität wissenschaftlicher Veröffentlichungen; dies gilt auch für die Einwerbung von Fördermitteln. Die für eine erfolgreiche Produktentwicklung erforderliche Erfahrung, Kompetenz und Logistik sind deswegen in deutschen und europäischen öffentlichen Forschungsinstituten kaum zu finden, d.h. für eine erfolgreiche Einführung von BAP und ähnlicher Produkte ist es nötig, das entsprechende Leistungsvermögen an ausgesuchten Instituten aufzubauen – oder aber die Produktentwicklung im Rahmen öffentlich-privater Partnerschaften an private Firmen auszugliedern (Al-Babili und Beyer 2005). Bisher ist eine solche Unterstützung durch den staatlichen Sektor kaum gegeben (Potrykus 2009).

Neben der Nutzung öffentlicher und privatwirtschaftlicher Kompetenzen ist bei der biologischen Anreicherung vor allem auch interdisziplinäre Arbeit nötig da, für die Entwicklung von BAP agrarwissenschaftliche Forschung mit Ernährungs- und Gesundheitsfragen verbunden werden muss, und da die Einführung von BAP das Verständnis des gesellschaftlichen Hintergrunds erfordert; eine solche Zusammenarbeit muss aktiv gefördert werden (Welch 2009, Dickinson et al. 2009, Sands et al. 2009, Hotz und McClafferty 2007, Nestel et al. 2006, Sanchez et al. 2005). Als zentralisierte, technologische Einzellösungen unterliegen BAP ansonsten der Gefahr an unzureichender Beachtung sozialer, kultureller und ökonomischer Prozesse zu scheitern (Johns und Eyzaguirre 2007). Übergreifende Ansätze sind insbesondere auch bei Informations- und Aufklärungskampagnen nötig, da diese bei Gesundheits- und Ernährungsprogrammen üblich sind, nicht jedoch bei landwirtschaftlichen Maßnahmen (Meenakshi et al. 2009). Außerdem hilft eine Einbindung von Medizin- und Ernährungswissenschaftlern auch dabei, dass biologische Anreicherung – als ein agrarwissenschaftlicher Ansatz – von diesen stärker mitgetragen wird (Ramaswami 2007).

Insbesondere muss vermieden werden, dass der Eindruck entsteht, BAP seien Allheilmittel: Sie müssen als Ergänzung des Maßnahmenkatalogs dargestellt werden, die die herkömmlichen Maßnahmen aus diesen anderen Disziplinen nicht verdrängen sollen (Juma et al. 2007). Denn die alleinige Verfolgung biologischer Anreicherung, die auf die Konzentration von mehr Nährstoffen in wenigen Nahrungsmitteln abzielt, wäre langfristig kontraproduktiv, da dadurch die Ernährung weiter vereinfacht anstatt vervielfältigt werden könnte (Johns und Eyzaguirre 2007); die Wichtigkeit einer Kost, die reich ist an Früchten und Gemüse, kann auch durch BAP nicht ersetzt werden (Tanumihardjo et al. 2007). Wird biologische Anreicherung dennoch (fälschlicherweise) als Allheilmittel verstanden, treffen auch andere Kritikpunkte zu, wie z.B. der, dass die Förderung einiger überlegener Pflanzensorten das Ziel der Bewahrung von Biodiversität untergräbt – und der Verlust von Landrassen wiederum das Anpassungsvermögen der Landwirte vor Ort verringert (Johns und Eyzaguirre 2007). Bei einem solchen Verständnis kann der mögliche Beitrag von BAP zur Verminderung der Mangelernährung – vor diesem Hintergrund – zurecht relativiert werden. BAP hingegen abzulehnen, nicht weil sie gewisse Ziele (wie Armutsreduzierung oder Gesundheitsverbesserung) nicht erreichen können, sondern weil sie als Teil eines technikgestützten Kapitalismus betrachtet werden, der die bestehenden Kräfteverhältnisse in der internationalen Forschungslandschaft festigt und eine Ermächtigung öffentlicher Forschungseinrichtungen in Entwicklungsländern verhindert sowie gesellschaftliche Vielfalt ignoriert, zielt ggf. eher auf dieses System denn auf die BAP an sich ab (Brooks et al. 2009).

Konkretere offene Fragen gibt es hingegen noch bezüglich der Stabilität der Nährstoffe während der Lagerung und Zubereitung der BAP, wozu weitere Forschung nötig ist (De Groote und Chege Kimenju 2008, Hotz und McClafferty 2007, Storozhenko et al. 2007, Heyd 2007, Stein et al. 2006). Gleichfalls muss die Bioverfügbarkeit der Nährstoffe, insbesondere in üblichen Mahlzeiten der Zielgruppen, sowie der tatsächliche Nutzen des Konsums von BAP belegt werden (Tang et al. 2009, Zhao und McGrath 2009, Hirschi 2009, Lönnerdal 2009, Krawinkel 2009, Denova-Gutiérrez et al. 2008, Hirschi 2008, Stevens und Winter-Nelson 2008, Harjest et al. 2008, Tako et al. 2008, Connolly 2008, Hjortmo et al. 2008, Davis et al. 2008, Khor 2008, Hotz und McClafferty 2007, Ortiz-Monasterio et al. 2007, Storozhenko et al. 2007, Lozano-Alejo et al. 2007, Ma et al. 2007, Juma et al. 2007, Johns und Eyzaguirre 2007, Heyd 2007, Howe und Tanumihardjo 2006, Broadley et al. 2006, Finglas et al. 2006, Stein et al. 2006, Allen et al. 2006, Storozhenko et al. 2005, Lyons et al. 2005, Hunt 2005, Welch 2005). Bei Kleinkindern, die einen hohen Mikronährstoffbedarf haben, jedoch relativ geringe Mengen an Grundnahrungsmitteln konsumieren, kann biologische Anreicherung womöglich nicht ausreichen, um Mangelernährung auszugleichen (Hambidge und Krebs 2007, Hotz und McClafferty 2007).

Fütterungsversuche können evtl. auch helfen, die Akzeptanz von BAP in der Öffentlichkeit zu erhöhen (Jeong und Guerinot 2008). Ferner müssen die Interaktionen zwischen verschiedenen Nährstoffen untersucht werden (Meenakshi et al. 2009, Yasuda et al. 2006, Genc et al. 2005, Welch 2005, Hess et al. 2005), und es kann sich auch als nötig erweisen, gewisse Hemmstoffe in den Pflanzen zu reduzieren, um die Wirksamkeit der angereicherten Mikronährstoffe zu gewährleisten (Shekhar Gautam et al. 2008, Engle-Stone et al. 2005, Cichy et al. 2005). Eine solche Reduzierung darf jedoch nicht zu Ertragseinbußen bei den BAP führen, wie es z.B. in einigen Fällen bei Zink beobachtet wurde (Hotz 2009). Darüber hinaus müssen BAP bzw. die in sie eingebrachten Nährstoffe auf ihre Sicherheit hin geprüft werden, insbesondere wenn gentechnische Verfahren eingesetzt wurden (Díaz et al. 2007, Johns und Eyzaguirre 2007, Ma 2007, Allen et al. 2006, Stein et al. 2006, Storozhenko et al. 2005). Bei eisen- und zinkreichen BAP muss z.B. eine unbeabsichtigte parallele Anreicherung mit Schwermetallen ausgeschlossen werden (Grennan 2009, Zhao und McGrath 2009, Krämer 2008), und bei seleniumreichen BAP muss der Gehalt an Selenium begrenzt werden, um Toxizität zu verhindern (Zhu et al. 2009).

Ganz allgemein ist weitere Forschung nötig, um den Stoffwechsel in den Pflanzen zu verstehen, um zu verstehen, welche Gene für Aufnahme, Transport und Einlagerung der Nährstoffe zuständig sind, welche molekularen und physiologischen Schritte erforderlich sind, um Mikronährstoffe in Pflanzenzellen anzureichern, und um zu verstehen wie verschiedene Nährstoffe zueinander in Beziehung stehen (Šimić et al. 2009, Sekimoto 2009, Hotz 2009, Waters und Grusak 2008, Palmgren et al. 2008, Botella-Pavía und Rodríguez-Concepción 2006, Rébeillé et al. 2006, Basset et al. 2005).

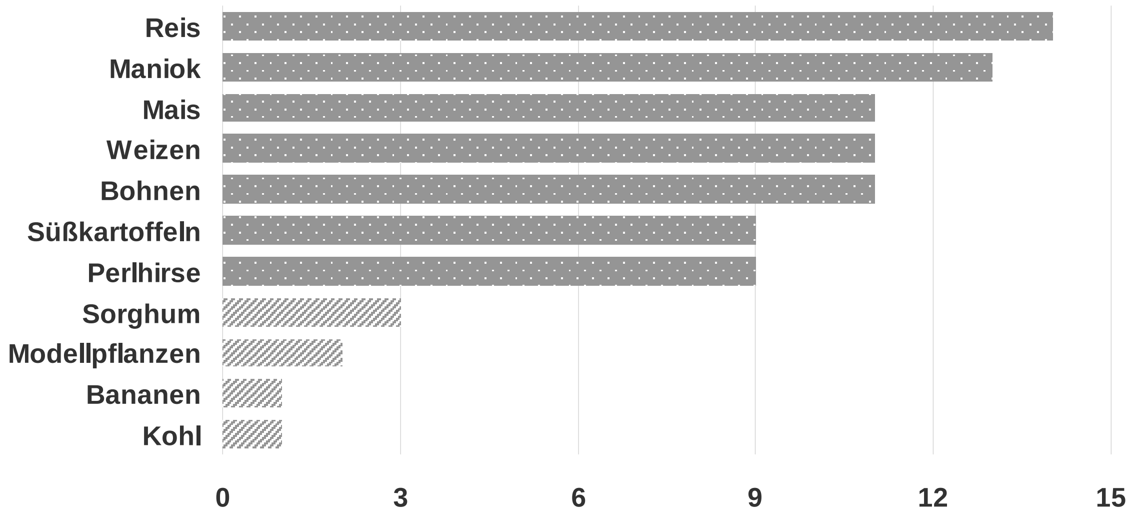
Da die Züchtung von BAP je nach Mikronährstoff und Pflanze noch langwierig sein oder nur zu geringfügigen Erhöhungen des Mikronährstoffs führen kann, insbesondere im Falle von mineralstoffarmen Böden, können andere Maßnahmen (z.B. Mineraldüngung oder industrielle Anreicherung) mit geringerem Aufwand zum Ziel führen (Hotz 2009, Cakmak 2009a/b, 2008). Langfristig ist Düngung jedoch teurer als die Züchtung von BAP (Broadley et al. 2006); außerdem bedarf sie einer entsprechenden Infrastruktur (White and Broadley 2009).

Dass biologische Anreicherung bisher nur für eine kleine Gruppe von Nährstoffen erfolgreich war und sie gegenwärtig kein Hauptziel der meisten Pflanzenzüchter ist (Sands et al. 2009, Davies 2007), ist weniger ein Mangel der Technologie als Zeichen dafür, dass dieser Ansatz sich noch in der Entwicklungsphase befindet. Auch dass die großflächige Einführung der meisten BAP noch Jahre entfernt ist (MI 2005), wenn auch z.T. nur aufgrund regulatorischer Hürden (Potrykus 2009, 2005, Pardey et al. 2007), stellt keine echte Einschränkung der Technologie dar.

4 Sichtweise aus der Praxis – Antworten der Experten

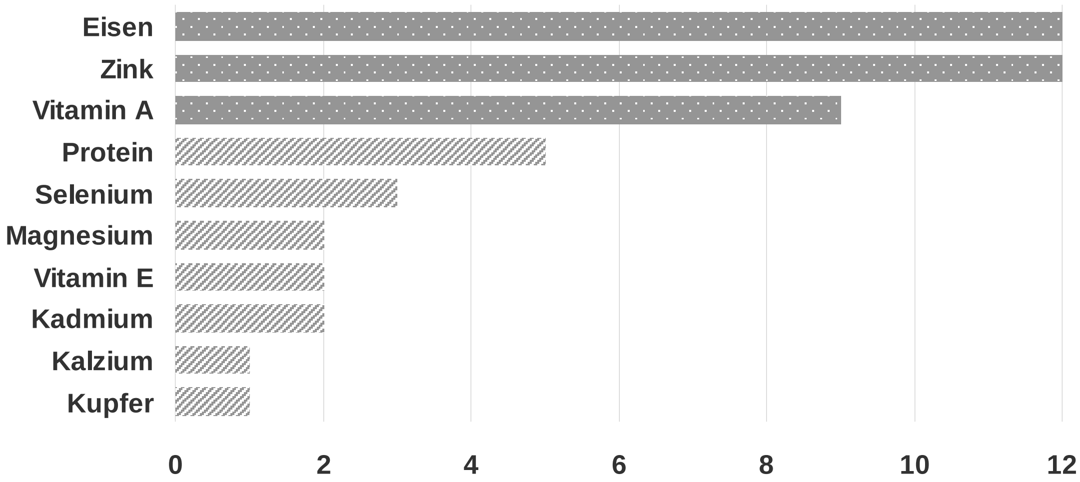
Zur Ergänzung der Literaturübersicht und um aktuell und aus der Praxis zu erfahren, welche Hindernisse es bei der Weiterentwicklung und Umsetzung der biologischen Anreicherung gibt, haben wir Fragebögen an Experten der diversen Projekte, die BAP entwickeln, geschickt (siehe auch Übersicht der Projekte in Abschnitt 2). Die beantworteten Fragebögen sind – soweit die Experten einer Veröffentlichung zustimmten – im Anhang im Detail wiedergegeben (siehe Abschnitt "Expertenbefragung"). Da der Rücklauf der Fragebögen von den Experten der verschiedenen Projekte unterschiedlich war (und da auch die Anschrift der Experten von ihrer Identifizierbarkeit und Kontaktierbarkeit über die entsprechenden Projekt-Webseiten abhing – insofern sie uns nicht persönlich bekannt waren), ist die Auswertung der Antworten nicht repräsentativ, selbst wenn insgesamt jeder zweite Experte geantwortet hat. Die gemeinsame Antwort von 8 HarvestPlus-Experten mag zudem zu einem gewissen Mangel an Differenzierung führen. (Andererseits kann auch eine Nichtbeantwortung des Fragebogens evtl. einen Hinweis darauf geben, wie relevant die entsprechenden Experten eine mögliche Unterstützung durch den Deutschen Bundestag einschätzen.)

Abb. 6: Pflanzen, mit denen die befragten Experten arbeiten



Anmerkung: Es wird die Anzahl der Fragebögen wiedergegeben, die die jeweilige Pflanze nennen; Mehrfachnennungen möglich.

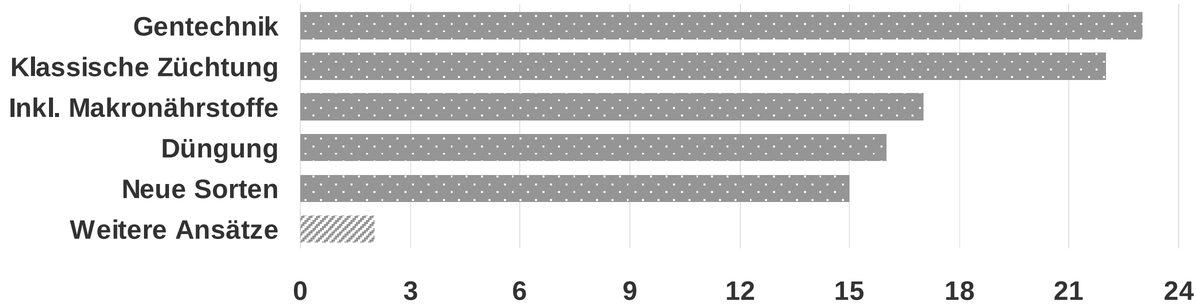
Abb. 7: Nährstoffe, mit denen die befragten Experten arbeiten



Den Fragebögen kann man jedoch entnehmen, dass wie in der Literatur auch (*Abb. 4*), Reis, Mais und Weizen in der angewandten Entwicklung zu den wichtigsten Zielpflanzen für die biologische Anreicherung gehören (*Abb. 6*). Bei den Nährstoffen, die in den Pflanzen biologisch angereichert werden, stimmt die Häufigkeit der in der Literatur genannten Nährstoffe (*Abb. 5*) ebenfalls mit den in der Praxis wichtigen Nährstoffen überein (*Abb. 7*); in beiden Fällen sind dies Eisen, Zink und Vitamin A, gefolgt von Protein (spezielle essenzielle Aminosäuren) und Selenium. Schließlich stimmen die befragten Experten auch bei der Definition biologischer Anreicherung mit der Literatur überein (*Abb. 3*), d.h., sie verstehen unter biologischer Anreicherung hauptsächlich die Anreicherung von Nahrungspflanzen mit Nährstoffen (mit Mikro- wie auch Makronährstoffen) durch klassische Züchtung und Gentechnik sowie zu einem geringeren Teil auch durch Düngung (*Abb. 8*); die Einführung ortsfremder nährstoffreicher Sorten wird in der Literatur ggf. mit klassischer Züchtung zusammengefasst. Dieser Abgleich deutet darauf hin, dass die Expertenantworten insgesamt – wenn auch nicht repräsentativ im strengen Sinn – eine ausgewogene Einschätzung ermöglichen. Im Folgenden werden daher die Antworten der befragten Experten hinsichtlich der Hürden bei der Entwicklung von BAP zusammengefasst, und ihre Einschätzung bzgl. der sinnvollsten Ausgestaltung möglicher Unterstützung wird wiedergegeben; die Namen in Klammern verweisen auf die im Anhang wiedergegebenen Fragebögen.

Anmerkung: Es wird die Anzahl der Fragebögen wiedergegeben, die den jeweiligen Nährstoff nennen; Mehrfachnennungen möglich. Vitamin A beinhaltet auch Nennungen von Karotin.

Abb. 8: Biologische Anreicherung im Verständnis der Experten



Anmerkung: Es wird die Anzahl der Fragebögen wiedergegeben, die die jeweilige Definition akzeptieren; Mehrfachnennungen möglich.

4.1 Hürden und Restriktionen für biologische Anreicherung

In Bezug auf die eigentliche Forschung zu BAP sehen die Experten z.T. Engpässe bei der Finanzierung (Broadley), insbesondere von angewandter Forschung und von notwendigen Großversuchen (sowohl Feld- als auch Fütterungsversuche mit BAP) (N1, Sayre, N2). In Europa ist es außerdem schwierig, Fördermittel für gentechnische Forschung zu erhalten, selbst wenn in einigen Fällen (d.h. bei gewissen Nährstoff-Pflanzen-Kobminationen) die Möglichkeiten klassischer Züchtung ausgeschöpft sind (Dubock, N2). Ein Problem stellen auch begrenzte Laufzeiten der Fördermittel und der Erwartungsdruck der Geldgeber dar, was die Durchführung langfristiger Forschungsprojekte erschwert (N2, Broadley); greifbare Ergebnisse in den Zielgruppen sind nicht unmittelbar möglich. Die gegenwärtige Verwaltung und Struktur der Förderprogramme erschwert zudem die Finanzierung interdisziplinärer Forschungsprojekte, insbesondere zwischen Agrar- und Ernährungswissenschaftlern (Beebe, 8 gemeinsam). Forschungsförderung durch private Firmen ist auch gering, da deren Fokus noch auf Ertragssteigerungen abzielt und Qualitätsmerkmale der Pflanzen bisher nur eine untergeordnete Rolle spielen (Krämer). Auf öffentlicher Seite gibt es jedoch oft keine Erfahrung und wenig Förderung, um Erkenntnisse aus Modellpflanzen oder erste Machbarkeitsstudien in praktischen Anwendungen weiterzuverfolgen (Cahoon, Potrykus). Außerdem sind die Entlohnungs- und Förderanreize in der Wissenschaft zu unflexibel und – da nur Forschungsergebnisse mit Neuheitswert in Fachzeitschriften veröffentlicht werden können – nur auf neue Entdeckungen (im Gegensatz zu Produktentwicklung) angelegt. Hier müssen Lösungen gefunden werden, um auch gesellschaftlich wertvolle Weiterentwicklungen solcher Entdeckungen zu finanzieren und den beteiligten Wissenschaftlern Karriereperspektiven zu eröffnen (Dubock). Eine andere Möglichkeit, langfristig Humankapital zu schaffen, für Kontinuität der Entwicklung in den Zielländern zu sorgen und den internationalen Austausch zu fördern, besteht in der Finanzierung von Stipendien für Studenten und Forscher aus Entwicklungsländern (Dubock).

Konkrete offene Fragen, bei denen die Experten noch Forschungsbedarf sehen, gibt es im Bereich der Pflanzenkunde auf molekularer und genetischer Ebene, wo das Verständnis der Anreicherung und Steuerung der Mikronährstoffe in den Pflanzen noch weiter entwickelt werden muss (Krämer, Clemens); die Rolle der Umwelteinflüsse auf die Anreicherung ist ebenfalls genauer zu untersuchen (Barry), wie auch mögliche Toxizität (Krämer). Ferner müssen die Mechanismen, die die Bioverfügbarkeit von Mikronährstoffen in der täglichen Ernährung der Zielgruppen steuern, weiter erforscht werden (Welch); zusätzliche Erkenntnisse der potenziellen Wirksamkeit von BAP sind auch nötig, um aufwendige Fütterungsversuche mit Menschen zu rechtfertigen (N2). Um die Wirksamkeit der BAP zu erhöhen, d.h. um hohen Mikronährstoffgehalt in die Pflanzen zu züchten, mangelt es an Technologien zur schnellen und preiswerten Bestimmung und Selektion der Züchtungslinien, insbesondere auch hinsichtlich der Bioverfügbarkeit der enthaltenen Mikronährstoffe (Clemens, Rai, Barry); bisher wurde die bestehende natürliche Variabilität verschiedener Sorten noch nicht umfassend erfasst (Krämer).

Für die Weiterentwicklung der BAP fehlt Forschern die Erfahrung (Potrykus). Praktische Probleme bestehen ferner in mangelnder eigener Kapazität, Feldversuche mit BAP durchzuführen; es fehlt auch an finanzieller Unterstützung um den Mikronährstoffreichtum in eine Vielzahl örtlicher und ertragreicher Sorten einzuzüchten (Sayre, Krawinkel). Hierbei besteht eine Abhängigkeit von den nationalen landwirtschaftlichen Forschungssystemen oder auch von privaten Saatgutfirmen (Rai). Während die nationalen Programme prinzipiell Erfahrung mit dieser Art von Arbeit haben, sind sie oft unterfinanziert und es mangelt an Personal und Kapazitäten (Beebe, 8 gemeinsam), was teilweise jedoch durch verhältnismäßig kleine Investitionen gelöst werden kann (Dubock). Überdies ist die Einbindung der biologischen Anreicherung in bestehende Programme zur Produktivitätssteigerung nicht von sich aus gegeben (8 gemeinsam). Der Schritt von der wissenschaftlichen Forschung und Entwicklung einer BAP zur tatsächlichen Züchtung entsprechender Sorten für die Verbreitung vor Ort ist jedoch entscheidend für die Wirksamkeit biologischer Anreicherung. In ähnlicher Weise gibt es in vielen Zielländern auf der ernährungswissenschaftlichen Seite Engpässe und mangelnde Kapazitäten bei der Analyse von Blutproben und der Messung der Bioverfügbarkeit der Nährstoffe, was dazu führt, dass die Proben außer Landes geschickt werden müssen; dies bringt weitere Probleme mit sich (8 gemeinsam, Beebe). Schließlich müssen weitere Wirksamkeits- und Akzeptanzstudien durchgeführt werden (De

Groote), und bei GV-BAP sind die Richtlinien zur Biosicherheit zu beachten und entsprechende Studien durchzuführen.

Im Zusammenhang mit der Regulierung von GV-Pflanzen sehen die meisten Experten erhebliche Probleme für die erfolgreiche Entwicklung und Einführung von BAP – insofern diese durch Einsatz der Gentechnik entwickelt werden (Krämer, Dubock). Hürden bestehen dabei sowohl bei der Entwicklung der Pflanzen wie auch bei deren Verbreitung, in den Entwicklungsländern selber wie auch in den Industrieländern. So ist es den Experten in Europa nahezu unmöglich, GV-Pflanzen in Feldversuchen zu testen (Clemens), aber auch in den USA ist es für die Experten schwierig, die regulatorischen Hindernisse für biotechnologische Forschung zu überwinden (N1), was auch an den Kosten liegt, die die Zulassungsverfahren mit sich bringen. Dies führt dazu, dass große Konzerne neue GV-Pflanzen zulassen können, dies kleineren Organisationen oder Universitäten jedoch nahezu unmöglich ist (Cahoon). Die eingeschränkte Nutzbarkeit relevanter Technologien aufgrund geistiger Eigentumsrechte stellt ein anderes Hindernis für die Entwicklung von BAP für Kleinbauern in Entwicklungsländern dar (Krawinkel, Cahoon). In Entwicklungsländern selber besteht hingegen das Problem, dass viele über keine Biosicherheitsbestimmungen verfügen oder es keine Zulassungsbehörde gibt (De Groote, Sayre, Cahoon), d.h. sowohl Versuche mit GV-BAP wie deren spätere Verbreitung sind derzeit nur begrenzt möglich (8 gemeinsam). Die Notwendigkeit derart aufwendiger und undifferenzierter Zulassungsvorschriften für GV-Pflanzen wird von den Experten kritisch hinterfragt, da es hierfür keine wissenschaftliche Grundlage in Bezug auf Risiken gibt (Dubock, Potrykus, Clemens).

Bei der Verbreitung von BAP sehen die Experten z.T. weniger Probleme, bzw. sie stufen diese als überwindbar ein. Es müssen Partner vor Ort gefunden werden, um eine nachhaltige und lokal gestützte Quelle für das Saatgut aufzubauen und Engpässe bei der Bereitstellung des Saatguts zu verhindern (Sayre, 8 gemeinsam). Hierfür ist oftmals externe Finanzierung notwendig, um die lokalen Partner zu unterstützen (8 gemeinsam); die Notwendigkeit solche Aktivitäten zu unterstützen wird von Geldgebern nicht immer richtig eingeschätzt (Dubock). Während in einigen Ländern die Saatgutproduktion und -verteilung gut entwickelt ist (Rai), besteht in anderen Ländern die Möglichkeit nichtstaatliche Organisationen und Bauernverbände in die Saatgutverbreitung mit einzubeziehen (Beebe). Und um neues, zertifiziertes Saatgut auch Kleinbauern zugänglich zu machen, kann es in kleinen, preiswerten (oder subventionierten) Packungsgrößen vertrieben werden – denn es gilt vor allem auch Subsistenzbauern zu erreichen, die aus Risikoscheu und Kostengründen und oftmals eigenes Saatgut von Jahr zu Jahr nachbauen (8 gemeinsam, Beebe). In diesem Zusammenhang müssen innovative Landwirte vor Ort in die Verbreitung eingebunden werden (8 gemeinsam). Für maximale Wirksamkeit der BAP muss erreicht werden, dass Mikronährstoffreichtum eine Voraussetzung für die Zertifizierung neuen Saatguts wird (8 gemeinsam, Rai); derzeit ist sie für Saatgutfirmen kein Kriterium (Krämer). Insofern Regierungen den Anbau von Exportpflanzen fördern, müssen auch diese von der Relevanz der Ernährungssicherung durch BAP überzeugt werden (8 gemeinsam).

Zwar ist die primäre Zielgruppe biologischer Anreicherung die ländliche Bevölkerung, die BAP zum Teil für den Eigenkonsum anbaut (Beebe), doch ist auch eine kommerzielle Weiterverbreitung von BAP möglich. In diesem Fall sehen die Experten die Hindernisse darin, dass entsprechende Vertriebswege sowie die Produkte erst noch entwickelt werden müssen (Broadley). Da gerade die Zielgruppen über keine oder nur geringe Zahlungskraft verfügen (Cahoon), es ohne Gewinnaussichten jedoch keine Förderung der BAP durch den privaten Sektor geben wird

(Welch), müssen bei der Schaffung der Produkte nationale Agrarforschungsinstitute und nichtstaatliche Organisationen ggf. finanziell unterstützt werden (Sayre). Zur Erhaltung einer größtmöglichen Wirksamkeit gilt es, die Produkte ohne übermäßige Vermischungen mit "normalen" Nahrungspflanzen zu den Zielgruppen zu bringen; hierfür können spezifische Lieferketten aufgebaut werden (z.B. über Schulspeisungen oder Regierungsläden) (8 gemeinsam, Beebe). Weitere Probleme können bei GV-BAP entstehen, die mit Hilfe geschützten geistigen Eigentums entwickelt wurden und wofür die Lizenzgebühren (nur) für humanitäre Zwecke erlassen wurden (8 gemeinsam).

Was die Annahme der BAP durch die Landwirte angeht, sehen die Experten allgemein weniger Probleme – unter der Prämisse, dass der Nährstoffreichtum den Ernteertrag nicht schmälert und BAP als beliebte und lokal angepasste Sorten erhältlich sind (Beebe, Cahoon); BAP mit zusätzlichen ackerbaulichen Vorteilen können ihre Annahme noch weiter fördern (Potrykus). Hingegen dürfen BAP nicht weniger gewinnbringend sein als beliebte konventionelle Sorten (8 gemeinsam), d.h. in Fällen, in denen Ertragsverluste in BAP unumgängliche sind, müssten die Landwirte kompensiert werden (Rai). Und wenn die biologische Anreicherung über Düngung erzielt wird, dürfen die Zusatzkosten für das Düngemittel die Gewinne, die durch höhere Erträge entstehen, nicht übersteigen (Broadley); ggf. sind staatliche Subventionen nötig (Welch). Neben ackerbaulichen Beratungsmaßnahmen in Bezug auf BAP (Sayre) können zu einem gewissen Grad auch spezifische Aufklärungskampagnen zu den Gesundheitsvorteilen der BAP helfen, deren Annahme durch die Landwirte – die immer zugleich auch Konsumenten sind – zu erleichtern, insbesondere wenn die BAP farbliche Veränderungen aufweisen (wie im Fall von betakarotinreichen Pflanzen) oder wenn sie gentechnisch verändert sind (8 gemeinsam). Hierfür ist wiederum die Zusammenarbeit unterschiedlicher Akteure sowie externe finanzielle Unterstützung nötig (Dubock).

Die Akzeptanz der BAP vom Blickwinkel der Konsumenten stellt für die Experten denn auch teilweise ein größeres Hindernis dar (Krämer). Während bei farb- und geschmacksneutralen Veränderungen in den BAP (wie bei der Anreicherung mit Eisen und Zink) keine Akzeptanzprobleme erwartet werden (Beebe, Rai), so ist die Akzeptanz von wahrnehmbar andersartigen BAP nicht selbstverständlich (8 gemeinsam, Krawinkel). Dies trifft auch auf BAP zu, die mit Hilfe der Gentechnik gezüchtet wurden. In diesen Fällen sehen die Experten die Notwendigkeit, Aufklärungs- und Informationsmaßnahmen zu fördern (Sayre). Insbesondere muss der Nutzen der BAP klar und nachvollziehbar vermittelt werden (Potrykus, Beebe, Rai) – und zwar auf lokaler Ebene und durch Personen und Kanäle, denen die Konsumenten in Gesundheitsfragen vertrauen (Welch, Barry). In diesem Fall können andersfarbige BAP ggf. als höherwertige Produkte wahrgenommen und akzeptiert werden (8 gemeinsam). Für solche Aktivitäten sind jedoch Kompetenzen nötig, die im öffentlichen Bereich wenig zu finden sind und von deren Finanzierung Geldgeber erst überzeugt werden müssen (Dubock). Zudem steht einer erfolgreichen Informationskampagne oftmals die (irrationale) Gentechnik-Diskussion im Wege – nicht nur in den Entwicklungsländern, sondern auch in Industrieländern (N1, Clemens, Dubock, Broadley), wo Wissenschaftler die zu GV-Pflanzen arbeiten z.T. von öffentlichen Verunglimpfungen betroffen sind. Insofern sehen die Experten hier allgemeinen Aufklärungsbedarf.

4.2 Gebiete auf denen Unterstützung für biologische Anreicherung sinnvoll ist

Im Bereich der Grundlagenforschung sehen die Experten viel Potenzial für Unterstützung, da die Möglichkeiten, den Nährwert von Nahrungspflanzen durch Züchtung zu steigern erst seit Kurzem erforscht werden. Insbesondere die markergestützte Selektion und die Gentechnik sind entwicklungsfähig und förderungswürdig (8 gemeinsam, Dubock). Hierfür müssen wirtschaftlichere Analyse- und Testverfahren sowie Marker entwickelt werden, um mikronährstoffreiche Pflanzen bei den Züchtungsbemühungen schnell bestimmen zu können (Rai, Barry, Clemens, Krämer). Außerdem ist es notwendig, im Bereich der Pflanzenphysiologie, Biochemie und Genetik die Mechanismen zu verstehen, die den Mikronährstoffgehalt in Pflanzen (auf molekularer Ebene) steuern und zu verstehen, wie der entsprechende pflanzliche Stoffwechsel beeinflusst werden kann (Clemens, Krämer, Beebe, Markert); hierbei ist auch die Rolle von Umwelteinflüssen zu klären (Beebe). In den Ernährungswissenschaften ist weitere Arbeit zu Hemmstoffen und Promotoren der Aufnahme von Nährstoffen bzw. deren Interaktion vielversprechend, um deren Absorptionsfähigkeit zu verbessern (8 gemeinsam, Welch, Beebe), wie auch die Rolle der Mikrobiota bei der Absorption weiterer Forschung bedarf (Welch). Um sicherzustellen, dass der Verzehr von BAP in normalen Portionen ausreichend Nährstoffe liefert, ist außerdem Forschung zu deren Erhaltung bei der Verarbeitung der BAP nötig, ggf. auch durch Rückgriff auf gentechnische Verfahren (Sayre). In allen Bereichen und auf allen Ebenen muss interdisziplinäre Forschung gefördert werden (Welch); die geschätzten Kosten für eine breitangelegte internationale Bemühung um die Entwicklung nährstoffreicher und dürreresistenter Grundnahrungspflanzen (angewandte Forschung auf internationalem Niveau sowie Wirksamkeitsstudien der Pflanzen vor Ort) liegen bei 500 Millionen Dollar (N1).

Bei der angewandten Forschung müssen Machbarkeitsstudien durchgeführt und Prototypen entwickelt werden, um spezifische Gene auf ihre Auswirkungen auf die Anreicherung der Nährstoffe zu testen (Krämer), wobei jedoch nicht übersehen werden darf, dass es noch ein langer Weg von einer Machbarkeitsstudie zu einer alltagstauglichen Anwendung ist (Potrykus). Zusätzliche Finanzierung für Übertragung der Erkenntnisse von Modellpflanzen auf Nutzpflanzen kann helfen, die Entwicklung der BAP zu beschleunigen (Cahoon). In Feldversuchen muss untersucht werden, welche Rolle Umwelteinflüsse auf den Mikronährstoffreichtum in Pflanzen habe (Beebe). Angewandte Züchtung sollte an internationalen Agrarforschungszentren stattfinden, auch wenn diese auf Länder mit großen Anbauflächen ausgerichtet sein kann (Rai). Allerdings gibt es Engpässe bei den Versuchsflächen und bei anderen Ressourcen sowie bei der Kooperationsbereitschaft nationaler Zentren um die Züchtung vor Ort zu beschleunigen (8 gemeinsam). Die Durchführung von Feld- und Fütterungsversuchen ist notwendig, um die Wirksamkeit der BAP zu belegen (Sayre). Neben diesen Belegen ist im Ernährungsbereich auch die Validierung von Tiermodellen ist nötig um die Bioverfügbarkeit von Nährstoffen vergleichbar zu machen (Barry). Allerdings sind weitergehende Versuche mit menschlichen Testpersonen erforderlich, um die tatsächlichen Auswirkungen der BAP auf den Gesundheitszustand zu bewerten; Blutproben alleine genügen nicht. Zudem müssen Studien durchgeführt werden die Essgewohnheiten und Ernährungsvorlieben mit einbeziehen und somit die Voraussetzung für Aufklärungsmaßnahmen zur Verhaltensänderung schaffen (N2); diese Versuche und Studien sollten in den Zielländern durchgeführt werden (N1). Schließlich müssen auch die Auswirkungen der Verarbeitung der BAP auf Gehalt und Bioverfügbarkeit der Mikronährstoffe untersucht werden (Welch).

Im Zusammenhang dieser Forschungsbemühungen sollten internationale Zusammenarbeit und Wissenstransfer in der Molekulargenetik und -physiologie angestrebt werden (Krämer). Um Kollaborationen zu fördern und insbesondere um Wissenschaftlern aus Entwicklungsländern zu Weiterbildungszwecken Aufenthalte in fortschrittlichen Labors zu ermöglichen, ist finanzielle Unterstützung nötig (Barry, Sayre); dies könnte durch die Schaffung von gezielten Promotionsstipendien für Doktoranden aus Entwicklungsländern geschehen (Dubock). Durch solche Weiterbildungsmaßnahmen und die Mitnahme von Material und Technologien bei der Rückkehr (zur Weiterentwicklung der BAP mit heimischen Sorten) kann in den Zielländern Teilhabe an den Projekten erreicht werden (Sayre); Zusammenarbeit auf dem nationalen Niveau ist insbesondere nötig, um solche angewandten Aufgaben durchzuführen (N1). In anderen Fällen können die Zielländer mehr Kompetenz aufweisen als die Geberländer, so haben Ernährungswissenschaftler in Lateinamerika z.B. ein stärkeres Bewusstsein für die öffentliche Gesundheitspflege als ihre Kollegen in Europa oder den USA (Beebe). In Bezug auf den Einsatz der Gentechnik gilt es hingegen durch massive Bildungs- und Informationsarbeit sowohl in Entwicklungs- wie auch in Industrieländern eine Aufklärung der Bevölkerungen zu erreichen (N1).

Für eine erfolgreiche Durchführung biologischer Anreicherung stellen auch die vorhandene Infrastruktur und die Einrichtungen im Bereich der Molekularbiologie sowie die Labors und Gewächshäuser für kontrolliertes Pflanzenwachstum, die zur Entwicklung von GV-Pflanzen nötig sind, Engpässe dar (Krämer). Für die weitergehende Produktentwicklung und Deregulierung der Pflanzen gibt es im öffentlichen Dienst keine Infrastruktur (Potrykus). In den Zielländern müssen die nationalen Agrarforschungszentren Kapazitäten zur Sichtung, Analyse und Selektion neuer Pflanzen aufbauen (Rai, Barry), insbesondere hinsichtlich ihrer Nährstoffkonzentration (8 gemeinsam, De Groote). Dies beinhaltet auch die Ausbildung des Personals und die Gewährleistung der Funktionstüchtigkeit der Einrichtungen in den Zielländern (Beebe, Barry). Für die Züchtung von GV-Pflanzen sind in den Zielländern auch Investitionen nötig, um entsprechende Einrichtungen aufzubauen, die den gesetzlichen Anforderungen gerecht werden (Dubock). In Zielländern, wo die gesamte Infrastruktur aufgebaut werden muss (Labors, Personal, Ausstattung, Material), ist langfristiges finanzielles Engagement nötig; auch der Aufbau landwirtschaftlicher Beratungsprogramme wäre ein wertvoller Beitrag (Sayre).

Im Bereich der Ernährungswissenschaften werden Einrichtungen benötigt, die Nährstoffe, Hemmstoffe, Promotoren und andere Einflussgrößen auf die Bioverfügbarkeit in der üblichen Kost der Zielgruppen identifizieren und quantifizieren können (Welch). Neben dem allgemeinen Aufbau der Kapazität zu Feldversuchen in beiden Bereichen (N1) sollte insbesondere die Analyse biologischer Proben (von Pflanzen sowie von Menschen) möglich sein (8 gemeinsam). In den einzelnen Projekten gibt es darüber hinaus weitere, spezifische Anliegen, deren Finanzierung helfen könnte, zur Lösung des Welternährungsproblems beizutragen (z.B. die Entwicklung von Saatgut für Maniok oder die Stapelung (Engl. "stacking") mehrerer Qualitätsverbesserungen in einer Pflanze) (Sayre).

Schließlich sehen die Experten auch im institutionellen und politischen Bereich Handlungsbedarf. So ist es notwendig, dass in der nationalen wie internationalen Agrarpolitik das Ziel einer Verbesserung der Ernährung explizit verfolgt wird, und dass den Akteuren im Bereich der Ernährungswissenschaften und des Gesundheitswesens nahegelegt bzw. vorgegeben wird, auch mit landwirtschaftlichen Ansätzen zu arbeiten, um Lösungen für das Welternährungsproblem zu finden (Welch), bzw. das Verständnis der jeweiligen Stärken der verschiedenen Disziplinen muss gefördert werden (8 gemeinsam). Unterstützung für biologische Anreicherung sollte im Rahmen eines weiter gefassten Konzepts zur Ernährungssicherung erfolgen (Broadley). Bündnisse wie HarvestPlus können dabei helfen, landwirtschaftliche Ansätze in Gesundheits- und Ernährungskreisen bekannt zu machen (Barry). Fürsprache ist auch wichtig, um bei den entsprechenden Akteuren in den Zielländern eine Teilhabe an der Technologie zu geben (8 gemeinsam) und um Identifikationsfiguren zu überzeugen als Verfechter der BAP zu wirken (Sayre). Auch Politiker in den jeweiligen Ländern müssen besser über biologische Anreicherung aufgeklärt werden, damit sie diese auf die Tagesordnung setzen (Beebe). Weitere Wirksamkeitsstudien können hierbei helfen (De Groote). Denn der Schlüssel für den Erfolg der biologischen Anreicherung liegt in der Unterstützung von staatlicher Seite – darauf aufbauend können die nächsten Schritte erfolgen; eine Abstimmung zwischen den Landwirtschafts- und Gesundheitsministerien ist dabei unerlässlich (8 gemeinsam). Insgesamt ist beim Herangehen an die biologische Anreicherung ein systemischer Blickwinkel nötig, der Produktion, Verarbeitung, individuellen Verbrauch, Erziehung und Aufklärung sowie die Regierungspolitik umfasst (Welch).

Die Auslieferung der verbesserten Pflanzensorten ist ein bisher weniger berücksichtigter Bereich – so haben in der Vergangenheit manche Verbesserungen nie die Landwirte oder Verbraucher erreicht. Die Auslieferung der BAP bedarf daher zusätzlicher Investitionen, z.B. um Saatgutsysteme und durchführbare Vertriebsstrategien zu entwickeln, auch die Akzeptanz durch die Konsumenten darf nicht ignoriert werden (De Groote); diesem Teil der Bemühungen um biologische Anreicherung muss mehr Beachtung geschenkt werden, da er mindestens so wichtig ist wie die eigentliche Entwicklung der BAP (8 gemeinsam). Öffentlich-private Partnerschaften können dabei eine wichtige Rolle spielen, da dem öffentlichen Sektor das für die Produktentwicklung und Deregulierung nötige Wissen fehlt, nicht zuletzt weil sich öffentliche Einrichtungen, die ursprünglich wissenschaftliche Erkenntnisse in brauchbare Anwendungen umsetzen sollten, mehr dem akademischen Bereich zuwenden. Doch bei öffentlich-privaten Partnerschaften muss beiderseitiges Interesse bestehen, öffentliche Güter haben der Privatwirtschaft aber wenig zu bieten (Potrykus). So ist das Potenzial einer solchen Zusammenarbeit zu diesem Zeitpunkt auch schwer einzuschätzen (8 gemeinsam).

Große politische Verantwortung sehen die Experten bei der Regulierung und öffentlichen Diskussion der Gentechnik. Für GV-BAP gibt es in den Zielländern eine Unzahl rechtlicher Komplikationen, die es so für klassisch gezüchtete BAP nicht gibt (8 gemeinsam). Während die Regierungen die Sicherheit neuer Pflanzen gewährleisten müssen (und z.B. Qualitätsstandards und eine Kennzeichnung für BAP einführen können (De Groote)), so müssen Regulierungen doch rational sein und auf einer wissenschaftlichen Basis aufbauen (Cahoon). Die Zulassungsverfahren müssen gestrafft und beschleunigt (bzw. erst geschaffen) werden, z.B. unter Führung der Weltgesundheitsorganisation (N1), oder indem ein internationaler Konsens erzielt wird, der es erlaubt, transgene Konstrukte anstatt spezifischer Transformationsereignisse zuzulassen (Sayre). Gegenwärtig ist eine rationale Verständigung zu Ernährungssicherung und Lebensmittelqualität kaum möglich, teilweise auch aufgrund von (vom wissenschaftlichen Standpunkt aus) absurder Gesetzgebung und politischer Signale in Bezug auf GV-Nahrungsmittel, die oftmals von ideologisierten Interessengruppen gefördert werden (Clemens, Dubock). Die Politik sollte hingegen alle Agrartechnologien fördern, die das Nahrungsangebot verbessern und erweitern können und ausreichend auf Sicherheit getestet sind, insbesondere – auch um vergangene Versäumnisse zu kompensieren – die grüne Gentechnik. Denn wenn auch bisher vor allem

Entwicklungsländer von den Konsequenzen der europäischen Haltung betroffen waren, so ist auch die landwirtschaftliche und wissenschaftliche Konkurrenzfähigkeit Europas bedroht (Dubock).

4.3 Mögliche Beiträge deutscher und europäischer Akteure

Neben den im vorigen Abschnitt angesprochenen Gebieten (Barry, Sayre) sehen die Experten z.T. auch spezifische Bereiche, wo deutsches Engagement besonders hilfreich sein könnte. Zunächst kann Deutschland finanzielle Hilfe leisten, insbesondere durch die Unterstützung etablierter Programme oder Projekte, z.B. durch Zusammenarbeit mit der Gates Stiftung (N1), durch die Förderung der entsprechenden Zentren des CGIAR (De Groote, Rai), oder durch die Unterstützung regionaler Netzwerke (Beebe). In Deutschland selber sollte die Arbeit zu goldenem Reis an der Universität Freiburg bzw. das "Golden Rice"-Projekt bei der Produkteinführung gefördert werden (Potrykus, Dubock). Auch aussichtsreiche Grundlagenforschung sollte finanziert werden, wie Pflanzenmechanismen (Clemens) und – anhand von Modellpflanzen – molekulare Physiologie und Genetik, um die Anreicherungswege von Mikronährstoffen und deren Steuerung besser zu verstehen; die Selbstregulation von Metallen stellt ein weiteres Gebiet dar (Krämer). Ferner sollten bestehende Stärken genutzt und ausgedehnt werden, wie die natürliche Vielfalt bei Pflanzen (wie Gerste und Weizen), für die Deutschland über umfangreiche Sammlungen pflanzengenetischen Materials und genetischer Ressourcen verfügt (Krämer). Doch Deutschland kann auch in vielen Zielländern einen Beitrag leisten, etwa aufgrund seiner Präsenz vor Ort und seiner Kenntnisse des Agrarsektors – ein Ansehen, das auf die Priorisierung der Lebensmittelqualität (inklusive Gemüse und Früchten) verwendet werden sollte (8 gemeinsam, Krawinkel). Des Weiteren ist aber auch Unterstützung derjenigen Länder nötig, für die Mangelernährung belegt ist, die bisher jedoch noch nicht in entsprechende Bemühungen eingebunden sind (Beebe); dies trifft insbesondere auf Afrika zu (N1, Sayre). Außerdem kann es sich als nützlich erweisen, zukünftigen Maßnahmen den Weg zu bereiten und z.B. die Überprüfung der Ernährungsgewohnheiten in Zielregionen zu finanzieren (Beebe).

Deutschland kann auch durch internationale Kooperationen zur erfolgreichen Umsetzung biologischer Anreicherung beitragen; dies kann insbesondere durch Partnerschaften, Austauschprogrammen und die Finanzierung von Weiterbildungsmaßnahmen von Wissenschaftlern aus den Zielländern erfolgen, bzw. durch die Entsendung junger Wissenschaftler in die Zielländer (Sayre, Cahoon, Beebe). Da die nationalen Programme nur geringe Kompetenz in Pflanzenernährung haben, wären entsprechende universitäre Ausbildungsangebote sinnvolle, solange sie praxisorientiert sind (Beebe); dies trifft auch auf die Ernährungswissenschaften zu (Krawinkel), wo die Ausbildung auf öffentliche Gesundheitspflege ausgerichtet sein sollte und nicht auf klinische Ernährung (Beebe). Im Bereich der Pflanzenzüchtung und der Gentechnik schreckt das politische Umfeld hingegen womöglich potenzielle Studenten vor einem Engagement ab (Potrykus). Nichtsdestotrotz haben deutsche Einrichtungen wie die Universität Freiburg oder die Max-Planck-Institute im Bereich der Nutrigenomik viel zu bieten und können bei der Identifizierung und dem Verständnis der molekularen und biochemischen Mechanismen der Gene helfen, die die Eisen- und Zinkniveaus oder die Synthese von Provitamin A regulieren; die Ergebnisse dieser Arbeit können bei der markergestützten Selektion oder der Bestimmung von Genen für den Gentransfer helfen (8 gemeinsam). Auch bei der Metabolomik von Nährstoffen könnten deutsche Einrichtungen wertvolle Forschungsarbeit leisten (8 gemeinsam, Beebe), wie auch bei der Pflanzenernährung (Beebe). Manche Arbeiten, z.B. für die Stapelung neuer Pflanzeneigenschaften, sind auch am besten in fortschrittlichen Labors in Europa oder den USA durchführbar (Sayre). Schließlich können auch innerhalb Europas die Forschungsnetzwerke gestärkt werden, z.B. um das molekular-genetische Verständnis der Selbstregulation von Metallen zu verbessern, für die Bestimmung und Selektion der natürlichen Vielfalt der Mikronährstoffanreicherung in Nutzpflanzen oder um die Sammlungen pflanzengenetischen Materials zu ergänzen (Krämer). Ganz allgemein kann Deutschland die gemeinschaftliche Forschung im Bereich der Agrar-, Ernährungs- und Lebensmittelwissenschaften auch auf internationaler Ebene fördern und dabei helfen, dass die treibenden Kräfte im Gesundheitswesen und der Landwirtschaft zusammenarbeiten (Welch, 8 gemeinsam).

5 Schlussfolgerungen – Die Rolle biologischer Anreicherung

In den vorangehenden Kapiteln wurde die Schwere des Welternährungsproblems beschrieben, wobei insbesondere die Relevanz des Mikronährstoffmangels hervorgehoben wurde. Nach einer allgemeinen Hinführung zu Maßnahmen, die gegen diese Form der Mangelernährung eingesetzt werden, wurde ein neuer Ansatz, die "biologische Anreicherung", anhand der in der Literatur genannten Stärken und Schwächen diskutiert und es wurden die Ergebnisse einer Expertenbefragung hinsichtlich der nächsten Schritte bei der Entwicklung dieses Ansatzes wiedergegeben. Unter biologischer Anreicherung werden im Allgemeinen alle landwirtschaftlichen Maßnahmen verstanden, die dazu dienen, die Bioverfügbarkeit oder Nährstoffdichte in Nutzpflanzen zu erhöhen, um Mangelernährung vorzubeugen. Im Einzelnen wird darunter vor allem die entsprechende Züchtung der Pflanzen verstanden, wobei biologische Anreicherung teilweise auch durch den Einsatz von Düngemittel erreicht werden kann.

Mikronährstoffmangel ist ein ernsthaftes Problem, das für die betroffenen Individuen teilweise schwerwiegende gesundheitliche Folgen bis hin zum Tod hat und insbesondere bei Kindern die körperliche und geistige Entwicklung hemmt, d.h., die Betroffenen können ihr menschliches Potenzial nicht ausschöpfen. Dies führt dazu, dass Mikronährstoffmangel – über das Leiden der einzelnen Betroffenen hinaus – auch gravierende und langfristige Folgen für die gesellschaftliche Entwicklung derjenigen Länder hat, wo diese Mangelerscheinungen verbreitet sind, da bei einer Vielzahl von Mangelernährten auch die gesamtwirtschaftliche Leistungskraft deutlich geschwächt wird. Da weltweit Milliarden Menschen an diversen Mikronährstoffmangelerscheinungen leiden, stellen Mikronährstoffdefizite auch ein beachtliches Hindernis für die Erreichung der Millennium-Entwicklungsziele der Vereinten Nationen dar. Maßnahmen zu ergreifen, um diese Form der Mangelernährung zu lindern, ist somit aus humanitärer, wirtschaftlicher und politischer Sicht nicht nur gerechtfertigt sondern, von höchster Priorität.

Es gibt eine Reihe von Maßnahmen, die gegen Mikronährstoffmangel eingesetzt werden können. Diese erstrecken sich von der gezielten Abgabe pharmazeutischer Mikronährstoffpräparate zur Behandlung oder Vorbeugung in ausgewählten Zielgruppen, über großflächige (industrielle) Anreicherung von Nahrungsmitteln mit Mikronährstoffen zur Erreichung der breiten Bevölkerung bis hin zu langfristigen Bemühungen um allgemein ausgewogene Ernährung durch Erweiterung der Alltagskost. Diese Maßnahmen haben alle ihre Stärken und Schwächen, bzw. sie unterscheiden sich hinsichtlich der Zeitspanne, innerhalb derer Ergebnisse erzielt werden können, der hierfür nötigen Infrastruktur und der sich daraus ergebenden Reichweite und geographischen Abdeckung, der durch sie erzielbaren Steigerung der Mikronährstoffaufnahme, der Anzahl der mitwirkungspflichtigen Akteure – und nicht zuletzt auch der absoluten und relativen Kosten. Aus dieser Auflistung ist leicht ersichtlich, dass es auch im Bereich des Mikronährstoffmangels keine Allheilmittel gibt, sondern allenfalls sich gegenseitig ergänzende und teilweise überschneidende Maßnahmen, deren Einsatz auf die Situation im jeweiligen Zielland abgestimmt werden muss.

Zwar gibt es das Ideal, dass sich alle Menschen ausreichend und ausgewogen zu ernähren vermögen (weil sie sich eine diversifizierte Kost leisten können, weil sie die Zeit und andere Ressourcen haben um z.B. einen Küchengarten zu unterhalten oder Wildpflanzen zu sammeln, weil sie über das notwendige Ernährungswissen verfügen und auch weil sie bereit sind ihr Ernährungsverhalten entsprechend zu ändern), doch ist die großflächige Umsetzung dieses

Ideals aufwendig und kurz- bis mittelfristig nicht realistisch: Momentan ist selbst die Erreichung der von der Staatengemeinschaft gesetzten Millennium-Entwicklungsziele sehr fraglich; zumindest hat der Generalsekretär der Vereinten Nationen, Ban Ki-Moon, noch im Vorwort des diesjährigen Berichts zu den Millennium-Entwicklungszielen geschrieben, "wir sind zu langsam vorangegangen um unsere Ziele zu erreichen" (UN 2009: 3)[3] – und das obwohl seinerzeit die Staats- und Regierungschefs versprochen hatten, dass sie "keine Mühen scheuen" würden, um diese Ziele zu erreichen (UNRIC 2000). In ähnlicher Weise werden erst fünf der wirtschaftlich entwickelten Staaten (Dänemark, Luxemburg, die Niederlande, Norwegen und Schweden) dem bereits 1970 in der Vollversammlung der Vereinten Nationen gemachten Beschluss gerecht, bloße 0,7 Prozent ihres Bruttosozialprodukts für die Entwicklungszusammenarbeit auszugeben (UN 1970, OECD 2009).

Vor diesem Hintergrund wird deutlich, dass selbst bei einer erheblichen Aufstockung der Hilfe bei der Wahl der Maßnahmen zur Linderung des Mikronährstoffmangels nicht nur ihre Effektivität, sondern auch ihre Effizienz bzw. Wirtschaftlichkeit in Betracht gezogen werden muss, d.h., es ist nicht nur wichtig zu fragen, ob eine Maßnahme wirkt, sondern es muss gefragt werden, wie viel Wirkung – in diesem Fall bessere Ernährung und Gesundheit – jeder für eine Maßnahme ausgegebene Euro erzielen kann. Im Hinblick auf eine regionale und generationsübergreifende Balance kann oder sollte zudem auch die räumliche und zeitliche Reichweite der Maßnahmen berücksichtigt werden. Die Stärken der biologischen Anreicherung, d.h. insbesondere der Züchtung von Nahrungspflanzen auf ihren Mikronährstoffgehalt hin, setzen genau bei diesen beiden Punkten an:

(1) Selbst wenn auch die Abgabe pharmazeutischer Ergänzungspräparate und die industrielle Anreicherung von Nahrungsmitteln als sehr kostengünstige Maßnahmen in der öffentlichen Gesundheitspflege gelten und ihre Berechtigung haben, so haben eine Reihe von Vorabstudien die potenziell höhere Wirtschaftlichkeit biologisch angereicherter Pflanzen (BAP) bestätigt. Die Effizienz der biologischen Anreicherung erschließt sich auch intuitiv aus der Realisierbarkeit der Skalenerträge: Sind die BAP erst entwickelt, so kann das genetische Material über Ländergrenzen hinweg geteilt und lokal angepasst werden, woraufhin die BAP dann von den Erzeugern Jahr für Jahr angebaut werden können, d.h., die Investition in die Entwicklung einer BAP zieht einen sich ausbreitenden und fortlaufenden Nutzenstrom nach sich. Offensichtlich gibt es diese Art von Skaleneffekten bei biologischer Anreicherung durch Düngung nicht; die Wirtschaftlichkeit dieser Maßnahme sollte noch weiter erforscht werden – so könnten z.B. Ertragsvorteile in der Landwirtschaft, die mit verbesserter Düngung einhergehen, die zusätzlichen Kosten wettmachen.

(2) Während die kontrollierte Abgabe pharmazeutischer Ergänzungspräparate an die Abdeckung des Gesundheitswesens gekoppelt ist und industrielle Anreicherung den regelmäßigen Konsum kontrolliert verarbeiteter Nahrungsmittel voraussetzt – d.h. beide Maßnahmen gehen von der Stadt aus und erstrecken sich mehr oder weniger tief in die ländlichen Gebiete –, geht biologische Anreicherung die entgegengesetzte Richtung: Die BAP werden auf dem Land an-

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[3] "We have made important progress in this effort, and have many successes on which to build. But we have been moving too slowly to meet our goals. And today, we face a global economic crisis whose full repercussions have yet to be felt. At the very least, it will throw us off course in a number of key areas, particularly in the developing countries. At worst, it could prevent us from keeping our promises, plunging millions more into poverty and posing a risk of social and political unrest. That is an outcome we must avoid at all costs."

gebaut, und was nicht von den Erzeugern selbst konsumiert wird, gelangt von dort aus in die Städte. Durch biologische Anreicherung können somit bisher vernachlässigte Bevölkerungsgruppen besser abgedeckt werden. Was den zeitlichen Horizont der Maßnahmen angeht, so füllt biologische Anreicherung eine Lücke zwischen den kurzfristiger implementierbaren (wenn auch regional begrenzten) Maßnahmen, wie pharmazeutischer Ergänzung und industrieller Anreicherung, sowie dem ferneren Ziel einer ausgewogenen Ernährung aller durch Diversifizierung und Verhaltensänderung.

Angesichts der potenziellen Wirtschaftlichkeit biologischer Anreicherung ist zu überlegen, inwiefern der Fokus dieser Maßnahme auf ländliche Gebiete ausgerichtet bleiben soll, und ob er nicht ggf. ausgedehnt werden kann, um auch städtische Zielgruppen günstiger mit mikronährstoffreicher Nahrung versorgen zu können. Doch können und sollen BAP keinen Ersatz der anderen Ernährungsmaßnahmen darstellen, vielmehr müssen die Stärken jeder Maßnahme für die Lösung des Welternährungsproblems genutzt werden. So gilt es bei den BAP, zunächst die Entwicklung weiter voranzutreiben und sie bei Landwirten wie Verbrauchern in den Zielländern erfolgreich einzuführen: Weitere Arbeit zu biologischer Anreicherung mit dem bloßen Hinweis auf fehlende Bewährung dieser – noch neuen – Maßnahme abzulehnen ist gerade in der Forschung wenig zielführend; weiteres Engagement ist durch die positiven Ergebnisse der diversen Vorabstudien und Versuche mit BAP gerechtfertigt. Während auch auf Seiten der Agrarwissenschaften noch Forschungsbedarf besteht hinsichtlich der Steuerung der Anreicherung der Mikronährstoffe in den Pflanzen und der Einflüsse der Umwelt auf die Anreicherung, so sind nun auf Seiten der Ernährungswissenschaften vor allem auch Wirksamkeitsstudien (mit menschlichen Testpersonen unter realistischen Bedingungen) nötig, um Bioverfügbarkeit und Wechselwirkungen der Nährstoffe in BAP zu klären. Neben den logistischen Aspekten der weiteren Züchtung und Erprobung der BAP muss überdies ihre praktische Einführung geplant werden, was neben dem Aus- und Aufbau bestehender Infrastrukturen im landwirtschaftlichen Bereich oder der Sondierung neuer Wege im Bereich der öffentlich-privaten Partnerschaften auch die Kommunikation mit Landwirten und Verbrauchern, mit Akteuren aus dem Agrar- sowie dem Gesundheitsbereich, aber auch mit der Politik in den Geber- wie den Zielländern einschließt.

Da in manchen Fällen biologische Anreicherung durch klassische Züchtung an ihre Grenzen stößt – weil die natürliche Variabilität des gewünschten Nährstoffs in den Pflanzen zu gering ist, weil der gewünschte Nährstoff in den essbaren Teilen der entsprechenden Zielpflanze nicht eingelagert wird oder weil die Pflanzen sich nur schwer klassisch züchten lassen – gibt es auch Projekte, die BAP mit Hilfe der Gentechnik züchten. Während es von wissenschaftlicher Seite aus keine fundierten Argumente gegen den Einsatz dieser Technologie *per se* gibt (die schon seit Jahren in der Produktion von Medikamenten oder der Gentherapie eingesetzt wird, bzw. mit deren Hilfe auch in der Landwirtschaft kommerziell relevante Nutzpflanzen verändert und bereits seit über einem Jahrzehnt angebaut werden), so ist aufgrund der vor allem in Europa herrschenden öffentlichen Unsicherheit in Bezug auf gentechnisch veränderte (GV) Pflanzen rationale Aufklärung nötig: Wenn Forscher im öffentlichen Dienst helfen Pflanzen zu züchten, die das Gemeinwohl in den ärmsten Ländern fördern und Menschen vor den Folgen von Mangelernährung schützen sollen, so mag der Nutzen dieser Pflanzen für den deutschen Verbraucher (der aus den Zeitungen allenfalls landwirtschaftlichen Überfluss kennt) nicht intuitiv erkennbar sein. Es gilt daher das Potenzial der BAP sowie auch die Verantwortung der Gesellschaften in den wirtschaftlich entwickelten Ländern, sich mit diesem Thema rational auseinanderzusetzen, aufzuzeigen und zu kommunizieren. Hier kann und muss auch die Politik eine wichtige Rolle spielen.

Biologische Anreicherung ist eine noch neue Maßnahme im Kampf gegen Mangelernährung, doch erste Ergebnisse deuten darauf hin, dass BAP das Potenzial haben, einen nachhaltigen Beitrag zur Lösung des Welternährungsproblems zu leisten. Eine Förderung der biologischen Anreicherung, sowohl bei der noch andauernden Forschung und Entwicklung sowie auch bei der praktischen Einführung der BAP und ihrer Integration in das Instrumentarium der Ernährungspolitik ist gerechtfertigt. Hierfür ist internationale und interdisziplinäre Zusammenarbeit notwendig – und eine klare politische Anerkennung und Aufwertung der positiven Rolle der Agrarforschung (inklusive aller ihrer Hilfsmittel) beim Kampf gegen Hunger, Armut und Krankheit wäre wünschenswert.

6 Ausblick – Was kann die deutsche Politik tun?

In diesem Gutachten ging es darum, einzuschätzen, welchen Beitrag die biologische Anreicherung zur Lösung des Welternährungsproblems leisten kann – insbesondere hinsichtlich der Dimension des Mikronährstoffmangels. Ausgehend vom Stand der einschlägigen Forschung und Entwicklung, welcher anhand einer umfassenden Literaturübersicht sowie der Auswertung einer Expertenbefragung erarbeitet wurde, wurden zukünftige Forschungsaufgaben, spezifische Restriktionen sowie die Felder identifiziert, in denen besonders relevante und weiterführende Fortschritte und Lösungsbeiträge zu erwarten sind. Während es zum einen durchaus konkrete Bereiche in der angewandten und Grundlagenforschung gibt, in denen neue Erkenntnisse letztendlich auch zu Fortschritten bei der biologischen Anreicherung führen, gerade auch am Schnittpunkt von Agrar- und Ernährungswissenschaften, so wird in diesem Gutachten zum anderen jedoch auch deutlich, dass eine enge Eingrenzung auf reine Forschungsarbeit wenig zielführend ist: Mikronährstoffmangel ist Realität, und somit müssen wissenschaftliche Erkenntnisse auch in der realen Welt getestet und zu konkreten und praxisbezogenen Anwendungen weiterentwickelt werden, die zudem unter Alltagsbedingungen in Entwicklungsländern funktionieren. Die Agrarforschung sowohl in den Entwicklungsländern wie auch auf internationaler Ebene sieht sich jedoch einer steigenden Zahl von (berechtigten und wichtigen) Anforderungen und immer neuen Projekten gegenüber. Dies führt zwangsläufig zu Restriktionen und Engpässen bei Infrastruktur, Ausstattung und Fachpersonal. Im Bereich neuer Technologien gibt es zudem rechtliche und gesellschaftliche Einschränkungen der wissenschaftlichen Handlungsfreiheiten. Vor diesem Hintergrund lassen sich die folgenden übergreifenden Handlungsempfehlungen ableiten:

1. Deutschland hat eine internationale Verantwortung, seinen Beitrag zur Lösung des Welternährungsproblems zu leisten; es gilt, seine spezifischen wissenschaftlichen Kapazitäten, seine allgemeinen finanziellen Möglichkeiten, seine Verbindungen in die Zielländer und sein Ansehen in der Welt einzusetzen, um dieser Verantwortung gerecht zu werden, d.h., dem Thema der Mangelernährung muss politisch ein höherer Stellenwert eingeräumt werden.

2. Die Agrarforschung kann – neben ihrem allgemeinen Beitrag im Kampf gegen Armut und Hunger – durch biologische Anreicherung gerade auch im Bereich des Mikronährstoffmangels einen nachhaltigen Beitrag leisten. Ohne einen Ausbau der Agrarforschung, sowohl an deutschen Forschungseinrichtungen (mit der klaren Zielsetzung der Nutzbarkeit und der interdisziplinären Zusammenarbeit, insbesondere mit den Ernährungswissenschaften, und eingebettet in internationale Kooperationen) wie auch an den seit Jahrzenten vernachlässigten Zentren der Beratungsgruppe für Internationale Agrarforschung (CGIAR), kann den bereits anstehenden und fortwährend wachsenden Herausforderungen der Landwirtschaft (Mangelernährung, Hunger und ländliche Armut einerseits, Bevölkerungswachstum, Klimawandel und zunehmende Ressourcenknappheit in Zukunft) nicht begegnet werden. Die entsprechende Finanzierung der international ausgerichteten Agrarforschung muss deutlich ausgedehnt werden. Entsprechende Zusagen der deutschen Bundesregierung (und auch anderer Regierungen) im Zuge der Ernährungskrise müssen konkretisiert und eingehalten werden.

3. Forschungsförderung in der Landwirtschaft beinhaltet nicht nur Laborforschung, sondern es muss auch berücksichtigt werden, dass überproportional hohe Kosten im Bereich der Produktentwicklung und Zulassung sowie der Verbreitung neuer Pflanzen in den Zielländern entstehen.

Bei der biologischen Anreicherung müssen darüber hinaus neue Strukturen der Zusammenarbeit zwischen Agrarwissenschaftlern und Ernährungswissenschaftlern geschaffen werden, insbesondere um die Wirksamkeit biologisch angereicherter Pflanzen weiter zu erforschen und um die Akteure aus dem Bereich des Ernährungs- und Gesundheitswesens einzubinden. Auch diese Komponenten müssen gefördert werden, wenn die zuvor geförderte Forschung nicht ins Leere laufen soll. Da die Entwicklung und Züchtung der Pflanzen ebenfalls nicht nur in fernen Labors durchgeführt werden kann – und sie dies aus Gründen der Teilhabe und des Kapazitätsaufbaus in den Zielländern auch nicht soll –, ist zudem der Auf- und Ausbau entsprechender (projektunabhängiger) Basiskapazitäten in den nationalen und internationalen Forschungszentren nötig; eine Zusammenarbeit mit fortschrittlichen Forschungseinrichtungen im Rest der Welt ist andernfalls kaum möglich.

4. Neben einer inhaltlichen und Rahmenfinanzierung der Arbeiten zur biologischen Anreicherung bzw. der Agrarforschung insgesamt (auf allen drei Ebenen: Deutschland – international – Zielländer), ist auch eine Förderung des Fachpersonals nötig. Zusätzlich zu dem internationalen Austausch von Wissenschaftlern bzw. der gezielten Ausbildung und Förderungen von Forschern aus Entwicklungsländern in Deutschland, müssen auch deutsche Forscher motiviert werden, an praktischen Anwendungen und Produktentwicklungen im humanitären Bereich zu arbeiten; die bisherigen Karriereperspektiven und (publikationsbezogenen) Anreizstrukturen für Wissenschaftler im öffentlichen Dienst machen ein solches Engagement hingegen uninteressant – und gerade im Bereich der Pflanzenzüchtung sehen sich selbst Wissenschaftler im öffentlichen Dienst, wenn nicht gar mit Anfeindungen, so doch mit öffentlichem Unverständnis hinsichtlich des Nutzens ihrer Arbeit konfrontiert.

5. In diesem Zusammenhang ist die deutsche Politik schließlich gefragt, durch klare Signale und verantwortungsvolle Kommunikation zu einer rationalen und faktenbasierten öffentlichen Auseinandersetzung mit dem Einsatz der Gentechnik auch im Agrarbereich beizutragen. Ausgehend von einer sachkundigen öffentlichen Debatte ist dann auch die Regulierung der grünen Gentechnik auf ihre wissenschaftliche Basis hin zu überprüfen und anderen Technologieanwendungen gleichzustellen. Den Bundesbürgern muss klarwerden, dass das hohe Niveau der Ernährungssicherung, das wir in Deutschland genießen, für Milliarden von Menschen keine Selbstverständlichkeit darstellt. Sie müssen erkennen, dass ohne einen Ausbau der Agrarforschung und (ganz allgemein) der Ausschöpfung des Potenzials der Wissenschaft es nicht möglich sein wird, Hunger und Mangelernährung nachhaltig zu bekämpfen. Dies wurde nicht zuletzt auch durch die Nahrungskrise des letzten Jahres und den erneuten Anstieg der Zahl der weltweit Hungernden verdeutlicht, die mittlerweile über eine Milliarde Menschen ausmachen. Es liegt u.a. auch in der Hand der Politik klarzustellen, dass (humanitäre) Forschungsprojekte an öffentlichen Einrichtungen nicht verdeckter Industriepropaganda dienen, sondern schlichtweg eine Fortführung der langen Tradition deutscher Agrarforschung darstellen; Investitionen und Innovationen im öffentlichen Sektor können vielmehr auch dabei helfen, dem industriellen Konzentrationsprozess im Bereich der Gentechnik entgegenzusteuern.

Bibliographie und Literaturverzeichnis

(Artikel zu "biofortification" oder "biofortified", die seit 2005 erschienen sind, sind mit Kurzbeschreibung wiedergegeben. Im Haupttext zusätzlich zitierte Quellen sind als einfache Referenzen angegeben.)

Abilgos-Ramos R, Murchie E, Anukul N, Bennett M, Corpuz-Arocena E, Garcia GDG, Manaois R, Julaton M, Stangoulis J, Graham R (2007). Rice biofortification. Comparative Biochemistry and Physiology, Part A 146: S247. http://dx.doi.org/10.1016/j.cbpa.2007.01.574

Rice is the staple food for more than half of the world's population and the main source of nutrients for most poor in many Asian countries. The recent report of the World Health Organization (WHO) showed that there are more than 3 billion iron-deficient people globally and most of them are the children and women in the Asian region. This is because rice contains low level (1-3 mg/kg) of the micronutrient in the polished form (white rice). Breeding efforts for high-iron rice started in 2001 under the Asian Development Bank-International Food Policy Research Institute (ADB-IFPRI) project (more popularly known as the high-iron rice project) with the introduction of IR68144 (cross between IR72×Zawa Bonday). Crosses were made between IR68144 with other popular varieties (e.g. IR64) while germplasms were screened for iron and zinc content. At the Philippine Rice Research Institute (PhilRice), 538 lines and varieties were subjected to inductively-coupled plasma-optical emission spectrometry (ICP-OES) analysis for grain mineral concentration (7.0-17.8 mg/kg Fe). A 9-month human efficacy study showed a 20% increase in the body iron stores of the subjects

Adams EJ (2008). A dynamic website for a government/industry-funded project exploring biofortification of wheat with selenium. Bioscience Horizons 1: 75-84. http://dx.doi.org/10.1093/biohorizons/hzn010

In 2005, scientists within several UK-based academic and industrial organizations came together to work on a research project, funded jointly by the UK Department for Environment, Food and Rural Affairs and several industry partners. The project was entitled Biofortification through Agronomy and Genotypes to Elevate the Levels of Selenium (BAGELS). The aim of the BAGELS project, which will report in 2009, is to determine if it is possible to increase safely the selenium (Se) content of bread, through the use of Se-containing fertilizers (i.e. agronomic biofortification). The BAGELS project is also seeking to study the natural genetic variation in grain Se concentration to determine if it might be possible to breed for Se-enriched wheat (i.e. genetic biofortification). The underlying rationale for the BAGELS project is that Se-biofortified wheat is a potential strategy for increasing the dietary intakes of Se and thereby improve human health for most of the population. It was recognized that an official website for the BAGELS project could be used to communicate the importance of Se to human health in addition to providing a simple means to exchange results between scientists. Therefore, the aim of my research project was to create a BAGELS project website, which delivered specific objectives to meet the needs of the project manager and project consortium members. After investigation into website design and construction, accessibility and web-authoring tools, a final dynamic website was created using the free open source software Joomla!. A review of the recent scientific studies on Se and health, and the options for increasing Se intake were included as a first step towards developing a source of public information. There is strong evidence linking low Se intake and status in humans and adverse health effects, including immune disfunction and cancer.

Al-Babili S, Beyer P (2005). Golden Rice – five years on the road – five years to go? Trends in Plant Science 10: 565-573. http://dx.doi.org/10.1016/j.tplants.2005.10.006

Provitamin A accumulates in the grain of Golden Rice as a result of genetic transformation. In developing countries, where vitamin A deficiency prevails, grain from Golden Rice is expected to provide this important micronutrient sustainably through agriculture. Since its original production, the prototype Golden Rice has undergone intense research to increase the provitamin A content, to establish the scientific basis for its carotenoid complement, and to better comply with regulatory requirements. Today, the current focus is on how to get Golden Rice effectively into the hands of farmers, which is a novel avenue for public sector research, carried out with the aid of international research consortia. Additional new research is underway to further increase the nutritional value of Golden Rice.

Allen L, de Benoist B, Dary O, Hurrell R (2006). Guidelines on food fortification with micronutrients. Geneva: World Health Organization. http://www.who.int/nutrition/publications/micronutrients/9241594012/

Interest in micronutrient malnutrition has increased greatly over the last few years. One of the main reasons for the increased interest is the realization that micronutrient malnutrition contributes substantially to the global burden of disease. In 2000, the World Health Report1 identified iodine, iron, vitamin A and zinc deficiencies as being among the world's most serious health risk factors. In addition to the more obvious clinical manifestations, micronutrient malnutrition is responsible for a wide range of non-specific physiological impairments, leading to reduced resistance to infections, metabolic disorders, and delayed or impaired physical and psychomotor development. The public health implications of micronutrient malnutrition are potentially huge, and are especially significant when it comes to designing strategies for the prevention and control of diseases such as HIV/AIDS, malaria and tuberculosis, and diet-related chronic diseases. Another reason for the increased attention to the problem of micronutrient malnutrition is that, contrary to previous thinking, it is not uniquely the concern of poor countries.

Allen L, de Benoist B, Dary O, Hurrell R (eds) (2006). Guidelines on food fortification with micronutrients. Geneva: World Health Organization. http://www.who.int/nutrition/publications/micronutrients/

Alloway BJ (2009). Soil factors associated with zinc deficiency in crops and humans. Environmental Geochemistry and Health 31: 537-548. http://dx.doi.org/10.1007/s10653-009-9255-4

Zinc deficiency is the most ubiquitous micronutrient deficiency problem in world crops. Zinc is essential for both plants and animals because it is a structural constituent and regulatory co-factor in enzymes and proteins involved in many biochemical pathways. Millions of hectares of cropland are affected by Zn deficiency and approximately one-third of the human population suffers from an inadequate intake of Zn. The main soil factors affecting the availability of Zn to plants are low total Zn contents, high pH, high calcite and organic matter contents and high concentrations of Na, Ca, Mg, bicarbonate and phosphate in the soil solution or in labile forms. Maize is the most susceptible cereal crop, but wheat grown on calcareous soils and lowland rice on flooded soils are also highly prone to Zn deficiency. Zinc fertilizers are used in the prevention of Zn deficiency and in the biofortification of cereal grains.

Aluru M, Xu Y, Guo R, Wang Z, Li S, White W, Wang K, Rodermel S (2008). Generation of transgenic maize with enhanced provitamin A content. Journal of Experimental Botany 59: 3551-3562. http://dx.doi.org/10.1093/jxb/ern212

Vitamin A deficiency (VAD) affects over 250 million people worldwide and is one of the most prevalent nutritional deficiencies in developing countries, resulting in significant socio-economic losses. Provitamin A carotenoids such as β-carotene, are derived from plant foods and are a major source of vitamin A for the majority of the world's population. Several years of intense research has resulted in the production of 'Golden Rice 2' which contains sufficiently high levels of provitamin A carotenoids to combat VAD. In this report, the focus is on the generation of transgenic maize with enhanced provitamin A content in their kernels. Overexpression of the bacterial genes crtB (for phytoene synthase) and crtI (for the four desaturation steps of the carotenoid pathway catalysed by phytoene desaturase and zeta-carotene desaturase in plants), under the control of a 'super gamma-zein promoter' for endosperm-specific expression, resulted in an increase of total carotenoids of up to 34-fold with a preferential accumulation of β-carotene in the maize endosperm. The levels attained approach those estimated to have a significant impact on the nutritional status of target populations in developing countries. The high β-carotene trait was found to be reproducible over at least four generations. Gene expression analyses suggest that increased accumulation of β-carotene is due to an up-regulation of the endogenous lycopene β-cylase. These experiments set the stage for the design of transgenic approaches to generate provitamin A-rich maize that will help alleviate VAD.

Ariza-Nieto M, Sanchez MT, Heller LI, Hu Y, Welch RM, Glahn RP (2006). Cassava (Manihot esculenta) has high potential for iron biofortification. FASEB Journal20: A624. http://www.fasebj.org/cgi/content/meeting_abstract/20/4/A624

Since cassava is a crop targeted for biofortification, we studied the relationship between iron content and iron bioavailability in three cassava varieties. Phenolic compounds, ascorbic acid, carotenoids, valence of iron and myo-inositol hexakisphosphate (IP6) were also measured. The in vitro digestion/Caco-2 model was used to assess bioavailable iron. Cassava is used in several traditional dishes that are represented by two preparations; cooked (e.g. soups, to be fried, or to be covered with salsa) and bread flour (e.g. dried and grinded for further used as an ingredient in several bread making recipes). More Fe was present in the bread flour (10.5-18.3 mg g-1) than in the cooked samples (5.6-7.5 mg g-1). Iron solubility ranged from 6-36 % in the cooked samples and from 17-30% in the bread flour samples. No phenolic compounds or ascorbic acid were detected. IP6 concentration was 2.0-4.9-mmol g-1. With respect to carotenoids only all-trans-b-carotene was found both in the cooked and flour samples at concentrations of 0.14-0.44-ng g-1. Caco-2 cell iron uptake of 0.082 mmoles of intrinsic cassava Fe was comparable to the uptake from 1mmole of FeCl3, indicating that cassava Fe was highly available within both the cooked and bread flour samples. This relatively high level of availability appears to be due to enhanced levels of Fe+2, suggesting the presence of a reducing compound in the cassava. These results suggest that Fe from cassava may be highly available, and that the cassava matrix may enhance the bioavailability of Fe of other sources of Fe consumed in the same meal.

Bamji MS (2008). Food technology for better nutrition. Current Science 94: 433-434. http://www.ias.ac.in/currsci/feb252008/contents.htm

Though India is the largest producer of milk and second largest producer of vegetables and fruits, the quantity produced is inadequate to meet the requirements of its population and out of reach of the poor due to lack of purchasing power. A confounding factor is the wastage that occurs due to inadequate and substandard storage facilities, lack of cold storage, and infrastructure for food-processing for valueaddition. About 30% of the fruits and vegetables grown in India (40 million tonnes amounting to US$ 13 billion) is estimated to get wasted annually. Wasted food can feed almost 232 million people. Multiplication factor for food processing is 2.4, i.e. for every one rupee wealth created directly, additional 2.4 rupees are earned indirectly through transportation, packaging, cold storage, etc.

Barklund Å (ed.) (2008). Golden Rice and other biofortified food crops for developing countries – challenges and potential. Kungl. Skogs- och Lantbruksakademiens Tidskrift 7: 114p. Stockholm: Royal Swedish Academy of Agriculture and Forestry. http://www.ksla.se/sv/redirect_frameset.asp?p=494&time=131927

Among humanity's largest challenges is how to come to grips with poverty and starvation, and how to feed the growing world population. As many as 24,000 people die every day of starvation and malnutrition, to a large extent because of micronutrient deficiencies. One of the most serious is vitamin A deficiency (VAD). Already in 2002, it was possible to biofortify rice with beta-carotene, from which the human body synthesizes vitamin A. But the crop is still not in the fields of the farmers, because the rice is genetically engineered. After solving the issue of the patents making the rice freely available, there has been a whole range of obstacles, which so far have delayed the launching of this Golden Rice by about ten years, compromising the lives of millions. The main focus of this report from the Bertebos Conference 2008, is on Golden Rice and other genetically modified and biofortified crops, on the potential they have for the world population, and on which challenges have to be overcome before they can be used. Of all priorities, the highest urgency is for the poor in the developing countries.

Basset GJC, Quinlivan EP, Gregory III JF, Hanson AD (2005). Folate synthesis and metabolism in plants and prospects for biofortification. Crop Science 45: 449-453. http://crop.scijournals.org/cgi/content/abstract/45/2/449

Folates are essential cofactors for one-carbon transfer reactions in most living organisms and are required for the biosynthesis of nucleic acids, amino acids, and pantothenate. Unlike plants and microorganisms, humans cannot synthesize folates de novo and must acquire them from the diet, primarily from plant foods. However, lack of folates is the most common vitamin deficiency in the world and has serious health consequences, including increased risk of neural tube defects in infants, cancers, and vascular diseases. Consequently, there is much interest in engineering plants with enhanced folate content (biofortification). In this review, we outline progress in defining the plant folate synthesis pathway and its unique compartmentation and point out sectors of folatemetabolism that have yet to be elucidated, including transport and catabolism. We also consider possible strategies to enhance plant folate synthesis and accumulation by metabolic engineering.

Baulcombe D, Crute I, Davies B, Dunwell J, Gale M, Jones J, Pretty J, Sutherland W, Toulmin C (2009). Reaping the benefits: science and the sustainable intensification of global agriculture. London: The Royal Society. http://royalsociety.org/document.asp?tip=0&id=8825

Food security is one of this century's key global challenges. By 2050 the world will require increased crop production in order to feed its predicted 9 billion people. This must be done in the face of changing consumption patterns, the impacts of climate change and the growing scarcity of water and land. Crop production methods will also have to sustain the environment, preserve natural resources and support livelihoods of farmers and rural populations around the world. There is a pressing need for the 'sustainable intensification' of global agriculture in which yields are increased without adverse environmental impact and without the cultivation of more land. Addressing the need to secure a food supply for the whole world requires an urgent international effort with a clear sense of long-term challenges and possibilities. Biological science, especially publicly funded science, must play a vital role in the sustainable intensification of food crop production. The UK has a responsibility and the capacity to take a leading role in providing a range of scientific solutions to mitigate potential food shortages. This will require significant funding of cross-disciplinary science for food security. The constraints on food crop production are well understood, but differ widely across regions. The availability of water and good soils are major limiting factors. Significant losses in crop yields occur due to pests, diseases and weed competition. The effects of climate change will further exacerbate the stresses on crop plants, potentially leading to dramatic yield reductions. Maintaining and enhancing the diversity of crop genetic resources is vital to facilitate crop breeding and thereby enhance the resilience of food crop production. Addressing these constraints requires technologies and approaches that are underpinned by good science. Some of these technologies build on existing knowledge, while others are completely radical approaches, drawing on genomics and high-throughput analysis. Novel research methods have the potential to contribute to food crop production through both genetic improvement of crops and new crop and soil management practices. Genetic improvements to crops can occur through breeding or genetic modification to introduce a range of desirable traits. The application of genetic methods has the potential to refine existing crops and provide incremental improvements.

Bekaert S, Storozhenko S, Mehrshahi P, Bennett MJ, Lambert W, Gregory III JF, Schubert K, Hugenholtz J, Van Der Straeten D, Hanson AD (2008). Folate biofortification in food plants. Trends in Plant Science 13: 28-35. http://dx.doi.org/10.1016/j.tplants.2007.11.001

Folate deficiency is a global health problem affecting many people in the developing and developed world. Current interventions (industrial food fortification and supplementation by folic acid pills) are effective if they can be used but might not be possible in less developed countries. Recent advances demonstrate that folate biofortification of food crops is now a feasible complementary strategy to fight folate deficiency worldwide. The genes and enzymes of folate synthesis are sufficiently understood to enable metabolic engineering of the pathway, and results from pilot engineering studies in plants (and bacteria) are encouraging. Here, we review the current status of investigations in the field of folate enhancement on the eve of a new era in food fortification.

Bereket A (2003). Rickets in developing countries. Endocrine Development 6: 220-232. http://dx.doi.org/10.1159/000072778

Bhagwati J, Bourguignon F, Kydland FE, Mundell R, North DC, Schelling T, Smith VL, Stokey N (2008). Copenhagen Consensus 2008 – Results. Frederiksberg: Copenhagen Consensus Center. http://www.copenhagenconsensus.com/Home.aspx

The goal of Copenhagen Consensus 2008 was to set priorities among a series of proposals for confronting ten great global challenges. These challenges are: Air pollution, Conflicts, Diseases, Education, Global Warming, Malnutrition and Hunger, Sanitation and Water, Subsidies and Trade Barriers, Terrorism,

Women and Development. A panel of economic experts, comprising eight of the world's most distinguished economists, was invited to consider these issues.

Bhat R, Karim AA (2009). Exploring the nutritional potential of wild and underutilized legumes. Comprehensive Reviews in Food Science and Food Safety 8: 305-331. http://dx.doi.org/10.1111/j.1541-4337.2009.00084.x

Providing safe, nutritious, and wholesome food for poor and undernourished populations has been a major challenge for the developingworld. Acute shortage, unreliable supply, and elevated costs of protein-rich foods of animal origin in the developing and underdeveloped countries have resulted in the search for inexpensive and reliable alternative sources of protein of plant origin. Some of the wild and underutilized legumes (such as Canavalia, Mucuna, andSesbania, for example) have been investigated and found to possess rich nutraceutical value.However, the greatest impediment to utilizing these legumes is the presence of antinutrients, which could be successfully removed or deactivated by employing certain processing methods (cooking, dry heat treatments, germination, irradiation, among others). This review focuses on providing the details on some of the wild and underutilized legumes that might have high potential to be used as human food and animal feed, along with providing information for overcoming the malnutrition-associated problems and also for future commercial exploitation such as a source of nutraceuticals, for new food formulations, biofortification, and in product development.

Bhat R, Kiran K, Arun AB, Karim AA (2009). Determination of mineral composition and heavy metal content of some nutraceutically valued plant products. Food Analytical Methods online 16 September. http://dx.doi.org/10.1007/s12161-009-9107-y

Minerals and heavy metal concentrations of 23 plants (arial parts, leaves, bark, stem, root, rhizome, dried berries, seeds) possessing health-promoting effects and used in indigenous medicines (as medicinal food) were determined using inductively coupled plasma atomic spectrometry. Vital essential minerals and heavy metals were present in all the samples analyzed. The majority of the plant materials were rich in some of the essential minerals like Na, K, Ca, Fe, Mg, Cu, Mn, and Zn, which are known to be beneficial for health. The plant material of Vitiveria zizinalis had highest concentration of toxic heavy metals, including arsenic (53.1 mg/100 g), chromium (6.74 mg/100 g), cobalt (10.2 mg/100 g), mercury (3.6 mg/100 g), and nickel (3.28 mg/100 g). Results of the present study provide vital data on the availability of some essential minerals, which can be useful to provide dietary information for designing value-added foods and for food biofortification. Apart from this, data on the contaminant levels of heavy metals highlights the necessity on the quality and safety concerns about their use.

Bhutta ZA, Ahmed T, Black RE, Cousens S, Dewey K, Giugliani E, Haider BA, Kirkwood B, Morris SS, Sachdev HPS, Shekar M, et al. (2008). What works? Interventions for maternal and child undernutrition and survival. Lancet online 17 January. http://dx.doi.org/10.1016/S0140-6736(07)61693-6

We reviewed interventions that affect maternal and child undernutrition and nutrition-related outcomes. These interventions included promotion of breastfeeding; strategies to promote complementary feeding, with or without provision of food supplements; micronutrient interventions; general supportive strategies to improve family and community nutrition; and reduction of disease burden (promotion of hand washing and strategies to reduce the burden of malaria in pregnancy). We showed that although strategies for breastfeeding promotion have a large effect on survival, their effect on stunting is small. In populations with sufficient food, education about complementary feeding increased height-for-age Z score by 0•25 (95% CI 0•01-0•49), whereas provision of food supplements (with or without education) in populations with insufficient food increased the height-for-age Z score by 0•41 (0•05-0•76). Management of severe acute malnutrition according to WHO guidelines reduced the case-fatality rate by 55% (risk ratio 0•45, 0•32-0•62), and recent studies suggest that newer commodities, such as ready-to-use therapeutic foods, can be used to manage severe acute malnutrition in community settings. Effective micronutrient interventions for pregnant women included supplementation with iron folate (which increased haemoglobin at term by 12 g/L, 2•93-21•07) and micronutrients (which reduced the risk of low birthweight at term by 16% (relative risk 0•84, 0•74-0•95). Recommended micronutrient interventions for children included strategies for supplementation of vitamin A (in the neonatal period and late infancy), preventive zinc supplements, iron supplements for children in areas where malaria is not endemic, and universal promotion of iodised salt. We used a cohort model to assess the potential effect of these interventions on mothers and children in the 36 countries that have 90% of children with stunted linear growth. The model showed that existing interventions that were designed to improve nutrition and prevent related disease could reduce stunting at 36 months by 36%; mortality between birth and 36 months by about 25%; and disability-adjusted life-years associated with stunting, severe wasting, intrauterine growth restriction, and micronutrient deficiencies by about 25%. To eliminate stunting in the longer term, these interventions should be supplemented by improvements in the underlying determinants of undernutrition, such as poverty, poor education, disease burden, and lack of women's empowerment.

Birner R, Kone SA, Linacre N, Resnick D (2007). Biofortified foods and crops in West Africa: Mali and Burkina Faso. AgBioForum 10: 192-200. http://www.agbioforum.org/v10n3/v10n3a09-birner.htm

Micronutrient deficiencies, especially deficiencies of Vitamin A, iron, and zinc, are widespread in Burkina Faso and Mali and contribute to high mortality rates. Biofortification of the major food staple crops consumed in these countries has considerable potential to increase the micronutrient status of vulnerable populations if the challenges of seed distribution can be overcome. This article examines the political landscape for the introduction of biofortified crops, including those developed through genetic engineering. Based on the experience with current strategies of food fortification, it is shown that the political environment for biofortified crops developed through conventional breeding is highly favorable. Analyzing the current state of biosafety legislation and the political debates regarding genetically modified (GM) crops in the region, where the current focus is on Bt cotton, this study concludes that the political environment for introducing GM biofortified food crops is at present not conducive. Strategies that prioritize the introduction of GM crops may jeopardize the favorable environment to welcome non-GM biofortified crops.

Blasco E, Rios JJ, Cervilla LM, Sánchez-Rodrigez E, Ruiz JM, Romero L (2008). Iodine biofortification and antioxidant capacity of lettuce: potential benefits for cultivation and human health. Annals of Applied Biology 152: 289-299. http://dx.doi.org/10.1111/j.1744-7348.2008.00217.x

Iodine is considered an essential trace element for mammals, and its deficiency is related to numerous pathologies as severe as goitre, reproductive failure, mental retardation and brain damage, among others. Currently, about 30% of the world's population are affected by this deficiency, and thus, in an attempt to ameliorate these nutritional disorders, we propose a biofortification programme with iodine by an application of different dosages and forms of this element (iodide versus iodate) in lettuce plants. In this work, a study has been made of the iodine concentration in roots and edible leaves and their influence on nutritional quality through an analysis of its antioxidant capacity. The results showed that the most appropriate application rates in hydroponic cultivation were 40 μM or lower in the form I^- because these concentrations did not reduce biomass in the treated plants with respect to control plants and caused a foliar accumulation of this element that guarantees the viability of this type of programmes. Furthermore, these data are novel, given that the treated plants show a significant increase in antioxidant compounds after the application of iodine.

BMZ (2009). Millenniumsentwicklungsziele. Web page. Berlin: Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung. http://www.bmz.de/de/service/glossar/millenniumsentwicklungsziele.html

Bóna L, Adányi N, Farkas R, Szanics E, Szabó E, Hajós G, Pécsváradi A, Ács E (2009). Variation in crop nutrient accumulation: selenium content of wheat and triticale grains. Acta Alimentaria 38: 9-15. http://dx.doi.org/10.1556/AAlim.2008.0027

Selenium (Se), a main antioxidant component in cereal grain, is essential for animals and human health reducing risk factors of many dangerous diseases. Over the past decades, intake of this trace element had dropped due to low Se content in large areas of European countries including Hungary. Se-rich, high-protein cereal products became a focus for both animal feed and human consumption. In the study, we examined the following: i) grain Se concentration of wheat (Triticum aestivum L.) and triticale (Triticosecale Wittm.) intake to detect intra-and inter-genetic variations and ii) possible comparison relationship of this trace element to end product integrity, quality and relevant technological aspects. Se content of the whole meal grain was tested via atomic absorption spectroscopy (AAS). Despite generally poor Se soil content of the experimental area where samples were collected, significant differences were found for both species. In general, triticale contained higher Se concentration than wheat did. Spring type cereals had significantly higher grain Se and protein concentration than those of winter ones. Grain Se content showed positive correlation with magnesium, copper, zinc, manganese, tocopherol and crude protein concentration. Remarkable intra-specific variations were found in Se concentration, however in future, additional studies, methods and resources will be required for identifying ways of increasing Se content in cereal foodstuff and feed.

Borwankar R, Sanghvi T, Houston R (2007). What is the extent of vitamin and mineral deficiencies? Magnitude of the problem. Food and Nutrition Bulletin 28: S174-S181. http://foodandnutritionbulletin.org/FNB/index.php/FNB/issue/view/138

Botella-Pavía P, Rodríguez-Concepción M (2006). Carotenoid biotechnology in plants for nutritionally improved foods. Physiologia Plantarum 126: 369-381. http://dx.doi.org/10.1111/j.1399-3054.2005.00632.x

Carotenoids participate in light harvesting and are essential for photoprotection in photosynthetic plant tissues. They also furnish non-photosynthetic flowers and fruits with yellow to red colors to attract animals for pollination and dispersal of seeds. Although animals can not synthesize carotenoids de novo, carotenoid-derived products such as retinoids (including vitamin A) are required as visual pigments and signaling molecules. Dietary carotenoids also provide health benefits based on their antioxidant properties. The main pathway for carotenoid biosynthesis in plants and microorganisms has been virtually elucidated in recent years, and some of the identified biosynthetic genes have been successfully used in metabolic engineering approaches to overproduce carotenoids of interest in plants. Alternative approaches that enhance the metabolic flux to carotenoids by upregulating the production of their isoprenoid precursors or interfere with light-mediated regulation of carotenogenesis have been recently shown to result in increased carotenoid levels. Despite spectacular achievements in the metabolic engineering of plant carotenogenesis, much work is still ahead to better understand the regulation of carotenoid biosynthesis and accumulation in plant cells. New genetic and genomic approaches are now in progress to identify regulatory factors that might significantly contribute to improve the nutritional value of plant-derived foods by increasing their carotenoid levels.

Botha GM, Viljoen CD (2008). Can GM sorghum impact Africa? Trends in Biotechnology 26: 64-69. http://dx.doi.org/10.1016/j.tibtech.2007.10.008

It is said that genetic modification (GM) of grain sorghum has the potential to alleviate hunger in Africa. To this end, millions of dollars have been committed to developing GM sorghum. Current developments in the genetic engineering of sorghum are similar to efforts to improve cassava and other traditional African crops, as well as rice in Asia. On closer analysis, GM sorghum is faced with the same limitations as 'Golden Rice' (GM rice) in the context of combating vitamin A deficiency (VAD) efficiently and sustainably. Thus, it is questionable whether the cost of developing GM sorghum can be justified when compared to the cost of investing in sustainable agricultural practice in Africa.

Bouis H (2008). Breeding better food. The New Economy 4: 186-187. http://www.theneweconomy.com/news/science-and-technology/article98.html

Howarth Bouis, Director of HarvestPlus, believes that for nutrition and health to improve in poor countries, agriculture has to do more than alleviate hunger – it has to make food crops more nutritious as well.

Bouis HE (2002). Plant breeding: a new tool for fighting micronutrient malnutrition. Journal of Nutrition 132: 491S-494S. http://jn.nutrition.org/cgi/content/abstract/132/3/491S

Bouis HE, Graham RD, Welch RM (2000). The Consultative Group on International Agricultural Research (CGIAR) micronutrients project: justification and objectives. Food and Nutrition Bulletin 21: 374-381. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/274

Brinch-Pedersen H, Borg S, Tauris B, Holm PB (2007). Molecular genetic approaches to increasing mineral availability and vitamin content of cereals. Journal of Cereal Science 46: 308-326. http://dx.doi.org/10.1016/j.jcs.2007.02.004

The present paper summarizes the current state of knowledge on molecular genetic approaches to increasing iron and zinc availability and vitamin content in cereals. We have also attempted to integrate the scientific issues into the wider context of human nutrition. In the cereal grain, iron and zinc are preferentially stored together with phytate in membrane-enclosed globoids in the protein storage vacuole (PSV) found in the aleurone and the embryo scutellum. The PSV is accordingly central for understanding mineral deposition during grain filling and mobilization of minerals during germination. Recent studies in Arabidopsis have led to the first identification of iron and zinc transporters of the PSV and further illustrate some of the dynamics associated with mineral and phytate transport and deposition into the vacuole. This provides new opportunities for modulating iron and zinc deposition in the cereal grain. Current strategies towards increasing the iron content of the endosperm are largely based on the expression of legume ferritin genes in an endosperm-specific manner. However, it is apparent that this approach, at least in rice, only allows a two- to three-fold increase in the iron content of the grain due to exhaustion of the iron stores in leaves. Further increases thus have to rely on additional uptake and transport of iron from the root. Phytate is generally considered to be the single most important anti-nutritional factor for iron and zinc availability. In the current paper we summarize attempts to increase phytase activity in the grain by transformation and evaluate the potential of this approach as well as the reduction of phytate biosynthesis for improving the bioavailability of iron and zinc. Vitamins constitute the second important group of micronutrients in grain and we discuss current efforts to increase the amounts of provitamin A, vitamin C and vitamin E.

Broadley M, Meacham M, Bowen H, Hammond J, Hayden R, Mead A, Teakle G, King G, White P (2009). Natural genetic variation in the mineral nutrient composition of Brassica oleracea. Comparative Biochemistry and Physiology, Part A 146: S246. http://dx.doi.org/10.1016/j.cbpa.2007.01.573

Plants require at least 14 mineral elements to complete their life cycles, which are acquired primarily from the soil. The mineral composition of plant tissues varies widely due to environmental factors, such as soil mineral availability, and due to plant developmental and genetic factors. Substantial natural genetic variation in the mineral composition of plant tissues occurs between populations and varieties of the same species. This within-species variation is being used in genetic biofortification programmes, i.e. to breed staple crops with higher mineral contents in their edible portions to alleviate human dietary mineral deficiencies. A significant proportion of the variation in the leaf composition of some minerals (e.g. Ca, K, Mg, Si, Zn) has also been attributed to phylogenetic effects occurring above the species level, for example, at the family level and above.Here, we conducted a thorough, species-wide, genetic dissection ofmineral composition using Brassica oleracea L. (Brassicaceae) as a genetic model.

Broadley MR, Hammond JP, King GJ (2009). Biofortifying Brassica with calcium (Ca) and magnesium (Mg). Paper 1256, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1256

Billions of people worldwide consume insufficient calcium (Ca) or magnesium (Mg) for adequate health. Dietary Ca and Mg intakes can potentially be increased through crop biofortification. Recently, we reported sufficient natural genetic variation and heritability in a leafy crop plant (Brassica oleracea; C-genome, 1n=9; cabbage, cauliflower, kale etc.) to indicate that genetic biofortification is feasible in vegetable Brassica. We also reported loci affecting shoot Ca and Mg concentration (shoot-Ca and Mg). Here, we extend the previous study to explore the closely related species B. rapa (A-genome, 1n=10; Chinese cabbage, pak choi, a more tractable species genetically, and the amphidiploid species B. napus (AC-genome, 1n=19; canola/oilseed rape etc.). Wide variation in shoot/leaf-Ca and Mg occurs among all three species. Shoot/leaf-Ca and Mg is significantly and highly heritable. Quantitative trait loci (QTL) affecting shoot/leaf Ca and Mg concentration occur in potentially paralogous regions of B. oleracea and B. rapa. If confirmed, allelic variation at such loci could be used in biofortification breeding programs for vegetable Brassica. As genome sequencing and marker generation improves, it will be possible to resolve these (and other) putative loci to the gene level. Further studies on the regulation, interaction and function of these genes will enable us to understand Ca and Mg dynamics in plants.

Broadley MR, White PJ, Bryson RJ, Meacham MC, Bowen HC, Johnson SE, Hawkesford MJ, McGrath SP, Zhao F-J, Breward N, Harriman M, Tucker M (2006). Biofortification of UK food crops with seleniumProceedings of the Nutrition Society 65: 169-181. http://dx.doi.org/10.1079/PNS2006490

Se is an essential element for animals. In man low dietary Se intakes are associated with health disorders including oxidative stress-related conditions, reduced fertility and immune functions and an increased risk of cancers. Although the reference nutrient intakes for adult females and males in the UK are 60 and 75 µg Se/d respectively, dietary Se intakes in the UK have declined from >60 µg Se/d in the 1970s to 35 µg Se/d in the 1990s, with a concomitant decline in human Se status. This decline in Se intake and status has been attributed primarily to the replacement of milling wheat having high levels of grain Se and grown on high-Se soils in North America with UK-sourced wheat having low levels of grain Se and grown on low-Se soils. An immediate solution to low dietary Se intake and status is to enrich UK-grown food crops using Se fertilisers (agronomic biofortification). Such a strategy has been adopted with success in Finland. It may also be possible to enrich food crops in the longer term by selecting or breeding crop varieties with enhanced Se-accumulation characteristics (genetic biofortification). The present paper will review the potential for biofortification of UK food crops with Se.

Brooks S, Leach M, Lucas H, Millstone E (2009). Silver bullets, grand challenges and the new philanthropy. STEPS Working Paper 24. Brighton: University of Sussex. http://www.steps-centre.org/publications/

Whether generic 'silver bullet' solutions can address complex development problems has been debated for many years. The 'grand challenge' extends the idea of the silver bullet in ways that speak to a goal-driven, global development agenda and a new generation of private philanthropists - or 'philanthro-capitalists' seeking to apply business methods to 'strategic' giving. These developments raise new Sustainability challenges, explored in this paper, drawing on examples from the health and agriculture sectors. Biofortification research funded by the Bill and Melinda Gates Foundation provides a detailed, illustrative case of how these ideas can reduce space to debate directionality and accountability. Imperatives towards rapid 'scaling up' infer homogenous populations and overlook patterns of diversity and distributional concerns; transforming complex and diverse needs into 'demand' for pre-defined technical solutions. This paper asks if the potential exists for a reinvigorated philanthropic sector to play a different role, and turn its power and resources towards learning processes that recognise diversity and use this to reshape programme design.

Cabanilla LS (2007). Socio-economic and political concerns for GM foods and biotechnology adoption in the Philippines. AgBioForum 10: 178-183. http://www.agbioforum.org/v10n3/v10n3a07-cabanilla.htm

The Philippines established the first National Institute of Biotechnology and Applied Microbiology in 1980. However, it was only in 2002 when Bt corn was first commercially introduced. Strong opposition by key sectors including the influential Roman Catholic Church contributed to this delay and will probably continue to affect the introduction of other GM crops in the future. With favorable adoption rates of Bt corn, opposition dissipated and local scientific initiatives have expanded to other crops (e.g., GM papaya, eggplant). The Philippine Rice Research Institute in collaboration with IRRI is currently engaged in the adaptation of Golden Rice (biofortified for Vitamin A) but it is not clear how the polity will react to this new technology when it is ready for adoption. It is a major food staple in contrast to Bt corn. The government's agenda also puts a high premium on food self-sufficiency, especially rice.

Cakmak I (2009). Enrichment of fertilizers with zinc: an excellent investment for humanity and crop production in India. Journal of Trace Elements in Medicine and Biology 23: 281-289. http://dx.doi.org/10.1016/j.jtemb.2009.05.002

Micronutrient malnutrition is a growing concern in the developing world, resulting in diverse health and social problems, such as mental retardations, impairments of the immune system and overall poor health. In recent years, the zinc (Zn) deficiency problem has received increasing attention and appears to be the most serious micronutrient deficiency together with vitamin A deficiency. Zinc deficiency is particularly widespread among children and represents a major cause of child death in the world. In countries where Zn deficiency is well documented as an important public health problem, cereal-based foods are the predominant source of daily calorie and protein intake. Because the concentration of Zn in cereal crops is inherently very low, growing cereals on potentially Zn-deficient soils further decreases grain Zn concentrations. It is, therefore, not surprising that high Zn deficiency incidence in humans occurs predominantly on areas where soils are deficient in plant-available Zn, as shown in many Southeast Asian countries. India has some of the most Zn-deficient soils in the world. Nearly 50% of cultivated soils in India are low in plant-available Zn; these soils are under intensive cultivation of wheat and rice with no or little application of Zn fertilizers. Consequently, cereal crops grown on such Zn-deficient soils contribute only marginally to daily Zn intake. In the rural areas of India, rice and wheat contributes nearly 75% of the daily calorie intake. These facts clearly point to an urgent need for improved Zn concentration of cereal grains in India. Recent calculations indicate that biofortification (enrichment) of rice and wheat grain with Zn, for example by breeding, may save lives of up to 48,000 children in India annually. Breeding new cereal genotypes for high grain Zn concentration is the most realistic and cost-effective strategy to address the problem. However, this strategy is a long-term one, and the size of plant-available Zn pools in soils may greatly affect the capacity of Zn-efficient (biofortified) cultivars to take up Zn and accumulate it in grains. Therefore, application of Zn-containing fertilizers represents a quick and effective approach to biofortifying cereal grains with Zn, thus being an excellent complementary tool to the breeding strategy for successful biofortification of cereals with Zn. Increasing evidence is available from field trials showing that soil and/or foliar application of Zn fertilizers improves grain Zn concentration up to 2- or 3-fold. In the countries where Zn deficiency is both a public health issue and an important soil constraint to crop production, like in India, enrichment of widely applied fertilizers with Zn would be an excellent investment for improving grain Zn while contributing to increased crop production. Recent work by the scientists of the Indian Agricultural Research Institute indicates that the use of Zn-enriched urea in rice and wheat significantly improves both grain Zn concentration and grain yield. It is obvious that enrichment of widely applied fertilizers with Zn and/or foliar application of Zn fertilizers appear to be a high priority with the strongest potential to alleviate Zn deficiency-related problems in India. A Government action and policy plan for enrichment of selected major fertilizers with Zn is required urgently.

Cakmak, I (2008). Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant and Soil 301: 1-17. http://dx.doi.org/10.1007/s11104-007-9466-3

Zinc deficiency is a well-documented problem in food crops, causing decreased crop yields and nutritional quality. Generally, the regions in the world with Zn-deficient soils are also characterized by widespread Zn deficiency in humans. Recent estimates indicate that nearly half of world population suffers from Zn deficiency. Cereal crops play an important role in satisfying daily calorie intake in developing world, but they are inherently very low in Zn concentrations in grain, particularly when grown on Zn-deficient soils. The reliance on cereal-based diets may induce Zn deficiency-related health problems in humans, such as impairments in physical development, immune system and brain function. Among the strategies being discussed as major solution to Zn deficiency, plant breeding strategy (e.g., genetic biofortification) appears to be a most sustainable and cost-effective approach useful in improving Zn concentrations in grain. The breeding approach is, however, a long-term process requiring a substantial effort and resources. A successful breeding program for biofortifying food crops with Zn is very much dependent on the size of plant-available Zn pools in soil. In most parts of the cereal-growing areas, soils have, however, a variety of chemical and physical problems that significantly reduce availability of Zn to plant roots. Hence, the genetic capacity of the newly developed (biofortified) cultivars to absorb sufficient amount of Zn from soil and accumulate it in the grain may not be expressed to the full extent. It is, therefore, essential to have a short-term approach to improve Zn concentration in cereal grains. Application of Zn fertilizers or Zn-enriched NPK fertilizers (e.g., agronomic biofortification) offers a rapid solution to the problem, and represents useful complementary approach to on-going breeding programs. There is increasing evidence showing that foliar or combined soil+foliar application of Zn fertilizers under field conditions are highly effective and very practical way to maximize uptake and accumulation of Zn in whole wheat grain, raising concentration up to 60 mg Zn kg^{-1}. Zinc-enriched grains are also of great importance for crop productivity resulting in better seedling vigor, denser stands and higher stress tolerance on potentially Zn-deficient soils. Agronomic biofortification strategy appears to be essential in keeping sufficient amount of available Zn in soil solution and maintaining adequate Zn transport to the seeds during reproductive growth stage. Finally, agronomic biofortification is required for optimizing and ensuring the success of genetic biofortification of cereal grains with Zn. In case of greater bioavailability of the grain Zn derived from foliar applications than from soil, agronomic biofortification would be a very attractive and useful strategy in solving Zn deficiency-related health problems globally and effectively.

Cakmak, I (2009). Agronomic approaches in biofortification of food crops with micronutrients. Paper 1451, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1451

Zinc (Zn) and iron (Fe) deficiencies are well-documented public health issue affecting nearly half of the world population. Developing countries are among the worst affected from Zn and Fe deficiencies which result in number of serious health complications, such as impairments in brain function and mental development, high susceptibility to deadly infectious disease and high risk for anemia. Recent reports indicate that, for example, Zn deficiency is responsible for death of nearly 450 000 children under 5-years old, annually. Very low concentrations and poor bioavailability of Zn and Fe in the commonly consumed foods seem to be the main reason for widespread occurrence of micronutrient deficiencies in human populations. Cereal-based foods are most commonly consumed foods and contribute up to 75 % of the daily calorie intake in the rural parts of the developing countries. Zinc and Fe deficiencies are also common micronutrient deficiencies in agricultural soils limiting both crop production and nutritional quality

Campos-Bowers MH, Wittenmyer BF (2007). Biofortification in China: policy and practice. Health Research Policy and Systems 5: 10. http://dx.doi.org/10.1186/1478-4505-5-10

Micronutrient deficiency undernutrition, due to insufficient levels of vitamins and minerals in the diet, remains one of the most prevalent and preventable nutritional problems in the world today. Micronutrient undernutrition is the most common form of malnutrition. Compared to the 180 million children with protein-energy malnutrition, 3.5-5 billion persons are iron-deficient, and 140-250 million persons are vitamin A-deficient. Micronutrient deficiencies diminish physical, cognitive, and reproductive development. Undernutrition is both a cause and a result of poor human health and achievement. Middle-income nations, such as China, also suffer from micronutrient undernutrition's effects. In China's poor western provinces, despite supplementation and fortification efforts, stunting and underweight (symptoms of micronutrient undernutrition) remain common. In recent decades, nutritional adequacy, in terms of available food energy, improved immensely, as the government made food security a top priority. A potential next step for China could be to address specifically micronutrient undernutrition. The paper aims to provide a discussion of policy issues relevant to biofortification, if China were to consider the implementation of this intervention in its rural provinces. Traditional nutritional interventions currently employ four main strategies: dietary modification, supplementation, commercial fortification, and biofortification. Biofortification, a relatively new technique, involves selectively breeding staple plant varieties to increase specific nutrient levels in plant tissues. Biofortification has the potential to provide benefits to humans, plants, and livestock; nourish nutrient-depleted soils; and help increase crop yields per acre. Biofortification methods include selective breeding, reducing levels of anti-nutrients, and increasing levels of substances that promote nutrient absorption. If China were to implement biofortification programs, with help from government agencies and international organizations, several policy questions would need to be addressed. The paper discusses several policy questions that pertain to the relationship between biofortified and genetically modified crops, human health and safety concerns, labeling of biofortified crops for consumers, consumer rights, potential environmental impacts, intellectual property rights, seed disbursement, government investment, private-sector research, and additional agricultural and commercial regulations. Biofortification has the potential to help alleviate the suffering, death, disability, and failure to achieve full human potential that results from micronutrient undernutrition-related diseases.

Carlo C, Durbek K (2008). Micronutrient composition of predominant potato (Solanum tuberosum L.) varieties cultivated in Uzbekistan. Potato Journal 35: 41-45. http://www.indianjournals.com/ijor.aspx?target=ijor:pj&volume=35&issue=1and2&article=007

Potato is an important co-staple in Central Asia, and also a potential source of bioavailable minerals for human nutrition. The content of minerals Fe, Zn, P and Ca was determined in the tubers of ten potato varieties using inductively coupled plasma mass spectrometry (ICPMS) assay. Varieties Picasso and Nevskiy had the highest iron content of 17.5 and 17.0 mg/kg on dry weight basis, respectively. It is interesting to notice that Nevskiy also ranked best in terms of zinc content (18 mg/kg dw). Positive and highly significant correlations (0.69 at $p \leq 0.001$) were observed between iron and calcium content.

Chassy B, Egnin M, Gao Y, Glenn K, Kleter GA, Nestel P, Newell-McGloughlin M, Phipps RH, Shillito R (2008). Nutritional and safety assessments of foods and feeds nutritionally improved through biotechnology: case studies. Comprehensive Reviews in Food Science and Food Safety 7: 50-113. http://dx.doi.org/10.1111/j.1365-2621.2004.tb15497.x

During the last 2 decades, the public and private sectors have made substantial international research progress toward improving the nutritional value of a wide range of food and feed crops. Nevertheless, significant numbers of people still suffer from the effects of undernutrition. In addition, the nutritional quality of feed is often a limiting factor in livestock production systems, particularly those in developing countries. As newly developed crops with nutritionally improved traits come closer to being available to producers and consumers, we must ensure that scientifically sound and efficient processes are used to assess the safety and nutritional quality of these crops. Such processes will facilitate deploying these crops to those world areas with large numbers of people who need them. This document describes 5 case studies of crops with improved nutritional value.

Chauhan RS (2006). Bioinformatics approach toward identification of candidate genes for zinc and iron transporters in maize. Current Science 91: 510-515. http://www.ias.ac.in/currsci/aug252006/contents.htm

Biofortification of crop plants requires the identification of candidate genes involved in micronutrient accumulation. Scanning of available maize genome sequence resulted in the identification of 33 genes predicted to be involved in iron and zinc transport in maize. Fifteen genes belong to the YS family, 9 to ZIP family, six to Nramp family, two to ferritin family and one to FRO family. Members of each gene family possessed characteristic signature sequences and transmembrane domains of functionally characterized genes. Genes have been named analogous to a rice nomenclature system such as ZmZIP for Zea mays ZIP-like proteins and similarly ZmYS genes, ZmNramp genes, etc. for other gene family members. Simple sequence repeats as well as single nucleotide polymorphisms were identified in the candidate genes. The current study has provided a useful resource of candidate genes for zinc and iron transport in maize from the available genome sequence data. Candidate genes are expected to be of potential use in genetic and association mapping, molecular marker-assisted selection and development of transgenic plants for micronutrient enrichment traits in maize.

Chege Kimenju S, De Groote H, Morawetz UB (2006). Comparing accuracy and costs of revealed and stated preferences: the case of consumer acceptance of yellow maize in East Africa. Annual Meeting, 12-18 August. Gold Coast: International Association of Agricultural Economists. http://purl.umn.edu/25642

For quite a while, stated preferences have been a major tool to measure consumer preferences for new products and services. Revealed preference methods, in particular experimental economics, have gained popularity recently because they have been shown to be more incentive compatible, and therefore more accurate. However, this advantage comes at the expense of higher survey costs. In the developing countries with limited funding for research, it is important to determine whether the extra cost can be justified by the extra gain in accuracy. A survey of 100 farmers was carried out in Western Kenya to determine consumer preference for yellow maize using the contingent valuation, choice experiments and experimental auction methods. Experimental auctions produced the most realistic results for mean willingness to pay. They are also the most accurate at all budget levels, but also the most expensive. Considering their accuracy and realistic results, we conclude that they should be the recommended method in measuring consumer preference in developing countries, since the extra cost is more than recovered by the gain in accuracy.

Chege Kimenju S, Morawetz UB, De Groote H (2005). Comparing contingent valuation method, choice experiments and experimental auctions in soliciting consumer preference for maize in western Kenya: preliminary results. 10th Annual Conference on Econometric Modeling in Africa, 6-8 July. Nairobi: African Econometric Society. http://www.cimmyt.org/english/wps/news/2005/aug/pdf/VAG.pdf (270 KB)

Vitamin A deficiency (VAD) is a serious problem causing severe eye problems and affects the immune system. One effort to reduce VAD is biofortification, the breeding for increased content of pro-vitamin A carotenoids. Since maize is a major food staple for East and Southern Africa, there is a large interest in breeding maize for increased carotenoids content, which however causes coloration of maize. Since most consumers in these regions prefer white maize, it is unclear how they will balance the improved nutritional quality against the undesired color change. It is therefore important to study consumers' attitudes and preferences before introduction of such products. In order to determine the most appropriate method for such a study, a methodological study trying three methods, Contingent Valuation, Choice Experiments and Experimental Auctions was undertaken in Western Kenya in 100 households. The experimental auction produced the most realistic preference estimates though it was more expensive.

Chen J, Wang G, Lu G (2009). Effects of genotypes and growing locations on iron and zinc contents in sweetpotatoes. Crop and Pasture Science 60: 684-690. http://dx.doi.org/10.1071/CP08291

Sweetpotato has a great potential for combating micronutrient malnutrition and vitamin A deficiency. To explore the potential of combining different micronutrients in the same cultivar through genetic improvement, we assessed the variation of Fe and Zn contents among 21 genotypes and 5 growing locations in the east region of China. Large genotypic difference for Fe and Zn were found in the storage roots. The Fe content ranged from 2.68 to 4.64 mg/100g.dwb (dry weight basis), whereas the Zn content ranged from 2.92 to 6.95 mg/100g.dwb. The variation caused by genotypes, locations and genotype × environmental interaction was highly significant for both Fe and Zn. No significant correlation was found between β-carotene and Fe and Zn contents in the storage roots. The results show that sweetpotato as a staple or co-staple food may provide a good proportion of bio-available Fe and Zn for the nutritional requirements of human populations. It appears feasible to increase Fe and Zn in orange-fleshed storage roots through the new variety breeding.

Cheng L, Wang F, Shou H, Huang F, Zheng L, He F, Li J, Zhao F-J, Ueno D, Feng Ma J, Wu P (2007). Mutation in nicotianamine aminotransferase stimulated the Fe (II) acquisition system and led to iron accumulation in rice. Plant Physiology 145: 1647-1657. http://dx.doi.org/10.1104/pp.107.107912

Higher plants acquire iron (Fe) from the rhizosphere through two strategies. Strategy II, employed by graminaceous plants, involves secretion of phytosiderophores (e.g. deoxymugineic acid in rice [Oryza sativa]) by roots to solubilize Fe (III) in soil. In addition to taking up Fe in the form of Fe (III)-phytosiderophore, rice also possesses the strategy I-like system that may absorb Fe (II) directly. Through mutant screening, we isolated a rice mutant that could not grow with Fe (III)-citrate as the sole Fe source, but was able to grow when Fe (II)-EDTA was supplied. Surprisingly, the mutant accumulated more Fe and other divalent metals in roots and shoots than the wild type when both were supplied with EDTA-Fe (II) or grown under waterlogged field conditions. Furthermore, the mutant had a significantly higher concentration of Fe in both unpolished and polished grains than the wild type. Using the map-based cloning method, we identified a point mutation in a gene encoding nicotianamine aminotransferase (NAAT1), which was responsible for the mutant phenotype. Because of the loss of function of NAAT1, the mutant failed to produce deoxymugineic acid and could not absorb Fe (III) efficiently. In contrast, nicotianamine, the substrate for NAAT1, accumulated markedly in roots and shoots of the mutant. Microarray analysis showed that the expression of a number of the genes involved in Fe (II) acquisition was greatly stimulated in the naat1 mutant. Our results demonstrate that disruption of deoxymugineic acid biosynthesis can stimulate Fe (II) acquisition and increase iron accumulation in rice.

Chhuneja P, Dhaliwal HS, Bains NS, Singh K (2006). Aegilops kotschyi and Aegilops tauschii as sources for higher levels of grain iron and zinc. Plant Breeding 125: 529-531. http://dx.doi.org/10.1111/j.1439-0523.2006.01223.x

Micronutrient malnutrition affects a very large proportion of the world's population. For combating micronutrient malnutrition, biofortification through genetic manipulation has been proposed as an alternative to traditional fortification for increasing the bioavailable nutrient content of food crops. Wheat, being a staple food for a large section of the world's population, is targeted for increasing the Fe and Zn content in the grains. The cultivated germplasm of wheat does not have sufficient variability for grain Fe and Zn content but the wild species of wheat do show wider variation for grain micronutrient density. The analysis of Aegilops kotschyi and A. tauschii for Fe and Zn content in the grains using an atomic absorption spectrophotometer (AAS) indicated that the S and D genome species accumulate significantly higher iron and zinc in the grains than the cultivated wheats. One of the CIMMYT synthetics also had significantly higher Fe and Zn in the grains as compared with the cultivated wheats. Aegilops kotschyi as a promising source for Fe and Zn, is reported for the first time. A systematic programme to identify and utilize the additional sources for high Fe and Zn has been initiated.

Chong M (2003). Acceptance of Golden Rice in the Philippine 'rice bowl'. Nature Biotechnology 21: 971-972. http://dx.doi.org/10.1038/nbt0903-971

Chowdhury S, Meenakshi JV, Tomlins K, Owori C (2009). Are consumers in developing countries willing-to-pay more for micronutrient-dense biofortified foods? Evidence from a field experiment in Uganda. Contributed Paper 125, 27th IAAE Conference, 16-22 August. Beijing: International Association of Agricultural Economists. http://purl.umn.edu/49945

Vitamin A deficiency is a major health problem in Africa and in many other developing countries. Biofortified staple crops that are high in pro vitamins A and adapted to local growing environment have the potential to reduce the prevalence of vitamin A deficiency. One such example is the orange-fleshed sweetpotato. However because of its distinctive orange color, which is in contrast to the white varieties that are typically consumed in Africa, it is important to assess whether consumers will accept it. It is this question that this paper attempts to address, using a choice experiment with the real product to quantify the magnitude of the premium or discount in consumers' willingness to pay that may be associated with it. In addition, it also considers the extent to which the provision of nutrition information affects valuations. Finally, it addresses whether the use of hypothetical scenarios, both with and without a cheap talk script is justified in a developing country context, and quantifies the magnitude of hypothetical bias that results as a consequence. The experiment was conducted in Uganda, which is a key target country for the dissemination of orange-fleshed sweetpotato. Our results suggest that in the absence of nutrition information, there is no difference in the willingness to pay between white and orange varieties, but there is a discount for yellow sweetpotato (which does not have any beta-carotene). The provision of nutrition information does translate into substantial premia for the orange varieties, indicating that an information campaign may be key to drive market acceptance of the new product. Finally, there is a substantial hypothetical bias in both the WTP and the marginal WTP for the new varieties, and while cheap talk mitigates this bias, it does not eliminate it.

Cichy KA, Caldas GV, Snapp SS, Blair MW (2009). QTL analysis of seed iron, zinc, and phosphorus levels in an andean bean population. Crop Science 49: 1742-1750. http://crop.scijournals.org/cgi/content/abstract/49/5/1742

Iron and zinc are essential micronutrients for human health often found in insufficient quantities in the diet. Biofortification of seed crops has been undertaken to reduce micronutrient malnutrition. The objectives of this study were to identify variability for seed Fe, Zn, P, and phytic acid levels in an F5:7 recombinant inbred line (RIL) population developed from a cross between AND696 and G19833, both common beans (Phaseolus vulgaris L.) of Andean origin. Quantitative trait loci (QTL) analysis was conducted with data from 2 yr and 2 P treatments with a previously described linkage map of AND696/G19833. Significant environmental and genetic variability for Fe, Zn, and P levels was identified, and Fe and Zn levels were correlated (up to r=0.53). Quantitative trait loci for seed Fe and Zn co-localized on three linkage groups (B1, B6, and B11). On B6, a QTL for Fe (R2 = 0.36) was found at the same marker interval as a QTL for seed Zn (R2 = 0.39), both derived from AND696. Quantitative trait loci for seed P were identified on six linkage groups and explained 17 to 55% of the total phenotypic variation depending on year and environment.

Cichy KA, Forster S, Grafton KF, Hosfield GL (2005). Inheritance of seed zinc accumulation in navy bean. Crop Science 45: 864-870. http://dx.doi.org/10.2135/cropsci2004.0104

Human zinc (Zn) deficiency is a widespread condition prevalent in people consuming grain and legume based diets. Dry beans (Phaseolus vulgaris L.) are frequently the major protein source in such diets. One way to reduce the incidence of Zn deficiency may be through the development of high Zn dry beans. Large variation for dry bean seed Zn concentration exists, which would aid in the development of Zn-rich cultivars. The objectives of this study were to determine the of seed Zn levels in navy bean and to measure seed phytic acid (PA) levels in relationship to seed Zn concentration as an indicator of Zn bioavailability. A high seed Zn cultivar 'Voyager' and a low seed Zn cultivar 'Albion' were used to create the F2 and backcross populations that were field grown in 1999 and 2000. Seed Zn was measured in both years and seed phytic acid was measured in 1999. The results of this experiment suggest that a single dominant gene controls the high seed Zn concentration in the Voyager/Albion cross. In addition, phytic acid levels between the parent cultivars used in this study showed little variability and there was no strong correlation between seed Zn and PA concentrations. The development of dry bean cultivars with increased seed Zn levels should be possible through breeding.

Cockell KA (2007). An overview of methods for assessment of iron bioavailability from foods nutritionally enhanced through biotechnology. Journal of AOAC International 90: 1480-1491. http://www.atypon-link.com/AOAC/doi/abs/10.5555/jaoi.90.5.1480

Iron deficiency and iron deficiency anemia continue to be significant public health problems worldwide. While supplementation and fortification have been viable means to improve iron nutriture of the population in developed countries, they may be less successful in developing regions for a number of reasons, including complexities in distribution and consumer compliance. Biofortification of staple crops, through conventional plant breeding strategies or modern methods of biotechnology, provides an alternative approach that may be more sustainable once initial investments have been made. Three types of biofortification strategies are being essayed, singly or in combination: increasing the total iron content of edible portions of the plant, decreasing the levels of inhibitors of iron absorption, and increasing the levels of factors that enhance iron absorption. Bioavailability is a key concept in iron nutrition, particularly for nonheme iron such as is found in these biofortified foods. An overview is presented of methods for evaluation of iron bioavailability from foods nutritionally enhanced through biotechnology.

Combs GF (2001). Selenium in global food systems. British Journal of Nutrition 85: 517-547. http://dx.doi.org/10.1079/BJN2000280

Connolly EL (2008). Raising the bar for biofortification: enhanced levels of bioavailable calcium in carrots. Trends in Biotechnology 26: 401-403. http://dx.doi.org/10.1016/j.tibtech.2008.04.007

Recent efforts to increase the levels of Ca in the edible portions of plants have used a modified calcium/proton antiporter [known as short cation exchanger 1 (sCAX1)] to increase Ca transport into vacuoles. New work has shown that consumption of Ca-fortified carrots results in enhanced Ca absorption. These studies highlight the potential of increasing plant nutrient content through expression of a high-capacity transporter and illustrate the importance of demonstrating that the fortified nutrient is bioavailable.

Cox DN, Bastiaans K (2007). Understanding Australian consumers perceptions of selenium and motivations to consume selenium enriched foods. Food Quality and Preference 18: 66-76. http://dx.doi.org/10.1016/j.foodqual.2005.07.015

Consumers' knowledge of antioxidants, minerals and selenium (Se), their relationship to disease risk reduction, preferences for increasing Se intakes and motivations to consume Se enriched foods to reduce the risk of some cancers were measured using two separate questionnaires: (1) "knowledge" (n = 62) and (2) "preferences and motivations" (n = 212). The two groups had similar socio-demographic characteristics. Knowledge of antioxidants and their role in disease prevention was generally low and Se, as an antioxidant, unknown however associations were made between antioxidants and foods. Se was not recognized as a mineral. There was favourability towards Se enrichment of foods, particularly biofortification (Se enrichment of soils) above enrichment during manufacturing, or supplements. Supplement users (34%) were significantly more favourable towards Se enrichment of foods generally. Multiple regression analysis applied to variables within protection motivation theory found that the "importance of consuming Se enriched foods" was predicted by product efficacy (b 0.35); severity/fear of cancer (b 0.19); self-efficacy (b 0.16) and vulnerability to cancer (b 0.15; all $p < 0.01$; R2 0.35). However when the dependent variable was product specific (likelihood to consume Se enriched bread, dairy, etc.) the main predictor was self-efficacy (b 0.70-0.86; $p < 0.001$; R2 0.55-0.76) with vulnerability an additional significant predictor for some products.

Cvitanich C, Przybyłowicz WJ, Mesjasz-Przybyłowicz J, Blair MW, Jensen EØ, Stougaard J (2009). Iron, zinc, and manganese distribution in mature soybean seeds. Paper 1231, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1231

Micronutrient deficiencies have a negative impact in the lives of millions of people worldwide. Most affected are children and pregnant women in developing regions. Biofortification is a sustainable way to alleviate micronutrient deficiencies in at-risk populations. To optimize the biofortification approach, it is important to consider both the quantities and bioavailability of the target micronutrients. Both the speciation and the localization of the micronutrients within the seed can have an impact on bioavailability. In this study we use the sensitive and non-destructive micro-PIXE technique to reveal the distribution of iron, zinc, manganese and phosphorus within soybean seeds. We show that high concentrations of iron accumulate in the seed coats of mature soybean seeds. This iron accounted for 20 to 40% of the total seed iron. Furthermore, manganese and iron accumulated in close proximity to each other in the provascular tissue of the soybean radicle. No regions with increased accumulation of iron, zinc, or manganese were observed in the cotyledons. The concentrations of both phosphorus and zinc were higher in the radicle compared to the cotyledons, and zinc accumulated primarily near the radicle tip. Our study provides a thorough description of the distribution of important micronutrients within the mature soybean seed.

Dai JL, Zhu YG, Huang YZ, Zhang M, Song JL (2006). Availability of iodide and iodate to spinach (Spinacia oleracea L.) in relation to total iodine in soil solution. Plant and Soil 289: 301-308. http://dx.doi.org/10.1007/s11104-006-9139-7

A greenhouse pot experiment was carried out to investigate the availability of iodide and iodate to soil-grown spinach (Spinacia oleracea L.) in relation to total iodine concentration in soil solution. Four iodine concentrations (0, 0.5, 1, 2 mg kg-1) for iodide (I-) and iodate (IO3-) were used. Results showed that the biomass productions of spinach were not significantly affected by the addition of iodate and iodide to the soil, and that iodine concentrations in spinach plants on the basis of fresh weights increased with increasing addition of iodine. Iodine concentrations in tissues were much greater for plants grown with iodate than with iodide. In contrast to the iodide treatments, in iodate treatment leaves accounted for a larger fraction of the total plant iodine. The soil-to-leaf transfer factors (TFleaf) for plants grown with iodate were about tenfold higher than those grown with iodide. Iodine concentrations in soil solution increased with increasing iodine additions to the soil irrespective of iodine species. However, total iodine in soil solution was generally higher for iodate treatments than iodide both in pots with and without spinach. According to these results, iodate can be considered as potential iodine fertilizer to increase iodine content in vegetables.

Darrigues A, Schwartz SJ, Francis DM (2008). Optimizing sampling of tomato fruit for carotenoid content with application to assessing the impact of ripening disorders. Journal of Agricultural and Food Chemistry 56: 483-487. http://dx.doi.org/10.1021/jf071896v

Color defines one aspect of quality for tomato and tomato products. Carotenoid pigments are responsible for the red and orange colors of tomato fruit, and thus color is also of dietary interest. The aims of this study were (1) to determine the relative importance of field sampling and analytical replication when measuring lycopene and β-carotene in tomato fruit and (2) to determine the effect of yellow shoulder disorder (YSD) on the content of lycopene and β-carotene in tomato juice and tissue. Our results show that increasing biological replications is an efficient strategy for reducing the experimental error associated with measurements of lycopene and β-carotene. Analytical replications did not contribute significantly to observed variation, and therefore experimental efficiency will be gained by reducing analytical replications while increasing field replication. We found that YSD significantly reduces lycopene in affected tissue and in juice made from affected fruit. In contrast, β-carotene concentrations were only reduced in affected tissue but were not significantly reduced in juice. With increasing interest in biofortified crops, modulating the carotenoid profile in tomato by minimizing YSD symptoms represents a strategy for improving tomato fruit quality that is currently supported by grower contract structure and processor grades.

Datta K, Rai M, Parkhi V, Oliva N, Tan J, Datta SK (2006). Improved 'golden' indica rice and post-transgeneration enhancement of metabolic target products of carotenoids (b-carotene) in transgenic elite cultivars (IR64 and BR29). Current Science 91: 935-939. http://www.ias.ac.in/currsci/oct102006/contents.htm

Transgene stability and post-translational expression levels of genes are of tremendous interest for developing value-added transgenic crops. Transgenic high-yielding indica rice cultivars (IR64 and BR29) with enhanced level of carotenoid accumulation have been developed by Agrobacterium-mediated transformation. Genetic transformation was done using non-antibiotic PositechTM marker system. Selectable marker gene, phosphomannose isomerase (pmi), and two carotenogenic pathway genes, phytoene synthase (psy) and phytoene desaturase (crtI) were introduced in two popular Asian rice cultivars, IR64 and BR29. The highest level of total carotenoids obtained in progenies of trangenic BR29 was 9.34 mg/g and b-carotene level alone reached to 3.92 mg/g in polished grains. Whereas the highest accumulation of total carotenoids obtained in transgenic progenies of IR64 was 2.32 mg/g in polished grains. T2 seeds showed higher carotenoid content than the original parental line which might be attributed to posttransgeneration effect.

Datta SK, Datta K, Parkhi V, Rai M, Baisakh N, Sahoo G, Rehana S, Bandyopadhyay A, Alamgir Md, Ali MdS, Abrigo E, Oliva N, Torrizo L (2007). Golden rice: introgression, breeding, and field evaluation. Euphytica 154: 271-278 . http://dx.doi.org/10.1007/s10681-006-9311-4

Considerable progress has been made on the genetic engineering of rice for improved nutritional content involving micronutrients and carotenoid content. Golden Rice, developed by genetic engineering (Agrobacterium and biolistic transformation) was used in rice breeding for the transfer of high-nutritional value to the local rice cultivars. Simultaneously, commercial Asian indica rice cultivars were also developed with expression of high-carotenoid levels. The lines were developed based on POSITECH (PMI) selection system or made marker free by segregating out the marker gene from the gene of interest. Anther culture was used to develop the homozygous stable lines, which could be of much use in further introgress-breeding and in farmer's field. Enhanced carotenoids levels (up to T3 generation) were observed in a number of lines compared to the T0-T1 seeds which could be due to transgeneration effect of growing under greenhouse versus field conditions. However, a few introgressed lines showed less carotenoid levels than the original lines used in the breeding process. Agronomic performance of introgressed lines, non-transgenic controls, and transgenic golden rice (IR64 and BR29) developed at IRRI showed acceptable and comparable data under identical limited field conditions (screenhouse data). Syngenta generated a new Golden Rice (US cultivar) containing high level of carotenoids grown in the field at Louisiana, USA is expected to be available to the public domain. Incorporation of genes for carotenogenesis in seeds by transgenesis or by introgression did not change any significant agronomic characteristics in rice plants. The ongoing and future study of bioavailability, quality, larger field testing and freedom to operate will ensure the benefit of Golden Rice to the people who need them most.

Davey MW, Keulemans J, Swennen R (2006). Methods for the efficient quantification of fruit provitamin A contents. Journal of Chromatography A 1136: 176-184. http://dx.doi.org/10.1016/j.chroma.2006.09.077

As part of a screening program to identify micronutrient-rich banana and plantain (Musa) varieties, a simple, robust, and comparatively rapid protocol for the quantification of the provitamin A carotenoids contents of fruit pulp and peel tissues by HPLC and by spectrophotometry has been developed. Major points to note include the use lyophilisation and extensive tissue disruption procedures to ensure quantitative recoveries, and the avoidance of saponification and/or concentration steps which lead to significant losses of provitamin A carotenoids. The protocol showed excellent reproducibility between replicate extractions, without the need for an internal standard. Application of the methodology demonstrated that Musa fruit pulp has a relatively simple provitamin A carotenoids content, quite different from the overlying peel, and that the proportions of a- and b-carotene are characteristic for each genotype. The protocol was also used to profile the provitamin A carotenoids of several other fruits.

Davey MW, Van den Bergh I, Markham R, Swennen R, Keulemans J (2009). Genetic variability in Musa fruit provitamin A carotenoids, lutein and mineral micronutrient contents. Food Chemistry 115: 806-813. http://dx.doi.org/10.1016/j.foodchem.2008.12.088

Bananas and plantains (Musa spp.) are a staple food for millions of impoverished people and as such are an important source of vitamins and micronutrients. To evaluate the potential of Musa spp. to meet dietary micronutrients requirements, we have screened 171 different genotypes for fruit provitamin A carotenoids (pVACs) contents, and a subset of 47 genotypes for macro- and micro-mineral (iron and zinc) contents using standardised sampling and analytical protocols. The results indicate that there is substantial variability in mean fruit pulp pVACs contents between cultivars, and that cultivars with a high fruit pVACs content are widely distributed across the different genome groups but only at a low frequency. The introduction of such high pVACs cultivars has much potential for improving the vitamin A nutritional status of Musa-dependent populations at modest and realistic fruit-consumption levels. In contrast, fruit pulp mineral micronutrient contents (iron and zinc), were low and showed limited inter-cultivar variability, even for genotypes grown under widely-differing environments and soil types. Results are discussed within the framework of the development of strategies to improve the nutritional health and alleviation of micronutrient deficiencies within Musa-consuming population groups.

Davies KM (2007). Genetic modification of plant metabolism for human health benefits. Mutation Research 622: 122-137. http://dx.doi.org/10.1016/j.mrfmmm.2007.02.003

There has been considerable research progress over the past decade on elucidating biosynthetic pathways for important human health components of crops. This has enabled the use of genetic modification (GM) techniques to develop crop varieties with increased amounts of essential vitamins and minerals, and improved profiles of 'nutraceutical' compounds. Much of the research into vitamins and minerals has focused on generating new varieties of staple crops to improve the diet of populations in developing nations. Of particular note is the development of new rice lines with increased amounts of provitamin A and iron. Research on modifying production of nutraceuticals has generally been aimed at generating new crops for markets in the developed nations, commonly to deliver distinctive cultivars with high consumer appeal. Most progress on nutraceuticals has been made with just a few types of metabolites to date, in particular in the production of novel long-chain polyunsaturated fatty acids in oil-seed crops and to increase amounts of flavonoids and carotenoids in tomato and potato. However, given the rapid progress on elucidating plant metabolite biosynthetic pathways, wide-ranging success with metabolic engineering for levels of human health-related compounds in plants would be expected in the near future. A key aspect for future success will be better medical information to guide metabolic engineering endeavors. Although the desired levels of many vitamins are known, detailed information is lacking for most of the nutraceuticals that have attracted much interest over the past few years.

Davis C, Jing H, Howe JA, Rocheford T, Tanumihardjo SA (2008). b-Cryptoxanthin from supplements or carotenoid-enhanced maize maintains liver vitamin A in Mongolian gerbils (Meriones unguiculatus) better than or equal to b-carotene supplements. British Journal of Nutrition 100: 786-793. http://dx.doi.org/10.1017/S0007114508944123

Maize with enhanced provitamin A carotenoids (biofortified), accomplished through conventional plant breeding, maintains vitamin A (VA) status in Mongolian gerbils (Meriones unguiculatus). Two studies in gerbils compared the VA value of b-cryptoxanthin with b-carotene. Study 1 (n 47) examined oil supplements and study 2 (n 46) used maize with enhanced b-cryptoxanthin and b-carotene. After 4 weeks' depletion, seven or six gerbils were killed; remaining gerbils were placed into weight-matched groups of 10. In study 1, daily supplements were cottonseed oil, and 35, 35 or 17•5 nmol VA (retinyl acetate), b-cryptoxanthin or b-carotene, respectively, for 3 weeks. In study 2, one group of gerbils was fed a 50% biofortified maize diet which contained 2•9 nmol b-cryptoxanthin and 3•2 nmol b-carotene/g feed. Other groups were given equivalent b-carotene or VA supplements based on prior-day intake from the biofortified maize or oil only for 4 weeks. In study 1, liver retinol was higher in the VA (0•74 (SD 0•11) mmol) and b-cryptoxanthin (0•65 (SD 0•10) mmol) groups than in the b-carotene (0•49 (SD 0•13) mmol) and control (0•41 (SD 0•16) mmol) groups (P,0•05). In study 2, the VA (1•17 (SD 0•19) mmol) and maize (0•71 (SD 0•18) mmol) groups had higher liver retinol than the control (0•42 (SD 0•16) mmol) group (P,0•05), whereas the b-carotene (0•57 (SD 0•21) mmol) group did not. Bioconversion factors (i.e. 2•74mg b-cryptoxanthin and 2•4 mg b-carotene equivalents in maize to 1mg retinol) were lower than the Institute of Medicine values.

Dawe D, Unnevehr L (2007). Crop case study: GMO Golden Rice in Asia with enhanced vitamin A benefits for consumers. AgBioForum 10: 154-160. http://www.agbioforum.org/v10n3/v10n3a04-unnevehr.htm

Golden Rice is genetically modified to provide beta-carotene in the rice grain and it could potentially address widespread Vitamin A deficiency in poor countries where rice is a staple. Political opponents have viewed Golden Rice as representing the interests of multi-nationals and as inherently unsafe for consumption. Progress has been made towards adapting this crop to tropical-rice growing environments, but it has not yet been introduced into farmer's fields. Efficacy and safety have not yet been fully tested. Substantial work remains to target and deliver this intervention to Vitamin A-deficient populations, and to overcome remaining resistance to this technology. The political response to the on-going development of Golden Rice is reviewed to draw lessons for biofortification efforts that employ modern biotechnology. Within Asian countries, successful development and delivery will require policy dialogue among agriculturalists, health specialists, and advocates for the poor.

Dawson IK, Hedley PE, Guarino L, Jaenicke H (2009). Does biotechnology have a role in the promotion of underutilised crops? Food Policy 34: 319-328. http://dx.doi.org/10.1016/j.foodpol.2009.02.003

Rapidly developing biotechnology applications aimed at improving major crops receive large investments and could, in theory, play a role in the promotion of underutilised plant species in the tropics and subtropics, in order to address current and emerging challenges for agriculture. The application of such methods is, however, sometimes controversial, and the frequently considerable costs involved must be weighed against the limited resources available to develop underutilised species, as well as against the many alternative methods available for promotion. Through database searches, we take an evidencebased approach to assess whether there are clear examples where biotechnology has been used practically to enhance the cultivation of underutilised plants at a field level. We conclude that tissue culture and micropropagation techniques have proven useful, but for other applications benefits are generally unclear at present, although ongoing work suggests genomic and genetic modification approaches may in future be significant for a subset of underutilised species. Successful outcomes, however, appear to be limited by a lack of integrated thinking during the use of biotechnology methods. We review the particular limitations and risks associated with applying biotechnology to underutilised crops, including the negative consequences of technology centralisation. In addition, the specific actions needed to ensure that smallholder farmers in low-income countries better benefit during the use of biotechnology on underutilised species, by placing a stronger emphasis on partnerships and by proper monitoring of benefits along value chains, are described.

de Benoist B, Andersson M, Egli I, Takkouche B, Allen H (eds) (2004). Iodine status worldwide: WHO global database on iodine deficiency. Geneva: World Health Organization. http://www.who.int/vmnis/iodine/status/

de Benoist B, McLean E, Egli I, Cogswell M (2008). Worldwide prevalence of anaemia 1993-2005: WHO global database on anaemia. Geneva: World Health Organization. http://www.who.int/vmnis/anaemia/prevalence/

De Groote H, Chege Kimenju S (2008). Comparing consumer preferences for color and nutritional quality in maize: application of a semi-double-bound logistic model on urban consumers in Kenya. Food Policy 33: 362-370. http://dx.doi.org/10.1016/j.foodpol.2008.02.005

Consumer preferences for white maize in East and Southern Africa concerns developers of maize biofortified with provitamin A carotenoids, since carotenoids impart a yellow or orange coloration. Urban consumers' willingness to pay (WTP) for yellow maize was estimated, using a semi-double-bounded logistic model, based on a survey of 600 maize consumers in Nairobi, Kenya, at posho mills, kiosks and supermarkets. Consumers showed a strong preference for white maize. Only a minority would buy yellow maize at the same price as white maize, and fewer consumers in the posho mills (24%) and kiosks (19%) than in the supermarkets (34%) would do so. On average, consumers need a price discount of 37% to accept yellow maize. This discount was less at the posho mills (35%) and kiosks (37%) than in the supermarkets (48%). Most respondents (76%) were aware of the existence of fortified meal and the generally showed an interest. The average premium for fortified maize was much less than the discount for yellow: 5.9% for those aware and 7.4% for those unaware. Consumer preferences were influenced by socioeconomic factors such as gender, education, income and ethnic background. Women have a stronger preference for both white maize and fortified maize than men, and consumers with more education have a stronger preference for white. Income decreases the WTP for yellow maize as well as the price elasticity, but increases the WTP for fortified maize. Consumers originating from Western Kenya have a lower preference for white, while those from Central Kenya had a stronger preference for fortified maize.

De Steur H, Gellynck X, Storozhenko S, Liqun G, Lambert W, Van Der Straeten D, Viaene J (2009). Willingness to accept and purchase genetically modified rice with high folate content in Shanxi province, China. Appetite in press. http://dx.doi.org/10.1016/j.appet.2009.09.017

Neural-Tube Defects (NTD) are considered to be the most common congenital malformations. As Shanxi Province, a poor region in the North of China, has one of the highest reported prevalence rates of NTD's in the world, folate fortification of rice is an excellent alternative to low intake of folate acid pills in this region. This paper investigates the relations between socio-demographic indicators, consumer characteristics (knowledge, consumer perceptions on benefits, risks, safety and price), willingness-toaccept and willingness-to-pay genetically modified (GM) rice. The consumer survey compromises 944 face-to-face interviews with rice consumers in Shanxi Province, China. Multivariate analyses consist of multinomial logistic regression and multiple regression. The results indicate that consumers generally are willing to accept GM rice, with an acceptance rate of 62,2 %. Acceptance is influenced by objective knowledge and consumer' perceptions on benefits and risks. Willingness-to-pay GM rice is influenced by objective knowledge, risk perception and acceptance. Communication towards the use of GM rice should target mainly improving knowledge and consumers' perceptions on high-risk groups within Shanxi Province, in particular low educated women.

DellaPenna D (2007). Biofortification of plant-based food: enhancing folate levels by metabolic engineering. PNAS 104: 3675-3676. http://dx.doi.org/10.1073/pnas.0700640104

Humans require a minimum daily intake of essential micronutrients, vitamins, and minerals to maintain optimal health. Micronutrient malnutrition, the dietary insufficiency of one or more micronutrients, has far-reaching negative health consequences at all stages of life and was a pervasive health issue for all countries at the turn of the 20th century. Micronutrient malnutrition has been significantly alleviated for those populations in developed countries as a result of programs established in the mid-20th century that fortified processed foods with the necessary micronutrients. Similar fortification efforts have had only modest success in developing countries because an industrial level of agriculture, food-processing, and distribution that is limited or lacking in many of the targeted countries is required. Micronutrient malnutrition thus has remained a widespread and persistent global health problem in developing countries where it continues to exact an enormous toll on individuals, populations, and society (1). In the past decade, a complementary approach to fortification of processed foods, termed biofortification, has been undertaken to deliver the necessary daily micronutrients directly in the staple crops being grown and consumed by at-risk populations in developing countries (2). All plants have the biochemical activities necessary to synthesize or accumulate a near full complement of essential dietary micronutrients (the exceptions being vitamins D and B12). Unfortunately, the plant-based foods most abundantly consumed by at-risk populations (e.g., rice, wheat, cassava, and maize) contain levels of several individual micronutrients that are insufficient to meet minimum daily requirements...

Dellapenna D (2007). Breeding for nutritional aspects2. Paper 176-1, ASA-CSSA-SSSA International Annual Meetings, 4-8 November. New Orleans, LA: ASA-CSSA-SSSA. http://a-c-s.confex.com/a-c-s/2007am/techprogram/P34119.HTM

Biofortification is the process of breeding food crops that are rich in bioavailable nutrients. It is neither an agricultural research project nor a public health research program. It is both. Through plant breeding, crops fortify themselves and load nutrients into their seeds and roots, which are then harvested and eaten. Through biofortification, scientists can provide farmers with crop varieties that naturally reduce anemia, cognitive impairment, and other nutritionally related health problems, and potentially reach hundreds of millions of people. But biofortification itself will not ensure nutritional sufficiency. Plant and nutrition scientists must work within a pathway to impact that addresses not only what is technologically possible but also integrates the needs of the undernourished with farmer preference. HarvestPlus is working to breed, test, and disseminate agronomically superior varieties of biofortified staple crops that are dense in bioavailable nutrients and preferred by farmer and consumer alike. Six staple crops and three nutrients form the core of the program. Ninety five researchers in over 40 countries conduct research and implementation work. For biofortification to be successful, researchers and implementation partners work along this pathway to impact that is the guiding framework marrying the powers of modern plant breeding, with rigorous nutritional testing, and marketing and behavior research to reduce undernutrition of millions of people whose diet is made up of primarily staple foods.

Denova-Gutiérrez E, García-Guerra A, Flores-Aldana M, Rodríguez-Ramírez S, Hotz C (2008). Simulation model of the impact of biofortification on the absorption of adequate amounts of zinc and iron among Mexican women and preschool children. Food and Nutrition Bulletin 29: 203-212. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/1994

Background. Biofortification is an agricultural process that attempts to increase the iron and zinc content of staple food crops. Improving the absorption of zinc and iron could contribute to reducing the high rates of deficiency of these micronutrients in developing-country settings. Objective. To simulate the effects of biofortification of staple food crops (maize, wheat, rice, and beans) on the absorption of zinc and iron among women and children in Mexico. Methods. We analyzed dietary data from the 1999 Mexican National Nutrition Survey. On the basis of the intake of the four staple food crops and the increase in zinc and iron content that could be achieved by conventional breeding in the short term, the prevalence of inadequacy in the amounts of absorbed zinc and iron was determined. The mean increase in the amounts of absorbed zinc and iron was compared according to rural and urban residence and according to region of the country. Results. In rural areas, simulated biofortification of maize resulted in a reduction in the prevalence of absorption of inadequate amounts of zinc of 47% in children and 56% in women but had no effect on the prevalence of absorption of inadequate amounts of iron. The increase in zinc absorption was greater in rural populations and in the Central and Southern regions ($p < .05$). Conclusions. Biofortification of maize could significantly improve zinc absorption among children and women in Mexico living in areas most vulnerable to zinc deficiency. Studies of the biological impact of biofortified maize on zinc status are warranted.

Díaz de la Garza RI, Gregory III JF, Hanson AD (2007). Folate biofortification of tomato fruit. PNAS 104: 4218-4222. http://dx.doi.org/10.1073/pnas.0700409104

Folate deficiency leads to neural tube defects and other human diseases, and is a global health problem. Because plants are major folate sources for humans, we have sought to enhance plant folate levels (biofortification). Folates are synthesized from pteridine, p-aminobenzoate (PABA), and glutamate precursors. Previously, we increased pteridine production in tomato fruit up to 140-fold by overexpressing GTP cyclohydrolase I, the first enzyme of pteridine synthesis. This strategy increased folate levels 2-fold, but engineered fruit were PABA-depleted. We report here the engineering of fruit-specific overexpression of aminodeoxychorismate synthase, which catalyzes the first step of PABA synthesis. The resulting fruit contained an average of 19-fold more PABA than controls. When transgenic PABA- and pteridine-overproduction traits were combined by crossing, vine-ripened fruit accumulated up to 25-fold more folate than controls. Folate accumulation was almost as high (up to 15-fold) in fruit harvested green and ripened by ethylene-gassing, as occurs in commerce. The accumulated folates showed normal proportions of one-carbon forms, with 5-methyltetrahydrofolate the most abundant, but were less extensively polyglutamylated than controls. Folate concentrations in developing fruit did not change in controls, but increased continuously throughout ripening in transgenic fruit. Pteridine and PABA levels in transgenic fruit were >20-fold higher than in controls, but the pathway intermediates dihydropteroate and dihydrofolate did not accumulate, pointing to a flux constraint at the dihydropteroate synthesis step. The folate levels we achieved provide the complete adult daily requirement in less than one standard serving.

Dickinson N, Macpherson G, Hursthouse AS, Atkinson J (2009). Micronutrient deficiencies in maternity and child health: a review of environmental and social context and implications for Malawi. Environmental Geochemistry and Health 31: 253-272. http://dx.doi.org/10.1007/s10653-008-9207-4

It is well documented that micronutrient malnutrition is of increasing concern in the developing world, resulting in poor health and high rates of mortality and morbidity. During pregnancy, deficiency of iron and zinc can produce cognitive and growth impairment of the foetus, which may continue into infancy. Iron and zinc are essential micronutrients for both plant growth and human nutrition. Despite significant work in the areas of soil fertility, crop biofortification and dietary interventions, the problems of micronutrient deficiencies persist in Africa. There is a need to examine why communities have not embraced intervention strategies which may offer health benefits. Bottom-up, interdisciplinary approaches are required to effectively study the relationships between local communities and their environment, and to assess the impact their behaviour has on the cycling of micronutrients within the soil-plant-human system. From a detailed consideration of diverse influencing factors, a methodological model is suggested for studying the barriers to improving micronutrient uptake within rural communities. It combines environmental understanding with health and social factors, emphasising the need for and potential benefits of understanding and coherence in true interdisciplinary working.

Ecker O, Qaim M (2008). Income and price elasticities of food demand and nutrient consumption in Malawi. Annual Meeting, 27-29 July. Orlando, FL: American Agricultural Economics Association. http://purl.umn.edu/6349

Widespread malnutrition in developing countries calls for appropriate interventions, presupposing good knowledge about the nutritional impacts of policies. Little previous work has been carried out in this direction. We present a comprehensive analytical framework, which we apply for Malawi. Using household data and a demand systems approach, we estimate income and price elasticities of food, calorie, and micronutrient consumption. These estimates are used for policy simulations. Given multiple nutrient deficiencies, income-related policies are better suited than price policies to improve nutrition. While consumer subsidies for maize increase calorie and mineral consumption, they contribute to a higher prevalence of vitamin deficiencies.

Engle-Stone R, Yeung A, Welch R, Glahn R (2005). Meat and ascorbic acid can promote Fe availability from Fe-phytate but not from Fe-tannic acid complexes. Journal of Agricultural and Food Chemistry 53: 10276-10284. http://dx.doi.org/10.1021/jf0518453

This study utilized an in vitro digestion/Caco-2 cell model to determine the levels of ascorbic acid (AA) and "meat factor" needed to promote Fe absorption from Fe complexed with phytic acid (PA) or tannic acid (TA). AA reversed the inhibition of Fe absorption by PA beginning at a molar ratio of 1:20:1 (Fe:PA:AA) but essentially had no effect on the Fe complexed with TA. Fish also reversed the inhibition of Fe uptake by PA but not by TA. TA and fish decreased total Fe solubility. Iron in the presence of PA was highly soluble. AA, but not fish, increased the percentage of soluble Fe as Fe2+ in the presence of both inhibitors. The results indicate that monoferric phytate is a form of Fe that can be available for absorption in the presence of uptake promoters. In contrast, a TA-Fe complex is much less soluble and unavailable in the presence of promoters.

Ezedinma CI, Nkang NM (2008). The effect of quality on gari prices in Nigeria: a hedonic analysis. Food, Agriculture & Environment 6: 18-23. http://www.world-food.net/scientficjournal/2008/issue1/abstracts/abstract3.php

This article examines the effect of quality attributes on price of gari, a major staple processed from cassava roots in Nigeria. The effect of quality on prices is estimated under the hedonic function by means of logit model. Two hundred key informants were interviewed in 94 rural markets visited and 100 wholesale traders were interviewed in a big urban market in Lagos, a major commercial city in Nigeria. The markets that supply gari to Lagos are located in the southeast and southwest zones of Nigeria. Gari prices from the southeast zone were generally lower than prices from the southwest zone even though rural markets in the southwest zone were closer to the urban market. Efficiency in cassava production and the processing of gari in the southeast zone may be important in determining the magnitude of the marketing margins and the price differences. Different colours (yellow or white) also command different prices in the market. The study reveals that yellow gari commands a better price than white gari. However, certain ethnic groups despite the better nutrition that can be gained when biofortified with vitamin A do not usually prefer yellow gari with coarse texture. There may be need to change producer and consumer preference through sensitisation and capacity building especially in areas were yellow gari is not currently preferred such as in southwest Nigeria. The relative higher price for yellow gari suggests that research on cassava biofortified with β-carotene (which imparts a yellow colour in a natural form) may also help to improve gari prices as well as improve consumer nutrition and shelf life of yellow gari. These results provide further socio-economic justification for research on crop biofortification in developing countries.

FAO (2009a). The state of food insecurity in the world 2009. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/publications/sofi/en/

FAO (2009b). FAO Summit boosts agriculture to end hunger. Media Centre. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/news/story/en/item/37465/icode/

Finglas PM, de Meer K, Molloy A, Verhoef P, Pietrzik K, Powers HJ, van der Straeten D, Jägerstad M, Varela-Moreiras G, van Vliet T, Havenaar R, Buttriss J, Wright AJA (2006). Research goals for folate and related B vitamin in Europe. European Journal of Clinical Nutrition 60: 287-294. http://dx.doi.org/10.1038/sj.ejcn.1602315

In the past decade, the understanding of folate bioavailability, metabolism and related health issues has increased, but several problems remain, including the difficulty of delivering the available knowledge to the populations at risk. Owing to the low compliance of taking folic acid supplements, for example, among women of child-bearing age who could lower the risk of having a baby with a neural tube defect, food-based strategies aimed at increasing the intake of folate and other B-group vitamins should be a priority for future research. These should include the development of a combined strategy of supplemental folate (possibly with vitamin B12), biofortification using engineered plant-derived foods and micro-organisms and food fortification for increasing folate intakes in the general population. Currently, the most effective population-based strategy to reduce NTDs remains folic acid fortification. However, the possible adverse effect of high intakes of folic acid on neurologic functioning among elderly persons with vitamin B12 deficiency needs urgent investigation. The results of ongoing randomized controlled studies aimed at reducing the prevalence of hyperhomocysteinemia and related morbidity must be available before food-based total population approaches for treatment of hyperhomocysteinemia can be recommended. Further research is required on quantitative assessment of folate intake and bioavailability, along with a more thorough understanding of physiological, biochemical and genetic processes involved in folate absorption and metabolism.

Fitzgerald MA, McCouch SR, Hall RD (2009). Not just a grain of rice: the quest for quality. Trends in Plant Science 14: 133-139. http://dx.doi.org/10.1016/j.tplants.2008.12.004

A better understanding of the factors that contribute to the overall grain quality of rice (Oryza sativa) will lay the foundation for developing new breeding and selection strategies for combining high quality, with high yield. This is necessary to meet the growing global demand for high quality rice while offering producing countries additional opportunities for generating higher export revenues. Several recent developments in genetics, genomics, metabolomics and phenomics are enhancing our understanding of the pathways that determine several quality traits. New research strategies, as well as access to the draft of the rice genome, will not only advance our understanding of the molecular mechanisms that lead to quality rice but will also pave the way for efficient and targeted grain improvement.

Fogel RW (2004). The escape from hunger and premature death, 1700-2100: Europe, America, and the Third World. Cambridge University Press, Cambridge, MA. http://www.cambridge.org/us/catalogue/catalogue.asp?isbn=9780511206979

Foyer CH, DellaPenna D, Van Der Straeten D (2006). A new era in plant metabolism research reveals a bright future for bio-fortification and human nutrition. Physiologia Plantarum 126: 289-290. http://dx.doi.org/10.1111/j.1399-3054.2006.00661.x

The first three to four decades of the 20th century have been called the golden age of nutrition science, because most of the dietary requirements to keep us alive and healthy were mapped out during this period. The vitamins, minerals, amino acids, and fatty acids necessary to avoid the typical symptoms and diseases of deficiency were identified and characterized, and the amounts of these nutrients required on a daily basis to avoid deficiency were estimated. Although micronutrient deficiencies and particularly vitamin deficiencies continue to have profound effects on human health on populations throughout the developing world, the application of nutritional science together with the massive social and economic changes that occurred during the last century has led to the virtual eradication of the nutrient-deficiency diseases, at least in the developed world. Hence, the preoccupation of modern nutrition in the developed world has shifted to trying to understand and if possible to prevent diseases where diet is but one risk factor. The etiology of these diseases such as cancers, atherosclerosis, and diabetes as well as obesity is complex and multifactorial. They are certainly not the consequence of an isolated nutrient deficiency, but a role for diet in significantly influencing the risk of incidence has been clearly established.

Genc Y, Humphries JM, Lyons GH, Graham RD (2005). Exploiting genotypic variation in plant nutrient accumulation to alleviate micronutrient deficiency in populations. Journal of Trace Elements in Medicine and Biology 18: 319-324. http://dx.doi.org/10.1016/j.jtemb.2005.02.005

More than 2 billion people consume diets that are less diverse than 30 years ago, leading to deficiencies in micronutrients, especially iron (Fe), zinc (Zn), selenium (Se), iodine (I), and also vitamin A. A strategy that exploits genetic variability to breed staple crops with enhanced ability to fortify themselves with micronutrients (genetic biofortification) offers a sustainable, cost-effective alternative to conventional supplementation and fortification programs. This is more likely to reach those most in need, has the added advantages of requiring no change in current consumer behaviour to be effective, and is transportable to a range of countries. Research by our group, along with studies elsewhere, has demonstrated conclusively that substantial genotypic variation exists in nutrient (e.g. Fe, Zn) and nutrient promotor (e.g. inulin) concentrations in wheat and other staple foods. A rapid screening technique has been developed for lutein content of wheat and triticale, and also for pro-vitamin A carotenoids in bread wheat. This will allow cost-effective screening of a wider range of genotypes that may reveal greater genotypic variation in these traits. Moreover, deeper understanding of genetic control mechanisms and development of molecular markers will facilitate breeding programs. We suggest that a combined strategy utilising plant breeding for higher micronutrient density; maximising the effects of nutritional promoters (e.g. inulin, vitamin C) by promoting favourable dietary combinations, as well as by plant breeding; and agronomic biofortification (e.g. adding iodide or iodate as fertiliser; applying selenate to cereal crops by spraying or adding to fertiliser) is likely to be the most effective way to improve the nutrition of populations. Furthermore, the importance of detecting and exploiting beneficial interactions is illustrated by our discovery that in Fe-deficient chickens, circulating Fe concentrations can be restored to normal levels by lutein supplementation. Further bioavailability/bioefficacy trials with animals and humans are needed, using varying dietary concentrations of Fe, Zn, carotenoids, inulin, Se and I to elucidate other important interactions in order to optimise delivery in biofortification programs.

Ghandilyan A, Vreugdenhil D, Aarts MGM (2006). Progress in the genetic understanding of plant iron and zinc nutrition. Physiologia Plantarum 126: 407-417. http://dx.doi.org/10.1111/j.1399-3054.2006.00646.x

In this review, we describe the need and progress to improve the iron and zinc contents in crop plants by genetic means. To achieve this goal either by transgenic approaches or classical breeding, knowledge about the physiological and molecular mechanisms of mineral uptake and mineral homeostasis will be very helpful. The progress in our understanding of the molecular processes and genes is described, and the use of the identified genes by transgenic approaches is illustrated. Genetic mapping of the existing variation will allow marker-assisted breeding to exploit the available natural variation in crop plants. For this application, ultimately the knowledge of the genes underlying this quantitative variation, called quantitative trait loci (QTL), will be required. It is expected that research in this field in the model species Arabidopsis thaliana, where the molecular tools are available, might help in the identification of the allelic variation at QTL.

Gibson RS (2006). Zinc: the missing link in combating micronutrient malnutrition in developing countries. Proceedings of the Nutrition Society 65: 51-60. http://dx.doi.org/10.1079/PNS2005474

The first cases of human Zn deficiency were described in the 1960s in the Middle East. Nevertheless, it was not until 2002 that Zn deficiency was included as a major risk factor in the global burden of disease, and only in 2004 did WHO/UNICEF include Zn supplements in the treatment of acute diarrhoea. Despite this recognition Zn is still not included in the UN micronutrient priority list, an omission that will continue to hinder efforts to reduce child and maternal mortality, combat HIV/AIDS, malaria and other diseases and achieve the UN Millennium Development Goals for improved nutrition in developing countries. Reasons for this omission include a lack of awareness of the importance of Zn in human nutrition, paucity of Zn and phytate food composition values and difficulties in identifying Zn deficiency. Major factors associated with the aetiology of Zn deficiency include dietary inadequacies, disease states inducing excessive losses or impairing utilization and physiological states increasing Zn requirements. To categorize countries according to likely risk of Zn deficiency the International Zinc Nutrition Consultative Group has developed indirect indicators based on the adequacy of Zn in the national food supplies

and/or prevalence of childhood growth stunting. For countries identified as at risk confirmation is required through direct measurements of dietary Zn intake and/or serum Zn in a representative sample. Finally, in at risk countries either national or targeted Zn interventions such as supplementation, fortification, dietary diversification or modification, or biofortification should be implemented, where appropriate, by incorporating them into pre-existing micronutrient intervention programmes.

Gilani GS, Ellefson W (2007). Safety and adequacy testing of foods/feeds nutritionally enhanced through biotechnology. Journal of AOAC International 90: 1439. http://www.atypon-link.com/AOAC/doi/abs/10.5555/jaoi.90.5.1439

Modern agricultural biotechnology, which includes the application of cellular and molecular methods to transfer DNA with a desired trait to food/feed crops, has tremendous potential to be a powerful complement to traditional plant breeding in enhancing the levels of essential mineral nutrients such as iron and zinc, vitamins such as provitamin A, indispensable amino acids such as lysine and methionine, and health-promoting fatty acids and antioxidants in order to offset their deficiencies and improve animal and human health. Furthermore, agribiotechnology can be used to decrease the levels of antinutrients such as allergens, phytates, and cyanogenic glucosides.

Gilani GS, Nasim A (2007). Impact of foods nutritionally enhanced through biotechnology in alleviating malnutrition in developing countries. Journal of AOAC International 90: 1440-1444. http://www.atypon-link.com/AOAC/doi/abs/10.5555/jaoi.90.5.1440

According to United Nations (UN) projections, the world's population will grow from 6.1 billion in 2000 to 8 billion in 2025 and 9.4 billion in 2050. Most (93%) of the increase will take place in developing countries. The rapid population growth in developing countries creates major challenges for governments regarding food and nutrition security. According to current World Health Organization estimates, more than 3 billion people worldwide, especially in developing countries, are malnourished in essential nutrients. Malnutrition imposes severe costs on a country's population due to impaired physical and cognitive abilities and reduced ability to work. Little progress has been made in improving malnutrition over the past few decades. The Food and Agriculture Organization of the UN would like to see more nutrient-rich foods introduced into these countries, because supplements are expensive and difficult to distribute widely. Biofortification of staple crops through modern biotechnology can potentially help in alleviating malnutrition in developing countries. Several genetically modified crops, including rice, potatoes, oilseeds, and cassava, with elevated levels of essential nutrients (such as vitamin A, iron, zinc, protein and essential amino acids, and essential fatty acids); reduced levels of antinutritional factors (such as cyanogens, phytates, and glycoalkaloid); and increased levels of factors that influence bioavailability and utilization of essential nutrients (such as cysteine residues) are advancing through field trial stage and regulatory processes towards commercialization. The ready availability and consumption of the biofortified crops would have a significant impact in reducing malnutrition and the risk of chronic disease in developing countries.

Glenn KC (2007). Nutritional and safety assessments of foods and feeds nutritionally improved through biotechnology: lysine maize as a case study. Journal of AOAC International 90: 1470-1479. http://www.atypon-link.com/AOAC/doi/abs/10.5555/jaoi.90.5.1470

During the last decade, the area of biotech crops modified for agronomic input traits (e.g., herbicide tolerance and insect protection) has increased to 90 million ha/year, grown by over 8 million farmers in a total of 17 countries. As adoption of these improved agronomic trait biotech crops has grown, so has interest in biotech crops that have improved nutritional characteristics for use as feed and food. A previous publication by the International Life Sciences Institute (ILSI) reported on the principles and concepts proposed for the nutritional and safety assessments of foods and feeds nutritionally improved through biotechnology. In this paper, the guidelines and principles recommended in the earlier publication are discussed relative to a specific case study, Lysine maize. Lysine maize is a feed ingredient with enhanced nutritional characteristics for poultry and swine and provides an alternative to the need for addition of supplemental lysine to some diets for these animals. The 2004 Task Force of the ILSI has also applied the concepts from that report to 4 other case studies: sweet potato enriched in provitamin A (2 examples, one using biotechnology and one using conventional breeding); Golden Rice 2; double-embryo maize; and ASP-1 enhanced protein sweet potato.

Gómez-Galera S, Rojas E, Sudhakar D, Zhu C, Pelacho AM, Capell T, Christou P (2009). Critical evaluation of strategies for mineral fortification of staple food crops. Transgenic Research online 15 Aug. http://dx.doi.org/10.1007/s11248-009-9311-y

Staple food crops, in particular cereal grains, are poor sources of key mineral nutrients. As a result, the world's poorest people, generally those subsisting on a monotonous cereal diet, are also those most vulnerable to mineral deficiency diseases. Various strategies have been proposed to deal with micronutrient deficiencies including the provision of mineral supplements, the fortification of processed food, the biofortification of crop plants at source with mineral-rich fertilizers and the implementation of breeding programs and genetic engineering approaches to generate mineral-rich varieties of staple crops. This review provides a critical comparison of the strategies that have been developed to address deficiencies in five key mineral nutrients – iodine, iron, zinc, calcium and selenium – and discusses the most recent advances in genetic engineering to increase mineral levels and bioavailability in our most important staple food crops.

González C, Johnson N, Qaim M (2009). Consumer acceptance of second-generation GM foods: the case of biofortified cassava in the north-east of Brazil. Journal of Agricultural Economics 60: 604-624. http://dx.doi.org/10.1111/j.1477-9552.2009.00219.x

Biofortified staple foods are currently being developed to reduce problems of micronutrient malnutrition among the poor. This partly involves use of genetic modification. Yet, relatively little is known about consumer acceptance of such second-generation genetically modified (GM) foods in developing countries. Here, we analyse consumer attitudes towards provitamin A GM cassava in the north-east of Brazil. Based on stated preference data, mean willingness to pay is estimated at 60-70% above market prices for traditional cassava. This is higher than the results from similar studies in developed countries, which is plausible given that micronutrient malnutrition is more severe in developing countries. GM foods with enhanced nutritive attributes seem to be well received by poor consumers. However, the results also suggest that acceptance would be still higher if provitamin A were introduced to cassava through conventional breeding. Some policy implications are discussed..

Graff G, Roland-Holst D, Zilberman D (2006). Agricultural biotechnology and poverty reduction in low-income countries. World Development 34: 1430-1445. http://dx.doi.org/10.1016/j.worlddev.2005.10.014

While biotechnology innovation is concentrated in high income, "Tier I" countries, international diffusion of innovations to improve the diet, health, and incomes of the poorest will be largely driven by "Tier II" innovators such as China and Brazil. Adoption of beneficial biotechnologies in "Tier II" and "Tier III" countries will increase as more transgenic versions of conventionally grown varieties become available and as costs decline, which in turn will depend upon regulatory approvals being needed only once for each transformation event and transaction costs for accessing technologies being minimized. Investments in higher education and intellectual property clearinghouse institutions can greatly facilitate technology transfer.

Grant B (2009). Where's the super food? The Scientist 23: 30. http://www.the-scientist.com/2009/09/1/30/1/

Scientists have genetically engineered several biofortified food plants to tackle a scourge of developing countries - micronutrient malnutrition. The crops have yet to be planted on a wide scale, but that may be about to change.

Gregory III JF, Quinlivan EP, Davis SR (2005). Integrating the issues of folate bioavailability, intake and metabolism in the era of fortification. Trends in Food Science & Technology 16: 229-240. http://dx.doi.org/10.1016/j.tifs.2005.03.010

The addition of folic acid to foods in the United States, Canada and several other countries has yielded improved folate nutritional status and reduced the incidence of neural tube defects. In spite of this success, a number of questions remain regarding the bioavailability of natural and added folates and the level of folate intake from dietary sources needed to meet nutritional requirements. Many aspects of current folate requirements are being expressed in terms of dietary folate equivalents, in which an adjustment is employed to account for differences in mean bioavailability of natural and added forms of folate. In this review, we discuss the scientific rationale behind such assumptions and research needs in the broad area of folate bioavailability. We also consider the merits of fortification strategies, including the biofortification of foods.

Grennan AK (2009). Identification of genes involved in metal transport in plants. Plant Physiology 149: 1623-1624. http://dx.doi.org/10.1104/pp.109.900287

Plants obtain mineral nutrients from the soil. If they are growing in soil with high levels of metals, they will take up an excess of what is needed for growth. Depending on the species, this can be detrimental to growth - or lethal - and can greatly limit the growth range of plants and the productivity of agricultural species. However, some plants have adapted to living in soil containing excess metals. A portion of these species will even hyperaccumulate the metals, leading to exceedingly high levels of metals in the plant tissues. The metal most commonly accumulated is nickel (Ni). How and why certain plants are able to accumulate - and tolerate - high levels of potentially toxic compounds has spawned diverse areas of research, including an article by Talke et al., "Zinc-dependent global transcriptional control, transcriptional deregulation, and higher gene copy number for genes in metal homeostasis of the hyperaccumulator Arabidopsis halleri," which appeared in the September 2006 issue of Plant Physiology.

Gruère G, Sengupta D (2009. GM-free private standards and their effects on biosafety decision-making in developing countries. Food Policy 34: 399-406. http://dx.doi.org/10.1016/j.foodpol.2009.04.002

Gunaratna NS, De Groote H, McCabe GP (2008). Evaluating the impact of biofortification: a meta-analysis of community-level studies on quality protein maize (QPM). XIIth EAAE Congress, 26-29 August. Ghent: European Association of Agricultural Economists. http://purl.umn.edu/44166

Biofortification, or the genetic improvement of the nutritional quality of food crops, is a promising strategy to combat undernutrition, particularly among the rural poor in developing countries. However, traditional methods of impact assessment do not apply to biofortified crops as little or no yield increases are expected. Significant progress has been made to develop maize varieties with improved protein quality, collectively known as quality protein maize (QPM). Evidence for the impact of QPM at the community level, as demonstrated by randomized, controlled studies, was evaluated using meta-analysis. A new and generalizable effect size was proposed to quantify the impact of QPM on a key outcome, child growth. The results indicated that consumption of QPM instead of conventional maize leads to an 8% (95% CI: 4-12%) increase in the rate of growth in height and a 9% (95% CI: 4-12%) increase in the rate of growth in weight in infants and young children with mild to moderate undernutrition from populations in which maize is a significant part of the diet. These results are the first step in evaluating the potential economic impact of QPM by establishing and quantifying a link between use of the improved crop and nutritional outcomes. QPM can serve as a model for other biofortification efforts, and in particular, the conceptual framework and methodologies for impact assessment are directly applicable to other biofortified crops.

Haas JD, Beard JL, Murray-Kolb LE, del Mundo AM, Felix A, Gregorio GB (2005). Iron-biofortified rice improves the iron stores of nonanemic Filipino women. Journal of Nutrition 135: 2823-2830. http://jn.nutrition.org/cgi/content/abstract/135/12/2823

Iron deficiency is endemic in much of the world, and food system-based approaches to eradication may be viable with new plant breeding approaches to increase the micronutrient content in staple crops. It is thought that conventional plant breeding approaches provide varieties of rice that have 400-500% higher iron contents than varieties commonly consumed in much of Asia. The efficacy of consuming high-iron rice was tested during a 9-mo feeding trial with a double-blind dietary intervention in 192 religious sisters living in 10 convents around metro Manila, the Philippines. Subjects were randomly assigned to consume either high-iron rice (3.21 mg/kg Fe) or a local variety of control rice (0.57 mg/kg Fe), and daily food consumption was monitored. The high-iron rice contributed 1.79 mg Fe/d to the diet in contrast to 0.37 mg Fe/d from the control rice. The 17% difference in total dietary iron consumption compared with controls (10.16 +- 1.06 vs. 8.44 +- 1.82 mg/d) resulted in a modest increase in serum ferritin (P = 0.10) and total body iron (P = 0.06) and no increase in hemoglobin (P = 0.59). However, the response was greater in nonanemic subjects for ferritin (P = 0.02) and body iron (P = 0.05), representing a 20% increase after controlling for baseline values and daily rice consumption. The greatest improvements in iron status were seen in those nonanemic women who had the lowest baseline iron status and in those who consumed the most iron from rice. Consumption of biofortified rice, without any other changes in diet, is efficacious in improving iron stores of women with iron-poor diets in the developing world.

Haas JH, Miller DD (2006). Overview of Experimental Biology 2005 Symposium: food fortification in developing countries. Journal of Nutrition 136: 1053-1054. http://jn.nutrition.org/cgi/content/short/136/4/1053

Micronutrient malnutrition is a major global public health problem affecting more than a third of the world population. Consequences of this malnutrition are widespread and severe. It has been estimated that iron deficiency impairs the mental development of 40 to 60% of children in developing countries, vitamin A deficiency affects 40% of children ,5 y of age in the developing world and is a factor in .1 million child deaths per year, and iodine deficiency during pregnancy causes mental impairment in 18 million babies born every year (1). Several strategies have been proposed to address the problem. They include food fortification, dietary diversification, dietary supplementation, nutrition education, and public health measures to control intestinal parasites and other infectious diseases. Although significant reductions in the high prevalences of micronutrient malnutrition will require multiple, complementary approaches, food fortification, the focus of this symposium, is arguably the most cost-effective and practically feasible strategy over the near term.

Hagenimana V, Low J (2000). Potential of orange-fleshed sweet potatoes for raising vitamin A intake in Africa. Food and Nutrition Bulletin 21: 414-418. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/291

Hambidge KM, Krebs NF (2007). Zinc deficiency: a special challenge. Journal of Nutrition 137: 1101-1105. http://jn.nutrition.org/cgi/content/abstract/137/4/1101

In the development and testing of programs designed to improve complementary feeding globally, local nonfortified foodbased solutions comprise an important strategy for the foreseeable future. These solutions are especially vital for the rural poor of less-developed countries. Zinc is notable among individual nutrients that have been designated as "problem" nutrients, adequate intake of which is difficult from complementary foods without fortification. This article considers the potential role of meat +- liver in addressing this apparent problem. In a recent Colorado study, beef and cereal have been determined to be equally acceptable between age 5-7 mo as first and regular complementary foods. Average intake and absorption of Zn from beef by 7 mo of age, together with the modest intake/absorption of Zn from breast milk at that age, were adequate to meet average dietary and physiologic zinc requirements, respectively. Barriers to acceptability and availability of affordable meat are considered, but these are neither universal nor irresolvable in all populations.

Harjes CE, Rocheford TR, Bai L, Brutnell TP, Bermudez Kandianis C, Sowinski SG, Stapleton AE, Vallabhaneni R, Williams M, Wurtzel ET, Yan J, Buckler ES (2008). Natural genetic variation in Lycopene epsilon cyclase tapped for maize biofortification. Science 319: 330-333. http://dx.doi.org/10.1126/science.1150255

Dietary vitamin A deficiency causes eye disease in 40 million children each year and places 140 to 250 million at risk for health disorders. Many children in sub-Saharan Africa subsist on maize-based diets. Maize displays considerable natural variation for carotenoid composition, including vitamin A precursors -carotene, β-carotene, and β-cryptoxanthin. Through association analysis, linkage mapping, expression analysis, and mutagenesis, we show that variation at the lycopene epsilon cyclase (lcyE) locus alters flux down -carotene versus β-carotene branches of the carotenoid pathway. Four natural lcyE polymorphisms explained 58% of the variation in these two branches and a threefold difference in provitamin A compounds. Selection of favorable lcyE alleles with inexpensive molecular markers will now enable developing-country breeders to more effectively produce maize grain with higher provitamin A levels.

Hawkesford MJ, Zhao F-J (2007). Strategies for increasing the selenium content of wheat. Journal of Cereal Science 46: 282-292. http://dx.doi.org/10.1016/j.jcs.2007.02.006

Selenium (Se) is essential for humans and animals but has no known function in plants. Excess accumulation is toxic to both plants and animals. Dietary intake of Se is low in a large number of people worldwide. This is due to low bioavailability of Se in some soils and consequently low concentrations of Se in plant tissues. Both selenate and selenite are taken up by plants and subsequently translocated around the plant. Selenate, an analogue of sulphate, is transported by the sulphate transporter family. Some plants are able to accumulate high internal concentrations of Se (hyperaccumulators); however, genetic variation in accumulation ability amongst non-accumulators such as cereals, is relatively small. Within plant tissues, Se enters the pathways for sulphate assimilation and metabolism and will replace cysteine and methionine in proteins, often with detrimental effect. Alternatively, Se may be accumulated as methylated derivatives or lost from the plant following volatilisation. Agronomic biofortification of crops with Se-containing fertilisers, which is practised in some countries, provides the best short-term solution for improving Se content of wheat. Longer-term genetic improvement, particularly by targeting substrate discrimination of transporters between selenate and sulphate, for example, may provide a means to enhance uptake and promote accumulation.

He X, Nara K (2007). Element biofortification: can mycorrhizas potentially offer a more effective and sustainable pathway to curb human malnutrition? Trends in Plant Science 12: 331-333. http://dx.doi.org/10.1016/j.tplants.2007.06.008

In the 10th Anniversary issue of Trends in Plant Science, Philip White and Martin Broadley highlighted the significance of mineral fertilization and/or plant breeding to fight against human malnutrition [1]. In addition to these two approaches, we would like to draw attention to another important aspect of element biofortification: symbiotic relationships between higher plants and mycorrhizal fungi (see Glossary). Most plants, including all major grain crops and almost all vegetables and fruits, are associated with mycorrhizal fungi that improve the uptake of essential mineral elements from soils and, therefore, enhance plant growth and productivity [2]. These symbiotic fungi, therefore, change, directly or indirectly, the mineral nutrition of plant products that are also essential for humans. However, so far management of mycorrhizas on element biofortification has not been piloted through agricultural practices. Here we propose that mycorrhizas can potentially offer a more effective and sustainable element biofortification to curb global human malnutrition.

Herring RJ (2008). Opposition to transgenic technologies: ideology, interests and collective action frames. Genetics 9: 458-463. http://dx.doi.org/10.1038/nrg2338

Genetic engineering has enabled significant, accepted innovations in medicine and other fields. In agriculture, however, a global cognitive divide around 'genetically modified organisms' (GMOs) has limited the diffusion and scope of this technology. The framing of agricultural products of recombinant DNA technology as GMOs lacks biological coherence, but has proved to be a powerful frame for opposition. Disaggregating the concept of the 'GMO' is a necessary condition for confronting misconceptions that constrain the use of biotechnology in addressing imperatives of development and escalating challenges from nature, especially in less-industrialized nations.

Hess SY, Lönnerdal B, Hotz C, Rivera JABrown KH (2009). Recent advances in knowledge of zinc nutrition and human health. Food and Nutrition Bulletin 30: S5-S11. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/2039

Zinc deficiency increases the risk and severity of a variety of infections, restricts physical growth, and affects specific outcomes of pregnancy. Global recognition of the importance of zinc nutrition in public health has expanded dramatically in recent years, and more experience has accumulated on the design and implementation of zinc intervention programs. Therefore, the Steering Committee of the International Zinc Nutrition Consultative Group (IZiNCG) completed a second IZiNCG technical document that reexamines the latest information on the intervention strategies that have been developed to enhance zinc nutrition and control zinc deficiency. In particular, the document reviews the current evidence regarding preventive zinc supplementation and the role of zinc as adjunctive therapy for selected infections, zinc fortification, and dietary diversification or modification strategies, including the promotion and protection of breastfeeding and biofortification. The purposes of this introductory paper are to summarize new guidelines on the assessment of population zinc status, as recommended by the World Health Organization (WHO), the United Nations Children's Fund (UNICEF), the International Atomic Energy Agency (IAEA), and IZiNCG, and to provide an overview on several new advances in zinc metabolism. The following papers will then review the intervention strategies individually.

Hess SY, Thurnham DI, Hurrell RF (2005). Influence of provitamin A carotenoids on iron, zinc, and vitamin A status. HarvestPlus Technical Monograph 6. Washington, DC: International Food Policy Research Institute. http://www.harvestplus.org/content/influence-provitamin-carotenoids-iron-zinc-and-vitamin-status

Bioavailable iron, vitamin A, and zinc are mainly provided in the human diet by animal source foods. In the developing world, where poorer individuals consume predominantly plant-based diets, deficiencies of these micronutrients are common and can occur in the same individual. Infants, children, and pregnant and lactating women are most at-risk of deficiency because of their extra requirements for growth.

Heyd H (2007). Food consumption, micronutrient malnutrition and the potential of orange-fleshed sweet potatoes in Uganda. Stuttgart: Universität Hohenheim.

Malnutrition in general and micronutrient malnutrition in particular are leading causes of premature death worldwide. Micronutrient deficiencies are also referred to as 'hidden hunger', because a feeling of hunger is not perceived as in comparison to protein-energy deficiency, the typically known form of hunger. The number of people affected by micronutrient deficiencies exceeds by far the people suffering from protein-energy malnutrition. Approximately 840 million people worldwide do not have enough energy and/or protein available, while more than two billion people are anemic from iron deficiency, 254 million preschool-aged children are vitamin A deficient and approximately 20% of the world's population is at risk of being zinc deficient. Micronutrient deficiencies can have serious health consequences and are associated with higher rates of infections, diarrhea and child mortality. Iron, zinc and vitamin A deficiency were identified in the 2002 World Health Report as being among the 10 leading health risks in developing countries. Particularly the poor and vulnerable groups in developing countries such as women and children are often affected. Poverty is frequently associated with micronutrient malnutrition, since animal products with larger amounts of minerals and vitamin A are often not affordable or not available in sufficient quantities for poor and rural populations.

Hirschi K (2008). Nutritional improvements in plants: time to bite on biofortified foods. Trends in Plant Science 13: 459-463. http://dx.doi.org/10.1016/j.tplants.2008.05.009

Modern breeding, molecular genetic and biotechnology studies frequently describe changes in plant metabolism to improve nutritional content; however, this is often where the process of assessing biofortification ends. Ideally, these modified plants need to be used in controlled animal and human feeding studies to assess nutritional impact. Such bioavailability studies are crucial if any claims are to be made regarding health benefits and might be an important component in public acceptance of biofortified foods.

Hirschi K (2009). Nutrient biofortification of food crops Annual Review of Nutrition 29: 401-421. http://dx.doi.org/10.1146/annurev-nutr-080508-141143

Plant-based foods offer an array of nutrients that are essential for human nutrition and promote good health. However, the major staple crops of the world are often deficient in some of these nutrients. Traditional agricultural approaches can marginally enhance the nutritional value of some foods, but the advances in molecular biology are rapidly being exploited to engineer crops with enhanced key nutrients. Nutritional targets include elevated mineral content, improved fatty acid composition, increased amino acid levels, and heightened antioxidant levels. Unfortunately, in many cases the benefits of these "biofortified" crops to human nutrition have not been demonstrated.

Hjortmo S, Patring J, Jastrebova J, Andlid T (2008). Biofortification of folates in white wheat bread by selection of yeast strain and process. International Journal of Food Microbiology 127: 32-36. http://dx.doi.org/10.1016/j.ijfoodmicro.2008.06.001

We here demonstrate that folate content in yeast fermented food can be dramatically increased by using a proper (i) yeast strain and (ii) cultivation procedure for the selected strain prior to food fermentation. Folate levels were 3 to 5-fold higher in white wheat bread leavened with a Saccharomyces cerevisiae strain CBS7764, cultured in defined medium and harvested in the respiro-fermentative phase of growth prior to dough preparation (135-139 µg/100 dry matter), compared to white wheat bread leavened with commercial Baker's yeast (27-43 µg/100 g). The commercial Baker's yeast strain had been industrially produced, using a fed-batch process, thereafter compressed and stored in the refrigerator until bakings were initiated. This strategy is an attractive alternative to fortification of bread with synthetically produced folic acid. By using a high folate producing strain cultured a suitable way folate levels obtained were in accordance with folic acid content in fortified cereal products.

Hoekenga O, Lung'Aho M, Kochian LV, Glahn RP (2009). Iron biofortification of maize grain. Abstract T32, 51st Annual Maize Genetics Conference, 12-15 March. St. Charles, IL: MaizeGDB. http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=237994

Mineral nutrient deficiencies are a worldwide problem that is directly correlated with poverty and food insecurity. The most common of these is iron deficiency; more than one-third of the world¿s population suffers from iron deficiency-induced anemia, 80% of which are in developing countries. The developed world has made tremendous success in alleviating nutrient deficiencies through dietary diversification, food product fortification, improved public health care, and supplementation. In developing countries, these strategies are often expensive and difficult to sustain. Poverty is the most common cause for dietary deficiency in developing countries, as consumers¿ dietary choices are limited as regards the quality, quantity, and diversity of foods consumed. The resource-poor typically consume what they grow and are dependent upon a small number of staple crops for the vast majority of their nutrition. Therefore, genetic improvement of staple crops (biofortification) is the most cost effective and sustainable solution to this global health problem. Here we describe an integrated genetic, physiological and biochemical analysis of iron nutrition in maize grain, to discover the genes and compounds that influence grain iron concentration and bioavailability. Multiple quantitative trait loci (QTL) for each trait have been identified and validated. QTL have been isolated in near isogenic lines, which were provided to collaborators in five states for planting in Summer 2008. Progress towards identifying the genetic and environmental factors that determine iron nutritional quality in maize grain will be discussed.

Hokmabadi H, Haidarinezhad A, Barfeie R, Nazaran MH, Ashtiani M, Aboutalebi A (2007). A new iron chelate introduction and their effect on quality of pistachio and as an iron fortification for better food quality. In: Fardous AN, Schnitzler W, Qaryouti M (eds). Fresh food quality standards: better food by quality and assurance. Acta Horticulturae 741. Amman: International Society for Horticultural Science. http://www.actahort.org/members/showpdf?booknrarnr=741_19

Iron chelate is one of the most effective fertilizers all around the globe. It is applied to treat chlorosis in lawns, plants, shrubs and trees as well as iron deficiency in different types of soil. A new Iron chelate with new formula is produced in Iran. Khazra iron chelate has the ability to provide active Iron for plants in quite difficult situations. Granular solid fertilizer of Khazra Iron chelate has a very stable and strong complex, which provides at least 9 percent soluble iron for plants when added to soils with different pH, ranging from 3 to 10. This chelate also can be applied as foliar spraying. We applied different amounts of this chelate both as soil applying and foliar spraying on Iranian pistachio cultivars in 5 different areas of pistachio production in Kerman province and the results were compared with 400 kg of iron Sulfate per hectare and control (without any iron applying as fertilizer). Results indicated with 20 kg of Khazra chelate during the winter as soil fertilizer in fertilizer channel and foliar spraying with 1% concentration of mentioned chelate after two weeks of full bloom increased amount of iron and calcium, in fruit and also about 40% increased in percentage of soluble sugar, but there was no significant deference between treatments in amount of fatty acid in nuts. In this paper we will discuss the effects of this chelate on quality of fruits and possibility of using it as iron fortificant for food fortification.

Hoppler M, Meile L, Walczyk T (2008). Biosynthesis, isolation and characterization of 57Fe-enriched Phaseolus vulgaris ferritin after heterologous expression in Escherichia coli. Analytical and Bioanalytical Chemistry 390: 53-59. http://dx.doi.org/10.1007/s00216-007-1691-3

Ferritin is the major iron storage protein in the biosphere. Iron stores of an organism are commonly assessed by measuring the concentration of the protein shell of the molecule in fluids and tissues. The amount of ferritin-bound iron, the more desirable information, still remains inaccessible owing to the lack of suitable techniques. Iron saturation of ferritin is highly variable, with a maximum capacity of 4,500 iron atoms per molecule. This study describes the direct isotopic labeling of a complex metalloprotein in vivo by biosynthesis, in order to measure ferritin-bound iron by isotope dilution mass spectrometry. [57Fe]ferritin was produced by cloning and overexpressing the Phaseolus vulgaris ferritin gene pfe in Escherichia coli in the presence of 57FeCl2. Recombinant ferritin was purified in a fully assembled form and contained approximately 1,000 iron atoms per molecule at an isotopic enrichment of more than 95% 57Fe. We did not find any evidence of species conversion of the isotopic label for at least 5 months of storage at −20 °C. Transfer efficiency of enriched iron into [57Fe]ferritin of 20% was sufficient to be economically feasible. Negligible amounts of non-ferritinbound iron in the purified [57Fe]ferritin solution allows for use of this spike for quantification of ferritin-bound iron by isotope dilution mass spectrometry

Horton S (2006). The economics of food fortification. Journal of Nutrition 136: 1068-1071. http://jn.nutrition.org/cgi/content/abstract/136/4/1068

This paper summarizes some of the literature on the cost effectiveness and cost benefit of food fortification with selected micronutrients most relevant for developing countries. Micronutrients covered include iron, iodine, vitamin A, and zinc. The main focus is on commercial fortification, although home fortification and biofortification are mentioned. Fortification with iron, vitamin A, and zinc averts significant numbers of infant and child deaths and is a very attractive preventive health-care intervention. Fortification with iron, iodine, and potentially zinc provides significant economic benefits and the low unit cost of food fortification ensures large benefit:cost ratios, with effects via cognition being very important for iron and iodine. Fortification will not reach all individuals and is most attractive as an investment where there is a convenient food vehicle, where processing is more centralized, and where either the deficiency is widespread or the adverse effects are very costly even though only a small group is affected.

Horton S, Alderman H, Rivera JA (2008). Hunger and malnutrition. Challenge Paper. Frederiksberg: Copenhagen Consensus Center. http://www.copenhagenconsensus.com/The%2010%20challenges/Malnutrition%20and%20Hunger-1.aspx

Despite significant reductions in income poverty in recent years, undernutrition remains widespread. Recent estimates published in the Lancet (Black et al 2008) suggest that "maternal and child undernutrition is the underlying cause of 3.5 million deaths, 35% of the disease burden in children younger than 5 years, and 11% of total global DALY's" (Disability-Adjusted Life Years). Undernutrition can be indicated both by anthropometric indices (underweight, stunting and wasting) and with missing micronutrients in poor quality diets. Undernutrition in turn has negative effects on income and on economic growth. Undernutrition leads to increased mortality and morbidity which lead to loss of economic output and increased spending on health. Poor nutrition means that individuals are less productive (both due to physical and mental impairment), and that children benefit less from education. The previous 2004 Copenhagen Consensus paper on the topic discusses these mechanisms in detail (Behrman, Alderman and Hoddinott, 2004, hereafter BAH 2004). Reducing undernutrition is one of the Millennium Goals (Goal 1 aims to eradicate extreme poverty and hunger), and is also a key factor underpinning several others. Achieving goals in primary education, reducing child mortality, improving maternal health, and combating HIV/AIDS, malaria and other diseases all depend crucially on nutrition. There are cost-effective interventions for improving nutrition.

Horton S, Ross J (2003). The economics of iron deficiency. Food Policy 28: 51-75. http://dx.doi.org/10.1016/S0306-9192(02)00070-2

Hotz C (2009). The potential to improve zinc status through biofortification of staple food crops with zinc. Food and Nutrition Bulletin 30: S172-S178. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/2032

Biofortification is an agricultural strategy that aims to increase the content of select micronutrients, including zinc, in staple food crops such as rice, wheat, maize, pearl millet, and others. When consumed among zinc-deficient populations, zinc-biofortified staple foods should improve the adequacy of zinc intakes and hence reduce the risk of dietary zinc deficiency. Several conditioning factors will contribute to the potential for this strategy to meet its goal, including the additional amount of zinc that can be bred into the staple crop food, the amount of zinc that remains in the staple crop food following usual processing methods, and the bioavailability of zinc from the staple crop food in the context of the usual diet. Reduction of the phytate content of cereals with the use of agricultural techniques is a potential complementary strategy for improving the bioavailability of zinc. The feasibility of biofortification to result in a meaningful increase in the adequacy of population zinc intakes and to reduce the consequences of zinc deficiencies still needs to be determined through efficacy trials. At the program level, the ability to widely disseminate biofortified crop varieties and the willingness of farmers to adopt them will also affect the magnitude of the impact of this strategy.

Hotz C, Brown KH (eds) (2004). Assessment of the risk of zinc deficiency in populations and options for its control. International Zinc Nutrition Consultative Group Technical Document No. 1, Food and Nutrition Bulletin 25: S91-S204. http://www.izincg.org/technical.php

Hotz C, McClafferty B (2007). From harvest to health: challenges for developing biofortified staple foods and determining their impact on micronutrient status. Food and Nutrition Bulletin 28: S271-S279. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/1855

Background. The use of conventional breeding techniques and biotechnology to improve the micronutrient quality of staple crops is a new strategy to address micronutrient deficiencies in developing countries. This strategy, referred to as "biofortification," is being developed and implemented through the international alliance of HarvestPlus to improve iron, zinc, and vitamin A status in low-income populations. Objective. The objective of this paper is to review the challenges faced by nutritionists to determine and demonstrate the ability of biofortified crops to have an impact on the nutritional and health status of target populations. Methods. We reviewed available published and unpublished information that is needed to design and evaluate this strategy, including issues related to micronutrient retention in staple foods, micronutrient bioavailability from plant foods, and evidence for the efficacy of high-micronutrient-content staple foods to improve micronutrient status. Results. Further information is needed on the retention of micronutrients in staple foods, in particular of provitamin A carotenoids, when stored and prepared under different conditions. The low bioavailability of iron from staple foods and the ability to demonstrate an impact on zinc status are specific challenges that need to be addressed. In target countries, infections and other micronutrient deficiencies may confound the ability to affect micronutrient status, and this must be taken into account in community-based studies. Conclusions. Information to date suggests that biofortification has the potential to contribute to increased micronutrient intakes and improved micronutrient status. The success of this strategy will require the collaboration between health and agriculture sectors.

Howe J (2007). Bioefficacy of carotenoid-biofortified cassava. Paper 79-7, ASA-CSSA-SSSA International Annual Meetings, 4-8 November. New Orleans, LA: ASA-CSSA-SSSA. http://a-c-s.confex.com/a-c-s/2007am/techprogram/P34086.HTM

In many areas of the world, vitamin A (VA) deficiency is a major health problem. Staple foods such as maize, rice, cassava, and wheat, are typically low in provitamin A. Recent efforts to genetically improve cassava with provitamin A carotenoids, e.g., β-carotene, have been successful, but whether this approach alleviates VA deficiency has not been determined. Two studies investigated the bioefficacy of provitamin A carotenoids from cassava and compared the effects of cassava percentage and carotenoid content on VA status in VA-depleted Mongolian gerbils (Meriones unguiculatus). Three near-isogenic cassava lines were used to prepare 6 feeds with variable carotenoid compositions. To deplete stored VA, gerbils were fed a white cassava VA-free diet for 4 wk. In study 1, treatments (n = 10 per group) included 45% high-β-carotene cassava, β-carotene and VA supplements (pair-fed to high-β-carotene maize), and oil control. In study 2, gerbils (n ~ 10 per group) were fed ~30% or ~15% of two different cassava varieties. After the 4-wk treatment phase, serum and liver VA were determined. For study 1, total liver VA was significantly higher in the VA group, lower in the control, and did not differ from the β-carotene supplement or baseline groups when compared with the high-β-carotene cassava group. On a β-carotene basis, bioconversion was ~4:1 (mg β-carotene:1 mg VA) in the high β-carotene cassava and ~3:1 in the β-carotene supplement group. Liver β-carotene was present in the high β-carotene cassava and β-carotene supplement groups. Storage of β-carotene, rather than conversion to VA, indicates gerbils had adequate VA. Study 2 showed no significant difference in liver VA regardless of diet, but stored β-carotene was greater in gerbils receiving the ~30% cassava diets compared to the ~15% diet. Biofortified cassava adequately maintained VA status in this model and was as effective as β-carotene supplementation.

Howe JA, Tanumihardjo SA (2006). Carotenoid-biofortified maize maintains adequate vitamin A status in Mongolian gerbils. Journal of Nutrition 136: 2562-2567. http://jn.nutrition.org/cgi/content/abstract/136/10/2562

Efforts to biofortify maize with provitamin A carotenoids have been successful, but the impact on vitamin A (VA) status has not been determined. We conducted two studies that investigated the bioefficacy of provitamin A carotenoids from maize and compared maize percentage and carotenoid concentrations on VA status in VA-depleted Mongolian gerbils (Meriones unguiculatus). Gerbils (n = 40/study) were fed a white maize diet 4 wk prior to treatment. In study 1, treatments (n = 10/group) included oil control, 60% high-b-carotene maize, and b-carotene or VA supplements (matched to highb-carotene maize). In study 2, gerbils were fed 30 or 60% orange or yellow maize diets. Gerbils were killed after 4 wk. In study 1, liver VA concentrations, compared with the high-b-carotene maize group (0.25 +- 0.15 mmol/g), were higher in the VA group (0.56 +- 0.15 mmol/g, $P < 0.05$), lower in the control (0.10 +- 0.04 mmol/g, $P < 0.05$), and did not differ in the b-carotene group (0.25 +- 0.08 mmol/g). Bioconversion was ~3 mg b-carotene to 1 mg retinol (1.5 mol b-carotene to 1 mol retinol). The liver b-carotene content was greater in the high-b-carotene maize group (26.4 +- 6.0 nmol) than in the b-carotene supplement group (14.1 +- 6.0 nmol; $P < 0.05$). In study 2, the gerbils' VA status improved with increasing dietary b-carotene. Liver VA in gerbils fed orange maize was greater than in those fed yellow maize, regardless of maize percentage ($P < 0.05$). Biofortified maize adequately maintained VA status in Mongolian gerbils and was as efficacious as b-carotene supplementation. In populations consuming maize as a staple food, using orange instead of white maize could dramatically affect VA status.

Howe JA, Tanumihardjo SA (2006). Evaluation of analytical methods for carotenoid extraction from biofortified maize (Zea mays sp.) Journal of Agricultural and Food Chemistry 54: 7992-7997. http://dx.doi.org/10.1021/jf062256f

Biofortification of maize with β-carotene has the potential to improve vitamin A status in vitamin A deficient populations where maize is a staple crop. Accurate assessment of provitamin A carotenoids in maize must be performed to direct breeding efforts. The objective was to evaluate carotenoid extraction methods and determine essential steps for use in countries growing biofortified maize. The most reproducible method based on coefficient of variation and extraction efficiency was a modification of Kurilich and Juvik (1999). Heat and saponification are required to release carotenoids from biofortified maize and remove oils interfering with chromatographic analysis. For maize samples with high oil content, additional base may be added to ensure complete saponification without compromising results. Degradation of internal standard before carotenoids were released from the maize matrix required the addition of internal standard after heating to prevent overestimation of carotenoids. This modified method works well for lutein, zeaxanthin, β-cryptoxanthin, α-carotene, and β-carotene.

Hulshof PJM, Kosmeijer-Schuil T, West CE, Hollman PCH (2007). Quick screening of maize kernels for provitamin A content. Journal of Food Composition and Analysis 20: 655-661. http://dx.doi.org/10.1016/j.jfca.2006.04.014

Improving the micronutrient content of foods by bio-fortification is one of the strategies to alleviate micronutrient deficiencies. One of the target crops being bred for increased provitamin A content is maize. In order to estimate the success of these activities, we developed a quick screening method that allows distinction between low, medium and high levels of provitamin A carotenoids in maize by semiquantitative analysis. Carotenoids in 13 lines of maize were extracted with acetone/hexane and carotenes and monohydroxy carotenoids were separated on a de-activated alumina column. The two fractions were quantified separately by absorption at 450 nm. Regression lines were constructed between the spectrophotometrically determined carotenoids in the fractions and the amount of retinol equivalents (RE) determined by HPLC in the full extract. Total carotene (mg/100 g) = 7.62 RE+176; r = 0:97, P<0:01; SEE = 10 RE/100 g. Total monohydroxy carotenoids (mg/100 g) = 15.36 RE+374; r = 0:86, P<0:01; SEE = 12 RE/100 g. The method described allows fast screening of maize kernels on levels of pro-vitamin A without the need of a full HPLC analysis of all samples, and hence reduces the cost of analyses.

Hunt JM (2005). The potential impact of reducing global malnutrition on poverty reduction and economic development. Asia Pacific Journal of Clinical Nutrition 14: S10-S38. http://apjcn.nhri.org.tw/server/APJCN/reviews.htm

This review is premised on the importance of reducing both underweight prevalence of children, as the key policy variable for hunger reduction, but also reducing "hidden hunger" - the micronutrient deficiencies that rob life, health, ability and productivity. The role of nutrition in development is discussed, balancing the importance of broad infrastructure policies and nutrition-relevant actions in health services and in community development. Convergent approaches to eliminating micronutrient deficiencies include supplementation, fortification and biofortification. Relative costs drive a reordering of the mix. Next, community-based health and nutrition programs in South Asia and Sub Saharan Africa could be the focus of a global strategy to reduce underweight prevalence among under-fives, and resource needs are discussed. An approximation of resources needed to meet the first Millennium Development Goal (halving global hunger), with side benefits to MDG # 4 on child mortality) is offered. The author draws upon his recent paper on costs and benefits of hunger alleviation prepared for the United Nations Hunger Task Force (Hunt 2004).

Islam Y, Hotz C (2009). Breeding crops for better nutrition. IAEA Bulletin 50-2: 45-47. http://www.iaea.org/Publications/Magazines/Bulletin/Bull502/50205794547.html

Millions of malnourished children in developing countries will never lead healthy, happy lives due to 'hidden hunger' caused by an insufficient amount of micronutrients in their diets. Micronutrients, such as vitamin A, zinc, and iron are more abundant in the diverse diets enjoyed by affluent populations – these micronutrients quietly do their work to help children grow, develop cognitive skills, and build their immune systems. Their presence, beneath the demeanour of a happy well-nourished child, goes unnoticed. However, the same cannot be said of their absence. During the accelerated growth phases from infancy through adolescence, micronutrient deficiencies can leave children ill, stunted, or even blind, and diminish their prospects for a healthy and productive adulthood.

Jauhar PP (2006). Modern biotechnology as an integral supplement to conventional plant breeding: the prospects and challenges. Crop Science 46: 1841-1859. http://dx.doi.org/10.2135/cropsci2005.07-0223

The art of plant breeding was developed long before the laws of genetics became known. The advent of the principles of genetics at the turn of the last century catalyzed the growth of breeding, making it a science-based technology that has been instrumental in substantial improvements in crop plants. Largely through exploitation of hybrid vigor, grain yields of several cereal crops were substantially increased. Intervarietal and interspecific hybridizations, coupled with appropriate cytogenetic manipulations, proved useful in moving genes for resistance to diseases and insect pests from suitable alien donors into crop cultivars. Plant improvement has been further accelerated by biotechnological tools of gene transfer, to engineer new traits into plants that are very difficult to introduce by traditional breeding. The successful deployment of transgenic approaches to combat insect pests and diseases of important crops like rice (Oryza sativa L.), wheat (Triticum aestivum L.), maize (Zea mays L.), barley (Hordeum vulgare L.), and cotton (Gossypium hirsutum L.) is a remarkable accomplishment. Biofortification of crops constitutes another exciting development in tackling global hunger and malnutrition. Golden Rice, genetically enriched with vitamin Aand iron, has, for example, the real potential of saving millions of lives. Yet another exciting application of transgenic technology is in the production of edible vaccines against deadly diseases. How these novel approaches to gene transfer can effectively supplement the conventional breeding programs is described. The current resistance to acceptance of this novel technology should be assessed and overcome so that its full potential in crop improvement can be realized.

Javelosa JC (2006). Measuring the potential payoffs from biofortification: the case of high-iron rice in the Philippines. Dissertation No. AAT 3228739. Gainesville, FL: University of Florida. http://proquest.umi.com/pqdlink?did=1196409241&Fmt=7&clientId=79356&RQT=309&VName=PQD

This study examines the potential social rate of return to biofortification, an international plant breeding initiative that develops food crops to contain more micronutrients. We conduct an ex ante cost-benefit analysis of introducing conventionally bred high-iron rice varieties in the Philippines, where rice is the staple food and where iron deficiency remains a public health problem. We explore several methodologies that focus estimation of potential consumer welfare gains from iron-dense rice. When no changes in the demand for and supply of rice is assumed as high-iron rice varieties are introduced in the market, we explore a non-market framework for welfare measurement through the use of (1) the disability-adjusted life years (DALY) index of health outcomes, a commonly used measure in evaluating projects with health impacts; and (2) a household production model, to derive the implicit demand for dietary iron as a basis for estimating consumer welfare gains from the intervention. Further, using past consumption choices and the estimated shadow price of dietary iron using a household production model, we test to predict whether the demand for rice will change when the improved access to iron through the rice grain is acknowledged by consumers to improve their welfare. We find that the demand for rice can slightly increase using a characteristics model and a complete food demand system. We then estimate potential consumer benefits through (1) consumer surplus changes associated with the projected increase in the demand for rice within a partial equilibrium framework; and (2) food cost savings obtained in a complete food demand system within a general equilibrium framework. Insights from the consumer welfare measurement effort are discussed. Estimates of potential Philippine consumer welfare improvements from all measurement approaches reveal that benefits from high-iron rice can outweigh its research and development costs. We find that donor contributions supporting biofortification can be worthwhile investments given relatively high benefit-cost ratios ranging from 42 to 5,253 and internal rates of returns of 36% to 96%. We also assess the viability of biofortification relative to existing nutrition interventions. In comparison to iron supplementation through pharmaceutical preparations, breeding for iron-dense rice can be more cost-effective. Yet, under strong assumptions, post-production fortification of rice with iron might be a cheaper way of addressing the iron-deficiency problem in the Philippines. Nonetheless, if the distribution of benefits were considered, biofortification could be an effective complementary strategy particularly in improving the nutrition of subsistence farmers who might be overlooked by the other initiatives, but who will benefit from growing iron-dense rice in their fields.

Javelosa JC, Moss CB, Schmitz A, Seale Jr JL (2006). Derived demand for food nutrients as welfare indicator of biofortified crops: high-iron rice in the Philippines. Annual Meeting, February 5-8. Orlando, FL: Southern Agricultural Economics Association. http://purl.umn.edu/35405

The study estimates potential consumer gains from the introduction of High-Iron Rice in the Philippines. By deriving the demand for dietary iron from a national survey on household food consumption and expenditure, we project consumer welfare implications under both non-market and market analytical frameworks.

Jeong J, Guerinot ML (2008). Biofortified and bioavailable: the gold standard for plant-based diets. PNAS 105: 1777-1778. http://dx.doi.org/10.1073/pnas.0712330105

Much of the world's population relies on a few staple foods (rice, maize, wheat, and cassava) that are poor sources of essential nutrients. Biofortification, the process of enriching the nutrient content of crops as they grow, provides a sustainable solution to malnutrition worldwide, because other methods, such as diversifying people's diets or providing dietary supplements, have proved impractical, especially in developing countries (1). One of the first biofortified crops was golden rice, which was engineered to produce beta-carotene or provitamin A in the edible portion of the grain (2). Since then, there have been similar successes with other crops, giving us a variety of carotenoid-enriched foods (1) as well as crops enriched with other micronutrients such as vitamin E (3) and folate (4). However, in each of these cases, assumptions about whether the nutrients are bioavailable - i.e., whether the nutrients can be readily absorbed by humans - remain untested. In a recent issue of PNAS, Morris et al. (5), using feeding studies with both mice and humans, report that carrots genetically engineered to accumulate twice as much calcium as control carrots are indeed a good source of this essential nutrient, resulting in a ≈50% increase in calcium absorption. Calcium is a critical mineral nutrient for bone health, and it is the most abundant mineral in the human body. Because the skeleton functions as a calcium reserve, calcium deficiency results in low bone mass, which is a major cause of osteoporosis (6). Studies have shown that adequate intake of calcium reduces the risk of osteoporotic fractures, as well as other diseases (6). According to the Institute of Medicine, the recommended adequate intake for calcium is 1,000-1,300 mg/d for adults and 1,300 mg/d for children above 9 years old (7). However, a significant percentage of both children and adults consume less than the recommended amount …

Jeong J, Guerinot ML (2009). Homing in on iron homeostasis in plants. Trends in Plant Science 14: 280-285. http://dx.doi.org/10.1016/j.tplants.2009.02.006

Iron is essential for plants but is not readily accessible and is also potentially toxic. As plants are a major dietary source of iron worldwide, understanding plant iron homeostasis is pivotal for improving not only crop yields but also human nutrition. Although iron acquisition from the environment is well characterized, the transporters and reductases involved in plant organellar iron transport and some of the transcription factors that regulate iron uptake have only recently been discovered. Here, we discuss newly characterized molecular players, focusing on Arabidopsis. Localization of iron to the right compartment and accessibility of iron stores are proving crucial for maintaining proper iron homeostasis and will need to be considered in biofortification efforts currently underway.

Jin Z, Minyan W, Lianghuan W, Jiangguo W, Chunhai S (2008). Impacts of combination of foliar iron and boron application on iron biofortification and nutritional quality of rice grain. Journal of Plant Nutrition 31: 1599-1611. http://dx.doi.org/10.1080/01904160802244803

To increase iron (Fe) concentration in edible portions of staple food crops, an agronomic approach via foliar Fe-containing solutions might be sustainable and economical strategy; however, little information is available in the literature. So the present work was carried out to examine the effects of Fe in association with boron (B) foliar fertilization on Fe biofortification and the nutritional quality of rice (Oryza sativa L.) grain. The work was conducted in 2006 at the research experiment station at Zhejiang University on japonica rice 'Bing 98110' planted on a silty loam soil in pots. The following spray treatments were performed at rice anthesis: (1) control (the deionized water spray); (2) 0.1% (w/v) FeSO4 · 7H2O; (3) 0.1% (w/v) Fe (II)-AA (Complex of 0.1% FeSO4 · 7H2O and 0.4% compound amino acids; 18.6% N); (4) 0.2% (w/v) H3BO3 (boric acid, 17.5% B); (5) combined spray of 0.1% (w/v) FeSO4 · 7H2O and 0.2% (w/v) H3BO3; (6) combined spray of 0.1% (w/v) Fe (II)-AA and 0.2% (w/v) H3BO3. Foliar Fe and B complex application did biofortify Fe concentration and other measured nutritive values in polished rice. Compared to the control, Fe concentration in seed increased significantly 18.9% with the combination of foliar Fe (II)-AA and B, Zn content increased significantly 26.7%, and protein and total 16 amino acids, such as lysine, threonine, and arginine that were essential for human nutrition as well as glutamic acid, aspartic acid, valine, leucine, and phenylalanine, etc., also increased markedly by 30.9% and by 37.0%, respectively.

Johns T, Eyzaguirre PB (2007). Biofortification, biodiversity and diet: A search for complementary applications against poverty and malnutrition. Food Policy 32: 1-24. http://dx.doi.org/10.1016/j.foodpol.2006.03.014

Biofortification, the focus of the HarvestPlus program of the Consultative Group on International Agriculture Research (CGIAR), represents a potentially powerful tool to increase dietary intake of essential nutrients in staple foods. This paper evaluates the compatibility of biofortification with the preferred option of dietary diversification and its potential impacts on the agricultural biodiversity essential for long term sustainability. In poor countries, biofortification requires increasing public investment in agricultural research and infrastructure for success. Rather than cereal commodities, biofortification for developing countries should focus on vegetatively propagated species or in improving quality of coarse cereals, as well as fodders. Community participatory approaches that identify local food resources with nutritional, agronomic and economic advantages to small-scale farmers could complement and set targets for biofortification as one of many approaches to alleviate nutritional deficiencies. Furthermore using agricultural biodiversity to reinforce dietary diversity can help situate biofortification within the larger context of sustainable food-based approaches. In this light, this paper evaluates specific biofortification interventions from environmental, sociocultural, political, economic, ethical, and biomedical perspectives.

Juma C, Paarlberg R, Pray C, Unnevehr L (2007). Patterns of political support and pathways to final impact. AgBioForum 10: 201-207. http://www.agbioforum.org/v10n3/v10n3a10-paarlberg.htm

A hypothetical scheme is offered for predicting which biofortified food technologies will enjoy greatest political support or opposition and from which actors on the political landscape. Beyond political support, benefits to nutrition from biofortified crops will also require acceptance by both farmers and consumers, as well as adequate nutrient uptake. Keys are reviewed to strengthening these three non-political links in the chain of final success. A four-pronged strategy for moving forward is then offered.

Kahn BM, Zaks D (2009). Investing in agriculture: far-reaching challenge, significant opportunity. Whitepaper. Frankfurt: Deutsche Bank Group. http://www.dbcca.com/research

The growing global population, with its increasing need for energy and food, presents a challenge for the planet: How can the ever-increasing demand for these resources be met in a sustainable manner? This is of particular importance in light of climate change: Emissions of greenhouse gases from energy and food production causes climate change. More people means more demand for energy and food production, and more demand for production means more carbon emissions. The focus of this paper is on how we can try to meet this challenge of boosting agricultural productivity to meet the needs of the Earth's ever hungrier population. The paper looks at this challenge through 2050, and presents as-of-yet unpublished data from agricultural models.

Kalgaonkar S, Lönnerdal B (2009). Receptor-mediated uptake of ferritin-bound iron by human intestinal Caco-2 cells. Journal of Nutritional Biochemistry. 20: 304-311. http://dx.doi.org/10.1016/j.jnutbio.2008.04.003

Ferritin (Ft) is a large iron (Fe)-binding protein (~450 kDa) that is found in plant and animal cells and can sequester up to 4500 Fe atoms per Ft molecule. Our previous studies on intestinal Caco-2 cells have shown that dietary factors affect the uptake of Fe from Ft in a manner different from that of Fe from FeSO4, suggesting a different mechanism for cellular uptake. The objective of this study was to determine the mechanism for Ft-Fe uptake using Caco-2 cells. Binding of 59Fe-labeled Ft at 4°C showed saturable kinetics, and Scatchard analysis resulted in a Kd of 1.6 μM, strongly indicating a receptor-mediated process. Competitive binding studies with excess unlabelled Ft significantly reduced binding, and uptake studies at 37°C showed saturation after 4 h. Enhancing and blocking endocytosis using Mas-7 (a G-protein activator) and hypertonic medium (0.5 M sucrose), respectively, demonstrated that Ft-Fe uptake by Mas-7-treated cells was 140% of control cells, whereas sucrose treatment resulted in a statistically significant reduction in Ft-Fe uptake by 70% as compared to controls. Inhibition of macropinocytosis with 5- (N,N-dimethyl)-amiloride (Na+/H+ antiport blocker) resulted in a decrease (by ~20%) in Ft-Fe uptake at high concentrations of Ft, suggesting that enterocytes can use more than one Ft uptake mechanism in a concentration-dependent manner. These results suggest that Ft uptake by enterocytes is carried out via endocytosis when Ft levels are within a physiological range, whereas Ft at higher concentrations may be absorbed using the additional mechanism of macropinocytosis.

Karley AJ, White PJ (2009). Moving cationic minerals to edible tissues: potassium, magnesium, calcium. Current Opinion in Plant Biology 12: 291-298. http://dx.doi.org/10.1016/j.pbi.2009.04.013

The principal dietary source to humans of the essential cationic mineral elements potassium, magnesium and calcium is through edible plants. The accumulation of these elements in edible portions is the product of selective transport processes catalysing their short-distance and long-distance movement within a plant. In this article we review recent work describing the identification and characterisation of the molecular mechanisms catalysing the uptake and distribution of potassium, magnesium and calcium between organs, cell types and subcellular compartments. Although potassium and magnesium are redistributed effectively within the plant, calcium concentrations in phloem-fed tissues, such as fruits, seeds and tubers, are generally low. However, limitations to the redistribution of mineral elements within the plant, and its consequences for the biofortification of edible crops, can be overcome by appropriate mineral fertilisation and plant breeding strategies. The techniques of ionomics can help identify better genotypes.

Khor GL. (2008). Food-based approaches to combat the double burden among the poor: challenges in the Asian context. Asia Pacific Journal of Clinical Nutrition 17: S111-S115. http://apjcn.nhri.org.tw/server/APJCN/Volume17/vol17suppl.1/abstracts.php

Estimates of FAO indicate that 14% of the population worldwide or 864 million in 2002-2004 were undernourished in not having enough food to meet basic daily energy needs. Asia has the highest number of undernourished people, with 163 million in East Asia and 300 million in South Asia. Meanwhile obesity and diet-related non-communicable diseases continue to escalate in the region. The double burden of malnutrition also affects the poor, which is a serious problem in Asia, as it has the largest number of poor subsisting on less than $1/day. As poverty in the region is predominantly rural, agriculture-based strategies are important for improving household food security and nutritional status. These measures include shifting toward production of high-value products for boosting income, enhancing agricultural biodiversity, increasing consumption of indigenous food plants and biofortified crops. Urban poor faces additional nutritional problems being more sensitive to rising costs of living, lack of space for home and school gardening, and trade-offs between convenience and affordability versus poor diet quality and risk of contamination. Time constraints faced by working couples in food preparation and child care are also important considerations. Combating the double burden among the poor requires a comprehensive approach including adequate public health services, and access to education and employment skills, besides nutrition interventions.

Khoshgoftarmanesh AH, Schulin R, Chaney RL, Daneshbakhsh B, Afyuni M (2009). Micronutrient-efficient genotypes for crop yield and nutritional qualityin sustainable agriculture. A review. Agronomy for Sustainable Development online 25 June. http://dx.doi.org/10.1051/agro/2009017

About 4 billion people will be added onto the present population by 2050. To meet further demand for food, agricultural production should increase on the existing land. Since the Green Revolution, higher crop production per unit area has resulted in greater depletion of soil phytoavailable micronutrients while less attention has been paid to micronutrients fertilization. Now, micronutrient deficiency has become a limiting factor for crop productivity in many agricultural lands worldwide. Furthermore, many food systems in developing countries cannot provide sufficient micronutrient content to meet the demands of their citizens, especially low-income families. There are several solutions such as soil and foliar fertilization, crop systems, application of organic amendments to correct micronutrients deficiency and to increase their density in edible parts of plants. This review article presents (1) agronomic approaches to improve crop yield and micronutrient content of food crops, and (2) genotypic variation in uptake and accumulation of micronutrients. Considering ecological concerns, cultivation and breeding of micronutrient-efficient genotypes in combination with proper agronomic management practices appear as the most sustainable and cost-effective solution for alleviating food-chain micronutrient deficiency. Micronutrient-efficient genotypes could provide a number of benefits such as reductions in the use of fertilizers, improvements in seedling vigor, and resistance to abiotic and abiotic stresses. Using bioavailable micronutrient-dense staple crop cultivars can also be used to improve the micronutrient nutritional status of human.

Krämer U (2008). The dilemma of controlling heavy metal accumulation in plants. New Phytologist 181: 3-5. http://dx.doi.org/10.1111/j.1469-8137.2008.02699.x

Previously it was believed that some nutrients, and especially toxic trace compounds, were accumulated passively by plants from the soil solution, largely through transpiration, entering the xylem via entirely apoplastic pathways in the root. We now know that one key process determining the accumulation of nutrients in the shoot is their loading into the root xylem through transporter proteins in the plasma membrane of the adjacent cells.

Krawinkel MB (2006). What we know and don't know about Golden Rice. Nature Biotechnology 25: 623. http://dx.doi.org/10.1038/nbt0607-624a

In the October issue, a letter from Alexander Stein and his collaborators (Nat. Biotechnol. 24, 1200-1201, 2006) discussed the potential impact and cost effectiveness of Golden Rice. What we know about Golden Rice today is that plant breeders have successfully genetically modified rice to express β-carotene; what we also know is that, after a first approach (Golden Rice 1) they obtained rice plants that supply only 15-20% of the recommended dietary allowance for vitamin A; further genetic tinkering has resulted in rice plants (Golden Rice 2) that accumulate levels of β-carotene 20-fold higher.

Krawinkel MB (2009). b-carotene from rice for human nutrition? American Journal of Clinical Nutrition 90: 695-696. http://dx.doi.org/10.3945/ajcn.2009.28142

The article by Tang et al (1) represents a valuable contribution to the discussion about the potential nutritional effect of b-carotenecontaining rice. With the use of an impressive methodology, the authors provide some evidence for an uptake of b-carotene from rice in humans. Given the enormous effort and elegance in the scientific methods used the study, however, the study fail to provide significant data for the evidence of a nutritional benefit from Golden Rice...

Laxminarayan R, Chow J, Klein E, Tarnapol Whitacre P (2008). A recipe to fight vitamin A deficiency in India: add mustard and stir? Resources 167: 28-31. Washington, DC: Resources for the Future. http://www.rff.org/Publications/Resources/Pages/Recipe_VitaminA.aspx

A biofortification strategy can play an important role as part of a broader approach to reducing the prevalence of VAD in India. Such strategies can be cost-effective, feasible, and implemented under conditions where supplementation and fortification are currently disadvantaged. However, there are significant barriers. Perhaps foremost of these is that recognition of the importance of VAD as a public health problem in India is low.Without this recognition, all strategies to address VAD are doomed. Even with it, supporters would have to overcome many operational challenges. Additional concerns specific to biotechnology also cannot be ignored, as they remain a continuing barrier to adoption of mustard or any other genetically modified foods. So, to biofortify or not to biofortify? Golden mustard is not the proverbial silver bullet to solve vitamin A or other micronutrient deficiencies. Yet, with evidence thatmillions of children and women in India and worldwide can benefit from even modest increases in consumption of the vitamin, it deserves a closer look.

Lemaux PG (2008). Genetically engineered plants and foods: a scientist's analysis of the issues (Part I). Annual Review of Plant Biology 59: 771-812. http://dx.doi.org/10.1146/annurev.arplant.58.032806.103840

Through the use of the new tools of genetic engineering, genes can be introduced into the same plant or animal species or into plants or animals that are not sexually compatible—the latter is a distinction with classical breeding. This technology has led to the commercial production of genetically engineered (GE) crops on approximately 250 million acres worldwide. These crops generally are herbicide and pest tolerant, but other GE crops in the pipeline focus on other traits. For some farmers and consumers, planting and eating foods from these crops are acceptable; for others they raise issues related to safety of the foods and the environment. In Part I of this review some general and food issues raised regarding GE crops and foods will be addressed. Responses to these issues, where possible, cite peerreviewed scientific literature.

Lönnerdal B (2009). Soybean ferritin: implications for iron status of vegetarians. American Journal of Clinical Nutrition 89: S1680-S1685. http://dx.doi.org/10.3945/ajcn.2009.26736W

Meeting the requirement for absorbed iron is difficult for vegetarians, and their iron status often is lower than that of nonvegetarians. Beans contain ferritin in low concentrations, but it is possible to enhance this content by plant breeding or by inserting the gene for ferritin into plants, eg, soybeans. Because each ferritin molecule can bind to thousands of iron atoms, this may be a sustainable means to increase the iron contents of plants. Before such efforts are launched, it is important to determine whether iron in ferritin is bioavailable. This has been assessed in vitro by using human intestinal (Caco-2) cells and in vivo by using radiolabeled ferritin and whole-body counting in human subjects. Dietary factors affecting iron absorption, eg, ascorbic acid, phytate, and calcium, had limited effect on iron uptake from intact ferritin by Caco-2 cells, which suggests that ferritin-bound iron is absorbed via a mechanism different from that of nonheme iron. In an in vitro digestion system, ferritin was shown to be relatively resistant to proteolytic enzymes. Binding of ferritin to Caco-2 cells was shown to be saturable, and the kinetics for binding were characteristic of a receptor-mediated process. In human subjects, iron from purified soybean ferritin given in a meal was as well absorbed as iron from ferrous sulfate. In conclusion, iron is well absorbed from ferritin and may represent a means of biofortification of staple foods such as soybeans.

Low JW, Arimond M, Osman N, Cunguara B, Zano F, Tschirley D (2007). Ensuring the supply of and creating demand for a biofortified crop with a visible trait: Lessons learned from the introduction of orange-fleshed sweet potato in drought-prone areas of Mozambique. Food and Nutrition Bulletin 28: S258-S270. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/1858

Background. Orange-fleshed sweet potato (OFSP) is a promising biofortified crop for sub-Saharan Africa because it has high levels of provitamin A carotenoids, the formed vitamin A is bioavailable, and white-fleshed sweet potato is already widely grown. Objectives. To examine whether farmers will adopt varieties with a distinct visible trait, young children will eat OFSP in sufficient quantities to improve vitamin A intake, OFSP can serve as an entry point for promoting a more diversified diet, and lessons can be drawn to assure sustained adoption. Methods. The 2-year quasi-experimental intervention study followed households and children (n = 741; mean age, 13 months at baseline) through two agricultural cycles in drought prone-areas of Mozambique. Results. OFSP is acceptable to farmers when introduced by using an integrated approach. In the second year, intervention children (n = 498) were more likely than control children (n = 243) to have consumed OFSP (54% vs. 4%), dark-green leaves (60% vs. 46%), or ripe papaya (65% vs. 42%) on 3 or more days in the previous week (p < .001 for all comparisons). Their vitamin A intakes were nearly eight times higher than those of control children (median, 426 vs. 56 µg RAE [retinol activity equivalents], p < .001). Diet diversification was limited by difficult agroecological conditions and low purchasing power. However, dietary diversity was higher among intervention than control children (32% vs. 9% consuming food from more than four groups; p < .001). Conclusions. An integrated OFSP-based approach had a positive impact on the vitamin A intake of young children. A market development component and improved vine multiplication systems are recommended to assure sustained adoption.

Low JW, Arimond M, Osman N, Cunguara B, Zano F, Tschirley D (2007). A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. Journal of Nutrition 137: 1320-1327. http://jn.nutrition.org/cgi/content/abstract/137/5/1320/

Vitamin A deficiency is widespread and has severe consequences for young children in the developing world. Food-based approaches may be an appropriate and sustainable complement to supplementation programs. Orange-fleshed sweet potato (OFSP) is rich in b-carotene and is well accepted by young children. In an extremely resource poor area in Mozambique, the effectiveness of introduction of OFSP was assessed in an integrated agriculture and nutrition intervention, which aimed to increase vitamin A intake and serum retinol concentrations in young children. The 2-y quasiexperimental intervention study followed households and children (n = 741; mean age 13 mo at baseline) through 2 agricultural cycles. In y 2, 90% of intervention households produced OFSP, and mean OFSP plot size in intervention areas increased from 33 to 359 m2. Intervention children (n = 498) were more likely than control children (n = 243) to eat OFSP 3 or more d in the last wk (55% vs. 8%, P < 0.001) and their vitamin A intakes were much higher than those of control children (median 426 vs. 56 ug retinol activity equivalent, P < 0.001). Controlling for infection/inflammation and other confounders, mean serum retinol increased by 0.100 mmol/L (SEM 0.024; P < 0.001) in intervention children and did not increase significantly in control subjects. Integrated promotion of OFSP can complement other approaches and contribute to increases in vitamin A intake and serum retinol concentrations in young children in rural Mozambique and similar areas in Sub-Saharan Africa.

Lozano-Alejo N, Vázquez Carrillo G, Pixley K, Palacios-Rojas N (2007). Physical properties and carotenoid content of maize kernels and its nixtamalized snacks. Innovative Food Science and Emerging Technologies 8: 385-389. http://dx.doi.org/10.1016/j.ifset.2007.03.015

Vitamin A and protein deficiencies afflict hundreds of millions of people, and because maize is a staple food providing a large portion of energy and nutrients for many, its genetic fortification or biofortification could significantly contribute to alleviating malnutrition. Therefore, we measured carotenoid and tryptophan contents for grain, nixtamalized (lime-cooked) maize, and processed snacks of 13 maize genotypes including landraces, quality protein maize (QPM) and non-QPM hybrids. An average 36% loss of provitamin A and an 8% increase in tryptophan were observed following nixtamalization and subsequent snack preparation by deep-frying. The correlations for physical properties of grain and maize flour with provitamin A were calculated to investigate whether secondary traits may be useful as indicators of provitamin A content. The correlation of chroma values with provitamin A contents was significant (Pb0.05) for 15% and 25% hydrated maize flour (r=0.57 and r=0.51, respectively), but was not significant for whole maize kernels.

Luka RJ, Aluru MR, Reddy MB (2009). Quantification of ferritin from staple food crops. Journal of Agricultural and Food Chemistry 57: 2155-2161. http://dx.doi.org/10.1021/jf803381d

Ferritin−iron has been shown to be as bioavailable as ferrous sulfate in humans. Thus, biofortification to breed crops with high ferritin content is a promising strategy to alleviate the global iron deficiency problem. Although ferritin is present in all food crops, its concentration varies between species and varieties. Therefore, a successful ferritin biofortification strategy requires a method to rapidly measure ferritin concentrations in food crops. The objective of this study was to develop a simple and reliable ELISA using an anti-ferritin polyclonal antibody to detect ferritin in various crops. Crude seed extracts were found to have 10.2 ± 1.0, 4.38 ± 0.9, 1.2 ± 0.3, 0.38 ± 0.1, and 0.04 ± 0.01 µg of ferritin/g of dry seed in red beans, white beans, wheat, maize, and brown rice, respectively. Although the measured absolute concentrations of ferritin values were low, the presented method is applicable for rapid screening for the relative ferritin concentrations of large numbers of seeds to identify and breed ferritin-rich crops.

Lyons GH, Ceballos H, Genc Y, Liu F, Graham RD (2007). Agronomic biofortification of cassava with zinc and other micronutrients to improve human health. Zinc Crops, 24-26 May. Istanbul: International Zinc Association and International Fertilizer Industry Association. http://www.zinc-crops.org/ZnCrops2007/page_session_3.htm

Cassava (Manihot esculenta Crantz) is an important staple crop, especially for resourcepoor populations in sub-Saharan Africa. Many soil types on which cassava is grown are deficient in Zn, Se and I, and these deficiencies are also prevalent, often concurrently, in the human populations in these areas (Vanderpas et al. 1990, Oldfield 1999). Recent genotype-environment interaction studies suggest that variation in Zn concentration in cassava roots is due mostly to soil available Zn level and soil pH (CIAT 2006). Although genotypic variation for Zn has been reported (Chavez et al. 2005), results were not conclusive. Therefore, breeding for higher Zn in cassava may not be feasible. However, it has been shown that Zn fertilisation can be highly effective in overcoming Zn deficiency in cassava, to which cassava is susceptible (Asher et al. 1980). Genotypic variation of Se and I density in edible parts of cereals also appears to be low (Lyons et al. 2005, Lyons et al. unpublished), hence (as for Zn), fertilisation of cassava may be preferable than trying to breed for higher density of these micronutrients. If cassava could be efficiently and inexpensively biofortified agronomically, it could become a valuable source of dietary Zn, Se (in storage roots) and I (in leaves, which are consumed widely in Africa), in addition to its important role as a provider of dietary energy.

Lyons GH, Judson GJ, Ortiz-Monasterio I, Genc Y, Stangoulis JCR, Graham RD (2005). Selenium in Australia: selenium status and biofortification of wheat for better health. Journal of Trace Elements in Medicine and Biology 19: 75-82. http://dx.doi.org/10.1016/j.jtemb.2005.04.005

Selenium (Se) is an essential micronutrient for humans and animals, but is deficient in at least a billion people worldwide. Wheat (Triticum aestivum L.) is a major dietary source of Se. The largest survey to date of Se status of Australians found a mean plasma Se concentration of 103 mg/l in 288 Adelaide residents, just above the nutritional adequacy level. In the total sample analysed (six surveys from 1977 to 2002; n = 834), plasma Se was higher in males and increased with age. This study showed that many South Australians consume inadequate Se to maximise selenoenzyme expression and cancer protection, and indicated that levels had declined around 20% from the 1970s. No significant genotypic variability for grain Se concentration was observed in modern wheat cultivars, but the diploid wheat Aegilops tauschii L. and rye (Secale cereale L.) were higher. Grain Se concentrations ranged 5-720 mg/kg and it was apparent that this variation was determined mostly by available soil Se level. Field trials, along with glasshouse and growth chamber studies, were used to investigate agronomic biofortification of wheat. Se applied as sodium selenate at rates of 4-120 g Se/ha increased grain Se concentration progressively up to 133-fold when sprayed on soil at seeding and up to 20-fold when applied as a foliar spray after flowering. A threshold of toxicity of around 325 mg Se/kg in leaves of young wheat plants was observed, a level that would not normally be reached with Se fertilisation. On the other hand sulphur (S) applied at the low rate of 30 kg/ha at seeding reduced grain Se concentration by 16%. Agronomic biofortification could be used by food companies as a cost-effective method to produce high-Se wheat products that contain most Se in the desirable selenomethionine form. Further studies are needed to assess the functionality of high-Se wheat, for example short-term clinical trials that measure changes in genome stability, lipid peroxidation and immunocompetence. Increasing the Se content of wheat is a food systems strategy that could increase the Se intake of whole populations.

Ma G (2007). Iron and zinc deficiencies in China: existing problems and possible solutions. PhD Thesis. Wageningen University: Wageningen. http://library.wur.nl/WebQuery/wda/lang?dissertatie/nummer=4114

Background: Micronutrient deficiencies affect the health and development of the population of China as well as its social and economic development. Iron and zinc deficiencies are quite prevalent, while insufficient intake and poor bioavailability are the major causes. Phytate is believed to be a potent inhibitor. Feasible, cost-effective and sustainable intervention programs to combat iron and zinc deficiencies need to be identified and developed. Objectives: To examine the phytate content in foods, and in the diets, and its inhibitory effect on the bioavailability of iron and zinc. To describe the magnitude of iron and zinc deficiencies and identify feasible, cost-effective and sustainable intervention strategies in China. Methods: The phytate intake and zinc intake adequacy were assessed using data of 68,962 subjects from the 2002 China National Nutrition and Health Survey (a national representative survey). The dietary assessment data were collected using consecutive three days 24h recall by trained interviewers. The phytate content in the food samples was determined using the anion-exchange method. The phytate/minerals molar ratios of the foods and the diets were calculated. The following suggested critical values were used as the indicator for the inhibitory effect of phytate on the bioavailability of minerals: phytate/iron >1, phytate/zinc >15, phytate/calcium >0.24, phytate×calcium/zinc >200. The costs and cost-effectiveness of supplementation, food diversification, and food fortification were estimated using the standard WHO ingredients-approach. For biofortification - a process of agronomic intervention or genetic selection of crop plants to increase the bioavailable concentrations of a component - the costs per capita were calculated according to the method in the literature. Cost-effectiveness of biofortification could not be determined. Biofortification of staples is believed to be a promising strategy for micronutrient deficiency. Results: The phytate content of 60 foods ranged from 0 to 1878 mg/100 g. Of the samples, 53 foods had phytate/iron molar ratio >1, a total of 31 foods had phytate/zinc molar ratio >15. Phytate in commonly consumed foods in China impairs the bioavailability of iron and zinc. The phytate intake was between 648 and 1433 mg/day. Urban residents consumed much less phytate than their rural counterparts (781 vs 1342 mg/day). The proportion of subjects with ratios above the critical values of phytate/iron and phytate/zinc were 95.4% and 23.1%. Phytate showed an inhibitory effect on the bioavailability of iron and zinc in the diets of people in China. The overall prevalence of anaemia was 20.1%. Approximately, 30% of children (<2 years), adults (>60 years), pregnant and lactating women, and 20% of women of reproductive age were anemic. The proportions of zinc intake inadequacy were between 2.8% and 29.4%. Significantly higher proportions of zinc inadequacy were found in the category of phytate/zinc molar ratio >15 for both rural and urban residents. About 20% of rural children are "at risk" of inadequate zinc intakes. The costs per capita for biofortification was the lowest intervention (International dollars (I$) = 0.01) for both iron and zinc deficiency. Food fortification was the most cost-effective for iron deficiency [I$ = 66/DALY (Disability Adjusted Life Years)], while dietary diversification for zinc deficiency (I$ = 103/DALY). Conclusion: Iron and zinc deficiencies are of public health significance in China, which affects a large number of people. Phytate in the diets inhibits the bioavailability of iron and zinc, and plays an important role in the deficiencies of iron and zinc. Supplementation and fortification can be applied as short-term intervention, while dietary diversification and biofortification are the long-term strategies. Biofortification with improved varieties for micronutrient content and availability is a feasible, cost-effective and sustainable solution, especially for the rural Chinese population.

Ma G, Jin Y, Li Y, Zhai F, Kok FJ, Jacobsen E, Yang X (2007). Iron and zinc deficiencies in China: what is a feasible and cost-effective strategy?Public Health Nutrition. 11: 632-638. http://dx.doi.org/10.1017/S1368980007001085

In order to prioritise interventions for micronutrient deficiencies in China, the populations affected by iron and zinc deficiencies were assessed based on data from the 2002 China National Nutrition and Health Survey. The costs and costeffectiveness of supplementation, food diversification and food fortification were estimated using the standard World Health Organization ingredients approach. Results indicated that 30% of children (,2 years), adults (.60 years), pregnant and lactating women, and 20% of women of reproductive age were anaemic, some 245 million people. Approximately 100 million people were affected by zinc deficiency (zinc intake inadequacy and stunting), the majority living in rural areas. Among interventions on iron and zinc deficiency, biofortification showed the lowest costs per capita, I$0.01 (international dollars), while dietary diversification through health education represented the highest costs at I$1148. The costeffectiveness of supplementation, food fortification and dietary diversification for iron deficiency alone was I$179, I$66 and I$103 per disability-adjusted life-year (DALY), respectively. Data for biofortification were not available. For zinc deficiency, the corresponding figures were I$399, I$153 and I$103 per DALY, respectively. In conclusion, iron and zinc deficiencies are of great public health concern in China. Of the two long-term intervention strategies, i.e. dietary diversification and biofortification with improved varieties, the latter is especially feasible and cost-effective for rural populations. Supplementation and fortification can be used as short-term strategies for specific groups.

Markert B, Schroeder P, Golan-Goldhirsh A, Schwitzguebel JP (2008). Nutrient biofortification and exclusion of pollutants in food plants. Environmental Science and Pollution Research 15: 172. http://dx.doi.org/10.1065/espr2007.12.472

COST (European CO-operation in the field of Scientific and Technical Research) is an important intergovernmental framework that allows the coordination of nationally funded research on a European level. Herein, COST Action 859 is a network on phytotechnologies to promote sustainable land use and to improve food safety. The activities of COST 859 are divided into 4 interlinking working groups (WGs), in which WG1 is related to plant uptake/ exclusion and translocation of nutrients and contaminants, WG2 concentrates on exploiting 'omics'-approaches in phytotechnologies, WG3 provides concepts for improving nutritional quality and safety of food crops and WG 4 deals with the integration and application of phytotechnologies (http://w3.gre.ac.uk/cost859/working-groups.html). In the frame of COST-Action 859, an interdisciplinary workshop of WG1 and WG3 was held in Israel, October 2007. The workshop was hosted by Ben Gurion University of the Negev, Jacob Blaustein Institutes for Desert Research (BIDR) at the Sede- Boqer Campus. The working group coordinators had invited the WG members to contribute to the important topic of 'Nutrient Biofortification and Exclusion of Pollutants in Food Plants' and had set up four scientific sessions – according to the four COST WGs – as well as a professional field trip for the COST delegates. Highly interesting plenary lectures have given an excellent insight into hot topics of this COST action.

Masuda H, Suzuki M, Morikawa KC, Kobayashi T, Nakanishi H, Takahashi M, Saigusa M, Mori S, Nishizawa NK (2008). Increase in iron and zinc concentrations in rice grains via the introduction of barley genes involved in phytosiderophore synthesis. Rice 1: 100-108. http://dx.doi.org/10.1007/s12284-008-9007-6

Increasing the iron (Fe) and zinc (Zn) concentrations of staple foods, such as rice, could solve Fe and Zn deficiencies, which are two of the most serious nutritional problems affecting humans. Mugineic acid family phytosiderophores (MAs) play a very important role in the uptake of Fe from the soil and Fe transport within the plant in graminaceous plants. To explore the possibility of MAs increasing the Fe concentration in grains, we cultivated three transgenic rice lines possessing barley genome fragments containing genes for MAs synthesis (i.e., HvNAS1, HvNAS1, and HvNAAT-A and HvNAAT-B or IDS3) in a paddy field with Andosol soils. Polished rice seeds with IDS3 inserts had up to 1.40 and 1.35 times higher Fe and Zn concentrations, respectively, compared to non-transgenic rice seeds. Enhanced MAs production due to the introduced barley genes is suggested to be effective for increasing Fe and Zn concentrations in rice grains.

Mayer JE (2007). Delivering Golden Rice to developing countries. Journal of AOAC International 90: 1445-1449. http://www.atypon-link.com/AOAC/doi/abs/10.5555/jaoi.90.5.1445

Micronutrient deficiencies create a vicious circle of malnutrition, poverty, and economic dependency that we must strive to break. Golden Rice offers a sustainable solution to reduce the prevalence of vitamin A deficiency-related diseases and mortality, a problem that affects the health of millions of children in all developing countries. The technology is based on the reconstitution of the carotenoid biosynthetic pathway by addition of 2 transgenes. The outcome of this high-tech approach will be provided to end users as nutrient-dense rice varieties that are agronomically identical to their own, locally adapted varieties. This intervention has the potential to reach remote rural populations without access to fortification and supplementation programs. As part of our delivery strategy, we are partnering with government and nongovernment, national and international agricultural institutions to navigate through cumbersome and expensive regulatory regimes that affect the release of genetically modified crops, and to create local demand for the biofortified rice varieties.

Mayer JE, Pfeiffer WH, Beyer P (2008). Biofortified crops to alleviate micronutrient malnutrition. Current Opinion in Plant Biology 11: 166-170. http://dx.doi.org/10.1016/j.pbi.2008.01.007

Micronutrient malnutrition affects more than half of the world population, particularly in developing countries. Concerted international and national fortification and supplementation efforts to curb the scourge of micronutrient malnutrition are showing a positive impact, alas without reaching the goals set by international organizations. Biofortification, the delivery of micronutrients via micronutrient-dense crops, offers a cost-effective and sustainable approach, complementing these efforts by reaching rural populations. Bioavailable micronutrients in the edible parts of staple crops at concentrations high enough to impact on human health can be obtained through breeding, provided that sufficient genetic variation for a given trait exists, or through transgenic approaches. Research and breeding programs are underway to enrich the major food staples in developing countries with the most important micronutrients: iron, provitamin A, zinc and folate.

Mazuze FM (2007). Analysis of adoption of orange-fleshed sweetpotatoes: the case study of Gaza Province in Mozambique. Research Report 4E. East Lansing, MI: Michigan State University. http://www.aec.msu.edu/fs2/mozambique/iiam/rr_4e.pdf (187 KB)

McDonald GK, Genc Y, Graham RD (2008). A simple method to evaluate genetic variation in grain zinc concentration by correcting for differences in grain yield. Plant and Soil 306: 49-55. http://dx.doi.org/10.1007/s11104-008-9555-y

Increasing the grain zinc (Zn) concentration of staple food crops will help alleviate chronic Zn deficiency in many areas of the world. Significant variation in grain Zn concentration is often reported among collections of cereals, but frequently there is a concomitant variation in grain yield. In such cases grain Zn concentration and grain yield are often inversely related. Without considering the influence of the variation in grain yield on Zn concentration, the differences in grain Zn concentration may simply represent a yield dilution effect. Data from a series of field and glasshouse experiments was used to illustrate this effect and to describe an approach that will overcome the yield dilution effect. In experiments with a wide range of bread wheat, synthetic hexaploids and accessions of durum wheat, variation in grain yield among the genotypes accounted for 30-57% of the variation in grain Zn concentration. Variation in kernel weight also occurred, but was poorly correlated with grain Zn concentration. To account for the influence of variation in grain yield on grain Zn concentration grain Zn yield was plotted against grain yield. By defining the 95% confidence belt for the regression genotypes that have inherently low or high grain Zn concentrations at a given yield level can be identified. This method is illustrated using two data sets, one consisting of bread wheat and one comprising a collection of synthetic hexaploids.

Meenakshi JV, Johnson NL, Manyong VM, DeGroote H, Javelosa J, Yanggen DR, Naher F, Gonzalez C, García J, Meng E (2009). How cost-effective is biofortification in combating micronutrient malnutrition? An ex ante assessment. World Development in press: 12p. http://dx.doi.org/10.1016/j.worlddev.2009.03.014

Biofortification is increasingly seen as an additional tool to combat micronutrient malnutrition. This paper estimates the costs and potential benefits of biofortification of globally important staple food crops with provitamin A, iron, and zinc for twelve countries in Africa, Asia, and Latin America. Using a modification of the Disability-Adjusted Life Years framework we conclude that overall, the intervention can make a significant impact on the burden of micronutrient deficiencies in the developing world in a highly cost-effective manner. Results differ by crop, micronutrient, and country; and major reasons underlying these differences are identified to inform policy.

Mei Z, Cogswell ME, Parvanta I, Lynch S, Beard JL, Stoltzfus RJ, Grummer-Strawn LM (2005). Hemoglobin and ferritin are currently the most efficient indicators of population response to iron interventions: an analysis of nine randomized controlled trials. Journal of Nutrition 135: 1974-1980. http://jn.nutrition.org/cgi/content/abstract/135/8/1974

Governments and donor agencies have implemented pilot and large-scale iron fortification programs, but there has been no consensus on the best choice of indicators to monitor population response to these interventions. We analyzed data from 9 randomized iron intervention trials to determine which of the following indicator (s) of iron status show the largest response in a population: hemoglobin (Hb), ferritin, transferrin receptor (TfR), zinc protoporphyrin (ZPP), mean cell volume (MCV), transferrin saturation (TS), and total body-iron store. We expressed the change in each indicator in response to the iron intervention in SD units (SDU) for the intervention group compared with the control group. Ferritin increased by >=0.2 SDU in all trials and was significant in 7. Hb changed by >=0.2 SDU in 6 and was significant in 5. TfR increased by >=0.2 SDU in 5 of 8 interventions in which it was measured and was significant in 4. ZPP increased by >=0.2 SDU and was significant in 3 of 6 interventions. Excluding Hb, the indicator with the largest change in SDU was ferritin in 4 trials, TS in 2 trials, body-iron store in 2 trials, and TfR in 1. In the 2 cases in which body-iron stores showed the largest change, the change in ferritin was nearly as large. Our results suggest that with currently available technologies, ferritin shows larger and more consistent response to iron interventions than ZPP or TfR. We cannot make confident inference about MCV or TS, which were included in only 4 and 2 trials, respectively. It is possible that the optimal indicator (s) may differ with age, sex, and pregnancy. There were too few trials in each age and sex group to allow us to explore this question.

Meyers WH (2005). Predicting the acceptance for high β-carotene maize: an ex-ante estimation method. 9th International Conference on Agricultural Biotechnology: Ten Years After, 6-10 July. Ravello: International Consortium on Agricultural Biotechnology Research. http://www.economia.uniroma2.it/conferenze/icabr2005/abstract/

In the development of high beta carotene (HBC) maize, the focus is on subsistence farms which do not get any (or at least very little) benefit from commercial fortification programs. The technology can be considered to be primarily for the small-scale subsistence farmer. The focus of this paper is on the adoption decision, which is a household joint production/consumption decision. Adoption depends both on production and consumption characteristics. In the case of HBC maize, the production characteristics may be less problematic than the consumption characteristics, but that remains to be seen. Research is underway in the High Beta Carotene (HBC) Maize Initiative to develop high pro-vitamin A – Beta Carotene seed technologies by both conventional and transgenic means. Studies on the cost-effectiveness of these technologies are being conducted, and this paper seeks to refine the theoretical foundations for estimating the adoption rate for such studies. Influencing the production decision are traits and tradeoffs on the seed and production side. There may be a GMO vs non-GMO issue, and they would likely have different BC content. There may be a trade-off on other traits but, in principal, the breeders plan no sacrifice of other desirable production traits when the BC is enhanced. More significant trade-offs are likely in the consumption traits. In most of Africa, white maize is highly preferred by consumers. More BC increases yellow colour, so this is a problem and again this trait may differ between GMO and non-GMO varieties. Differences in taste and texture could also be factors affecting consumer acceptance. We postulate a household decision model that takes into account the production and consumption tradeoffs between traditional vs biofortified seed. The objective is to understand the effect of these differing traits on the adoption decision, keeping in mind that it is a joint decision of production and consumption. The model is designed to estimate the adoption rate based on known or assumed characteristics of alternative technologies and preferences of households. It could also be seen as a way to guide policy makers and scientists pursuing maize fortification through technology for subsistence farmers.

MI (2005). Controlling vitamin & mineral deficiencies in India: meeting the goal. New Delhi: The Micronutrient Initiative. http://www.micronutrient.org/CMFiles/PubLib/VMd-GPR-English1KWW-3242008-4681.pdf (1.2 MB)

Today, as the toll on human life due to diseases, infections and epidemics rises steeply, and causes a deep economic impact, nations are realizing the importance of the adage health is wealth. The world is now collectively rising to curb the onslaught of diseases like AIDS, cholera and malaria and eradicate problems like polio. But even as these are the more visible faces of illness, there is a hidden danger lurking within most developing countries that is sapping their vitality. A danger which, if it is not addressed fast, could weaken these nations beyond measure. It is the danger of micronutrient deficiencies. In other words, the lack of essential micronutrients like Vitamin A, iron, iodine, folic acid and zinc.

MI/UNICEF (2004). Vitamin and mineral deficiency: a global progress report. Ottawa: The Micronutrient Initiative. http://www.micronutrient.org/English/View.asp?x=614

Miller HI (2009). A golden opportunity, squandered. Trends in Biotechnology 27: 129-130. http://dx.doi.org/10.1016/j.tibtech.2008.11.004

Even when used to make products of negligible risk and that contribute significantly to public health, recombinant DNA technology (a.k.a. 'genetic modification', or GM) applied to agriculture has a tough row to hoe. 'Golden Rice', which has been enriched by the addition of genes that allow rice to synthesize b-carotene (the precursor of vitamin A) in its edible endosperm, has endured resistance from activists and a decade of imposing and gratuitous obstacles to regulatory approval. This is an ominous precedent for other 'biofortified' foods made with recombinant DNA technology. The announcement in November 2008 by a group of multi-national European scientists that they had produced an extraordinary new, recombinant DNA-modified tomato variety garnered a great deal of media attention worldwide. This variety, which contains two snapdragon transcription factors, boasts deep purple skin and flesh and contains levels of antioxidants threefold greater than its unmodified parent. Most important, when fed to highly cancer-susceptible mice, the tomatoes significantly extended the life span of the animals

Mills JP, Simon PW, Tanumihardjo SA (2008). Bioactive compounds with high antioxidant potential in biofortified carrots do not influence provitamin A carotenoid bioefficacy in gerbils. FASEB Journal22: 1105.5. http://www.fasebj.org/cgi/content/meeting_abstract/22/1_MeetingAbstracts/1105.5

Dietary Guidelines for Americans recommend a diet rich in fruits and vegetables of a variety of colors. Colored carrots contain several groups of phytochemicals. Provitamin A carotenoid bioefficacy was measured in four carrot varieties (purple/orange, purple/orange/red, orange/red and orange) using gerbils. Freeze-dried carrot powders were mixed into diets to achieve 6 nmol beta-carotene equivalents/g diet and fed to 4 groups (n = 11/group) for 4 wk. Diets were equalized for carrot powder using carotenoid-free white carrot powder. Diets containing carrot varieties rich in lycopene and/or anthocyanins were formulated to have equal concentrations of these compounds. Antioxidant capacities of the carrot powder, diets, serum and livers were determined with the ABTS+ free radical scavenging decolorization assay. All four colored carrot-fed groups had higher liver retinol stores (0.230 + 0.029 to 0.259 + 0.047 μmol/g) compared to the white carrot-fed control group (0.124 + 0.036 μmol/g), but did not differ from each other. Hydrophilic antioxidant capacities of the anthocyanin-rich purple varieties were 5 and 10-fold higher than white carrot. Lipophilic antioxidant capacities were 10 to 20-fold higher in the carotenoid-rich colored carrots compared to white carrot. Provitamin A carotenoids in biofortified carrots maintained vitamin A status with no discernable influence of lycopene or anthocyanins on bioefficacy at the levels fed in this study.

Mills JP, Simon PW, Tanumihardjo SA (2008). Biofortified carrot intake enhances liver antioxidant capacity and vitamin A status in Mongolian gerbils. Journal of Nutrition 138: 1692-1698. http://jn.nutrition.org/cgi/content/abstract/138/9/1692

Biofortification efforts have increased concentrations of bioactive compounds in carrots. We measured the antioxidant potential and vitamin A bioefficacy of 4 biofortified carrot varieties [purple/orange, purple/orange/red, orange/red, and orange] in Mongolian gerbils (n = 73). Following a 4-wk vitamin A depletion period and baseline kill (n = 7), freeze-dried carrot powders were mixed into purified feeds and fed to 6 groups (n = 11/group) for 4 wk. White carrot-fed control and vitamin A-supplemented groups were used to calculate carrot provitamin A bioefficacy. Antioxidant capacities of carrot powders, sera, and livers were determined using the 2, 2'-azinobis- (3-ethylbenzothiazoline-6-sulfonic acid) radical cation decolorization assay and carotenoid and retinol concentrations were determined by HPLC. Antioxidant capacity of liver extracts from the 4 colored carrot-fed groups [10.1 ± 1.2 μmol Trolox equivalent antioxidant capacity (TEAC)/g] was significantly higher than the white carrot-fed control group (9.3 ± 0.9 μmol TEAC/g) and vitamin A-supplemented group (8.8 ± 1.4 μmol TEAC/g) ($P < 0.05$). Liver retinol stores in the colored carrot-fed groups (0.62 ± 0.13 to 0.67 ± 0.08 μmol retinol/liver) did not differ and were higher than the white carrot-fed control group (0.32 ± 0.08 μmol retinol/g) ($P < 0.0001$). Serum antioxidant capacity and retinol did not differ among treatment groups. Liver antioxidant capacity and vitamin A stores were higher in gerbils fed colored carrots than in those fed white carrots. Antioxidant activity is one of several proposed mechanisms by which plant foods, like biofortified carrots, may provide additional health benefits beyond maintenance of vitamin A status.

Montagnac JA, Davis CR, Tanumihardjo SA (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. Comprehensive Reviews in Food Science and Food Safety 8: 181-194. http://dx.doi.org/10.1111/j.1541-4337.2009.00077.x

Cassava is a drought-tolerant, staple food crop grown in tropical and subtropical areas where many people are afflicted with undernutrition,making it a potentially valuable food source for developing countries. Cassava roots are a good source of energy while the leaves provide protein, vitamins, and minerals. However, cassava roots and leaves are deficient in sulfur-containing amino acids (methionine and cysteine) and some nutrients are not optimally distributed within the plant. Cassava also contains antinutrients that can have either positive or adverse effects on health depending upon the amount ingested. Although someof these compounds act as antioxidants and anticarcinogens, they can interfere with nutrient absorption and utilization andmay have toxic side effects. Efforts to add nutritional value to cassava (biofortification) by increasing the contents of protein, minerals, starch, and beta-carotene are underway. The transfer of a 284 bp synthetic gene coding for a storage protein rich in essential amino acids and the crossbreeding of wild-type cassava varieties with Manihot dichotoma or Manihot oligantha have shown promising results regarding cassava protein content. Enhancing ADP glucose pyrophosphorylase activity in cassava roots or adding amylase to cassava gruels increases cassava energy density. Moreover, carotenoidrich yellow and orange cassava may be a foodstuff for delivering provitamin A to vitamin A-depleted populations. Researchers are currently investigating the effects of cassava processing techniques on carotenoid stability and isomerization, as well as the vitamin A value of different varieties of cassava. Biofortified cassava could alleviate some aspects of food insecurity in developing countries if widely adopted.

Moschini GC (2008). Biotechnology and the development of food markets: retrospect and prospects. European Review of Agricultural Economics 35: 331-355. http://dx.doi.org/10.1093/erae/jbn014

Biotechnology has had an important impact on the agricultural and food industries over the last 12 years by way of fast and extensive adoption of a few genetically modified (GM) crops. This has produced large efficiency gains, including higher yields and reduced costs of weed and pest control, as well as some environmental benefits. The expected development of crops with additional agronomic traits, and with output traits to improve the nutrition and health attributes of food products, holds the potential for even more pervasive impacts. Full realisation of such promises may require overcoming the constraining effects of restrictive GM product regulations.

Muzhingi T, Langyintuo AS, Malaba LC, Banziger M (2008). Consumer acceptability of yellow maize products in Zimbabwe. Food Policy 33: 352-361. http://dx.doi.org/10.1016/j.foodpol.2007.09.003

This study analyzes consumers' awareness of and attitudes towards yellow maize products in Zimbabwe and suggests intervention strategies that will ensure increased production and consumption of the crop, which is rich in provitamin A to help prevent the incidence of vitamin A deficiency prevalent among vulnerable groups. Data from 360 randomly selected rural and urban households show that yellow maize is known to all but few are aware of its nutritional qualities or consume it. The main source of supply is imported food aid. Rich in oils, carotenoids and fructose, yellow maize easily undergoes chemical changes to produce unacceptable organoleptic properties (or bad taste) if poorly handled during importation. These two factors are responsible for it being perceived inferior to white maize by consumers. Quality assurance during importation can improve consumer confidence but a long-term strategy will be to vigorously promote domestic production of yellow maize varieties rich in high levels of b-carotene that meet the preferences of consumers. Drawing from a probit model regression analysis, nutritional education can potentially promote yellow maize consumption, especially if targeted at low income households. Domestic production and consumption of yellow maize will decrease vitamin A deficiency among vulnerable groups and improve food insecurity through reduced grain prices and increased incomes for farmers. These results draw attention to the need for policy makers in developing countries to review their agricultural policies to ensure that they do not undermine the local production and consumption of nutritionally valuable crops.

Mwaniki A (2006). Achieving food security in Africa: challenges and issues. New York, NY: United Nations Office of the Special Adviser on Africa. http://www.un.org/africa/osaa/reports.html

Achieving food security in its totality continues to be a challenge not only for the developing nations, but also for the developed world. The difference lies in the magnitude of the problem in terms of its severity and proportion of the population affected. In developed nations the problem is alleviated by providing targeted food security interventions, including food aid in the form of direct food relief, food stamps, or indirectly through subsidized food production. These efforts have significantly reduced food insecurity in these regions. Similar approaches are employed in developing countries but with less success. The discrepancy in the results may be due to insufficient resource base, shorter duration of intervention, or different systems most of which are inherently heterogeneous among other factors. Food security; a situation in which all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active healthy life; is affected by a complexity of factors. These include unstable social and political environments that preclude sustainable economic growth, war and civil strive, macroeconomic imbalances in trade, natural resource constraints, poor human resource base, gender inequality, inadequate education, poor health, natural disasters, such as floods and locust infestation, and

the absence of good governance. All these factors contribute to either insufficient national food availability or insufficient access to food by households and individuals. The root cause of food insecurity in developing countries is the inability of people to gain access to food due to poverty.

Naqvi S, Zhu C, Farre G, Ramessar K, Bassie L, Breitenbach J, Perez Conesa D, Ros G, Sandmann G, Capell T, Christou P (2009). Transgenic multivitamin corn through biofortification of endosperm with three vitamins representing three distinct metabolic pathways. PNAS 106: 7762-7767. http://dx.doi.org/10.1073/pnas.0901412106

Vitamin deficiency affects up to 50% of the world's population, disproportionately impacting on developing countries where populations endure monotonous, cereal-rich diets. Transgenic plants offer an effective way to increase the vitamin content of staple crops, but thus far it has only been possible to enhance individual vitamins. We created elite inbred South African transgenic corn plants in which the levels of 3 vitamins were increased specifically in the endosperm through the simultaneous modification of 3 separate metabolic pathways. The transgenic kernels contained 169-fold the normal amount of β-carotene, 6-fold the normal amount of ascorbate, and double the normal amount of folate. Levels of engineered vitamins remained stable at least through to the T3 homozygous generation. This achievement, which vastly exceeds any realized thus far by conventional breeding alone, opens the way for the development of nutritionally complete cereals to benefit the world's poorest people.

Nestel P, Bouis HE, Meenakshi JV, Pfeiffer W (2006). Biofortification of staple food crops. Journal of Nutrition 136: 1064-1067. http://jn.nutrition.org/cgi/content/abstract/136/4/1064

Deficiencies of vitamin A, iron, and zinc affect over one-half of the world's population. Progress has been made to control micronutrient deficiencies through supplementation and food fortification, but new approaches are needed, especially to reach the rural poor. Biofortification (enriching the nutrition contribution of staple crops through plant breeding) is one option. Scientific evidence shows this is technically feasible without compromising agronomic productivity. Predictive cost-benefit analyses also support biofortification as being important in the armamentarium for controlling micronutrient deficiencies. The challenge is to get producers and consumers to accept biofortified crops and increase their intake of the target nutrients. With the advent of good seed systems, the development of markets and products, and demand creation, this can be achieved.

Newell-McGloughlin M (2008). Nutritionally improved agricultural crops. Plant Physiology 147: 939-953. http://dx.doi.org/10.1104/pp.108.121947

Agricultural innovation has always involved new, science-based products and processes that have contributed reliable methods for increasing productivity and sustainability. Biotechnology has introduced a new dimension to such innovation, offering efficient and cost-effective means to produce a diverse array of novel, value-added products and tools. The first generation of biotechnology products commercialized were crops focusing largely on input agronomic traits whose value was largely opaque to consumers. The coming generations of crop plants can be grouped into four broad areas, each presenting what, on the surface, may appear as unique challenges to regulatory oversight. The present and future focus is on continuing improvement of agronomic traits such as yield and abiotic stress resistance in addition to the biotic stress tolerance of the present generation; crop plants as biomass feedstocks for biofuels and "biosynthetics"; value-added output traits such as improved nutrition and food functionality; and plants as production factories for therapeutics and industrial products. From a consumer perspective, the focus on valueadded traits, especially improved nutrition, is of greatest interest.

Nunes ACS, Kalkmann DC, Aragão FJL (2009). Folate biofortification of lettuce by expression of a codon optimized chicken GTP cyclohydrolase I gene. Transgenic Research 18: 661-667. http://dx.doi.org/10.1007/s11248-009-9256-1

Folates are essential coenzymes involved in one-carbon metabolism. Folate deficiency is associated with a higher risk of newborns with neural tube defects, spina bifida, and anencephaly, and an increased risk of cardiovascular diseases, cancer, and impaired cognitive function in adults. In plants folates are synthesized in mitochondria from pterin precursors, which are synthesized from guanosine-5'-triphosphate (GTP) in the cytosol (pterin branch), and p-aminobenzoate (PABA), derived from chorismate in plastids (PABA branch). We generated transgenic lettuce lines expressing a synthetic codon-optimized GTP-cyclohydrolase I gene (gchI) based on native Gallus gallus gene. Immunoblotting analyses confirmed the presence of the gchI in transgenic lines. Twenty-nine transgenic lines were generated and 19 exhibited significant increase in the folate content, ranging from 2.1 to 8.5-fold higher when compared to non-transgenic lines. The folate content in enriched lettuce would provide 26% of the Dietary Reference Intakes for an adult, in a regular serving. Although the lettuce lines generated here exhibited high folate enhancement over the control, better folate enrichment could be further achieved by engineering simultaneously both PABA and pterin pathways.

Nyhus CM (2009). Iron bioavailability in India: historical perspectives and current concerns. Theses and Dissertations Collection. Ithaca, NY: Cornell University. http://hdl.handle.net/1813/12823

Indian women and children continue to suffer the highest rates of anemia in the world the despite economic and agricultural growth of the past four decades. High rates of iron deficiency anemia are attributed to low iron intakes and, perhaps more importantly, to low iron bioavailability from diets high in cereals and low in animal source foods. A better understanding of trends in iron deficiency risk in India over the past thirty is warranted and examined through intakes of dietary bioavailable iron. Adult 24-hour recall data from four cross-sectional survey rounds in 1975-80, 199697, 2000-01 and 2004-05 (n=45,026) were analyzed. A bioavailability algorithm was used to calculate dietary bioavailable iron (DBI) for each individual based on iron intake as well as intake of major iron inhibitors and enhancers, like phytates, tannins and ascorbic acid. Objectives of the research were to understand trends in DBI, to compare cereal-based diets in their ability to provide DBI and finally, the potential impact of iron-biofortified crops on improving DBI intakes. Results indicate that unlike iron intakes, which have remained unaltered from 1975-2000, DBI has improved, due to dietary shifts increasing iron bioavailability. However, trends indicate a drop in DBI in the last five years and parallel recent anemia findings. Analysis of specific cereal-based diets reveal that pearl millet and wheat diets are more protective against low DBI intake (less than 50% of basal requirements for iron) than rice based diets. Finally, iron biofortified rice and wheat have the potential to increase DBI intake levels to shift at least 4.5 million people out of iron deficiency. Findings indicate that the risk of iron deficiency has reduced over the past thirty years, with the exception of the last five years, and research on improving pearl millet production and/or continuing research on iron-biofortified rice could significantly reduce iron deficiency in India. Finally, this research highlights the need to examine iron intake at the level of bioavailable iron and that bioavailability algorithms, though they may require further refinement, are a useful tool for iron nutrition.

Nyhus Dhillon CM, Pinstrup-Andersen P, Haas JD, Balakrishna N, Brahmam GNV (2008). The effect of biofortified rice and wheat in India's food supply on dietary bioavailable iron. FASEB Journal22: lb770. http://www.fasebj.org/cgi/content/meeting_abstract/22/2_MeetingAbstracts/770

Iron deficiency anemia rates in India are among the highest in the world, with 79% of children and 52% of pregnant women affected1, and are attributed to the low bioavailability of iron in the diet. Biofortification efforts aim to improve the nutrient level of basic cereals crops and are a strategy proposed to improve micronutrient intakes in India. The objective of this study is to determine the effect of iron-biofortified rice and wheat on bioavailable iron in rural Indian diets. Twenty-four hour recall data were analyzed from the National Nutrition Monitoring Board in India from 2005. Observations included in the analysis (n=22,221) were all individuals over 3 years of age in seven states. Risk of inadequate bioavailable iron (calculated using the Hallberg & Hulthen2 algorithm) was defined as <50% of basal requirements according to sex, age and physiological status. Additional iron from biofortified rice and wheat were 0.7 mg and 2.9 mg per 100g of rice and wheat, respectively. Results indicate that replacing current iron and wheat with biofortified varieties would improve the average amount of bioavailable iron in the diet by 28%, shifting 8% of the population or 22.6 million individuals out of risk of inadequate bioavailable iron. The replacement of current rice and wheat varieties with iron-biofortified varieties could yield substantial improvements in iron intakes for many Indians, especially in rice-consuming states.

OECD (2009). Development aid at its highest level ever in 2008. Online news release, 30 March. Paris: Organisation for Economic Co-operation and Development. http://www.oecd.org/document/35/0,3343,en_2649_34447_42458595_1_1_1_1,00.html

Ortiz-Monasterio JI, Palacios-Rojas N, Meng E, Pixley K, Trethowan R, Peña RJ (2007). Enhancing the mineral and vitamin content of wheat and maize through plant breeding. Journal of Cereal Science 46: 293-307. http://dx.doi.org/10.1016/j.jcs.2007.06.005

More than half of the world's population suffers micronutrient undernourishment. The main sources of vitamins and minerals (iron, zinc, and vitamin A) for low-income rural and urban populations are staple foods of plant origin that often contain low levels or low bioavailability of these micronutrients. Biofortification aims to develop micronutrient-enhanced crop varieties through conventional plant breeding. HarvestPlus, the CGIAR's biofortification initiative, seeks to breed and disseminate crop varieties with enhanced micronutrient content that can improve the nutrition of the "hard to reach" (by fortification or supplementation programmes) rural and urban poor in targeted countries/regions. In attempting to enhance micronutrient levels in maize and wheat through conventional plant breeding, it is important to identify genetic resources with high levels of the targeted micronutrients, to consider the heritability of the targeted traits, to explore the availability of high throughput screening tools and to gain a better understanding of genotype by environment interactions. Biofortified maize and wheat varieties must have the trait combinations which encourage adoption such as high yield potential, disease resistance, and consumer acceptability. When defining breeding strategies and targeting micronutrient levels, researchers need to consider the desired micronutrient increases, food intake and retention and bioavailability as they relate to food processing, anti-nutritional factors and promoters. Finally, ex ante studies are required to quantify the burden of micronutrient deficiency and the potential of biofortification to achieve a significant improvement in human micronutrient status in the deficient target population in order to determine whether a biofortification program is cost-effective.

Ozturk L, Altintas G, Erdem H, Gokmen OO, Yazici A, Cakmak I (2009). Localization of iron, zinc, and protein in seeds of spelt (Triticum aestivum ssp. spelta) genotypes with low and high protein concentration. Paper 1391, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1391

Localization of iron (Fe), zinc (Zn), and protein was studied in a set of spelt (Triticum aestivum ssp. spelta) genotypes selected for low (i.e. 12 %) or high (i.e. 25 %) grain protein concentration. Following instrumental analysis for Fe, Zn and protein, spelt seeds were longitudinally excised and stained with specific dyes for assessment of Fe, Zn, and protein localization. For Fe and Zn staining, pre-defined methods with Perls' Prussian blue and dithizone were applied whereas protein staining was performed by a modified Bradford reagent. Following staining, seed surfaces were examined by light reflectance microscopy and photographed to (i) examine the localization of Fe, Zn and protein and (ii) visually compare the variations in color intensity with the concentration data obtained by instrumental analysis of seeds with contrasting protein concentration. The applied staining method revealed that Fe localization was limited to scutellum and aleuron; however Zn and protein was localized in the whole germ and the aleuron as well. It was concluded that the staining methods applied for protein and Fe localization can also be used for mass screening of spelt genotypes for high seed protein and Fe concentration. The role of seed proteins as a sink for Fe and Zn in the spelt seed is discussed.

Paarlberg R, Pray C (2007). Political actors on the landscape. AgBioForum 10: 144-153. http://www.agbioforum.org/v10n3/v10n3a03-paarlberg.htm

The introduction of novel foods and crops into the developing world triggers different reactions from different political actors. Quite often, the patterns of response in developing countries run parallel to policy debates in rich countries, reflecting the close relationships that still can be found between government ministries, companies, and NGOs in rich countries and their subordinate partners in the developing world. In general, the strongest supporters of novel foods and crops will be scientists, agricultural ministries, and the private companies trying to sell the new technology. The strongest skeptics are likely to be NGOs claiming to speak for the poor, as well as environmental ministries. If the novel foods and crops are GMO varieties, the patterns of local support will be much weaker, and the opposition is likely to be broader and significantly stronger.

Pachón H, Ortiz DA, Araujo C, Blair MW, Restrepo J (2009). Iron, zinc, and protein bioavailability proxy measures of meals prepared with nutritionally enhanced beans and maize. Journal of Food Science 74: H147-H154. http://dx.doi.org/10.1111/j.1750-3841.2009.01181.x

Nutritionally enhanced beans (NEB) with more Fe and Zn than conventional beans (CB) and nutritionally enhanced maize (NEM) with more tryptophan and lysine than conventional maize (CM) were developed as part of a crop-biofortification strategy to improve human nutrition. Proxy measures were used to assess Fe and Zn bioavailability and protein digestibility of a bean recipe (fríjol sancochado) and a maize-milk recipe (mazamorra) prepared with enhanced or conventional crops in Colombia. Fe concentration was similar in the cooked NEB and CB and in NEM and CM ($P \geq 0.05$); in vitro Fe dialyzability was similar in cooked NEB (9.52%) and CB (9.72%) and greater for NEM (37.01%) than CM (32.24%). Zn concentration was higher in the uncooked and cooked NEB than in the CB ($P < 0.05$); phytate: Zn molar ratios were high in cooked NEB (36: 1) and CB (47: 1), suggesting low Zn bioavailability, and not different from each other ($P = 0.07$). There were no differences in Zn concentration or phytate: Zn molar ratio in the maize recipes. Nitrogen, tryptophan, and lysine concentrations were higher in the cooked NEM than CM; nitrogen was higher in the cooked NEB than CB ($P < 0.05$). In vitro protein digestibility was comparable (82% to 83%) for NEM and CM and higher for NEB (84%) than for CB (82%). The higher nutrient concentrations + similar bioavailability (protein in NEM, Zn in NEB), same nutrient concentrations + higher bioavailability (Fe in NEM) or higher nutrient concentrations + higher bioavailability (protein in NEB) can translate into more nutrients absorbed and utilized by the body.

Palmgren MG, Clemens S, Williams LE, Krämer U, Borg S, Schjørring JK, Sanders D (2008). Zinc biofortification of cereals: problems and solutions. Trends in Plant Science 13: 464-473. http://dx.doi.org/10.1016/j.tplants.2008.06.005

The goal of biofortification is to develop plants that have an increased content of bioavailable nutrients in their edible parts. Cereals serve as the main staple food for a large proportion of the world population but have the shortcoming, from a nutrition perspective, of being low in zinc and other essential nutrients. Major bottlenecks in plant biofortification appear to be the root-shoot barrier and – in cereals – the process of grain filling. New findings demonstrate that the root-shoot distribution of zinc is controlled mainly by heavy metal transporting P1B-ATPases and the metal tolerance protein (MTP) family. A greater understanding of zinc transport is important to improve crop quality and also to help alleviate accumulation of any toxic metals.

Pardey P, Alston J, James J, Glewwe P, Binenbaum E, Hurley T, Wood S (2007). Science, technology and skills. Background Paper 41371. Rome: CGIAR Science Council Secretariat. http://go.worldbank.org/WW4BTHM0D0

The invention of agriculture that occurred around 10,000 years ago heralded a shift from nomadic hunting and gathering to more managed forms of food, feed and fibre production. The domestication of crops initially involved the saving of seed from one season for planting in subsequent years. Later, farmers purposefully selected crop varieties and so in practice began matching and, by repeated selection over many years, adapting crop genetics to the environment in which the crop was grown. From its inception, enhancing G x E (i.e., gene by environment) interactions was an intrinsic, if not defining, feature of agriculture.

Park S, Elless MP, Park J, Jenkins A, Lim W, Chambers E, Hirschi KD (2009). Sensory analysis of calcium-biofortified lettuce. Plant Biotechnology Journal 7: 106-117. http://dx.doi.org/10.1111/j.1467-7652.2008.00379.x

Vegetables represent an attractive means of providing increased calcium nutrition to the public. In this study, it was demonstrated that lettuce expressing the deregulated Arabidopsis H (+)/Ca (2+) transporter sCAX1 (cation exchanger 1) contained 25%-32% more calcium than controls. These biofortified lettuce lines were fertile and demonstrated robust growth in glasshouse growth conditions. Using a panel of highly trained descriptive panellists, biofortified lettuce plants were evaluated and no significant differences were detected in flavour, bitterness or crispness when compared with controls. Sensory analysis studies are critical if claims are to be made regarding the efficacy of biofortified foods, and may be an important component in the public acceptance of genetically modified foods.

Pedrero Z, Madrid Y (2009). Novel approaches for selenium speciation in foodstuffs and biological specimens: a review. Analytica Chimica Acta 634: 135-152. http://dx.doi.org/10.1016/j.aca.2008.12.026

Selenium is an essential element for human health. It has been recognized as an antioxidant and chemopreventive agent in cancer. Selenium is known to develop its biological activity via selenocysteine residue in the catalytically active centre of selenoproteins. The main source of selenium in human beings is the diet. However, in several regions of the world the content of selenium in diet has been estimated insufficient for a correct expression of the proteins. The beneficial effects of selenium on human health are strongly dependent on its chemical form and concentration. This review critically evaluated the stateof-the art of selenium speciation in biological matrices mainly focused in nutritional and food products. Besides the number of publications related to selenium speciation, isolation and accurate characterization and quantification of selenium species is still a challenge. Hyphenated techniques based on coupling chromatography separation with inductively coupled plasma spectrometry (ICP-MS) and its combination with molecular mass spectrometry (ESI-MS, ESI-MS-MS and MALDI-TOF) and isotopic dilution allow identification, quantification and structural characterization of selenium species. Particular attention is paid in the development of Se-enriched food and nutritional products and howthe application of the techniques mentioned above is mandatory to get reliable results on selenium metabolisms in these particular matrices.

Pfeiffer WH, McClafferty B (2007). HarvestPlus: Breeding Crops for Better Nutrition. Crop Science 47: S88-S105. http://dx.doi.org/10.2135/cropsci2007.09.0020IPBS

Micronutrient malnutrition, the so-called hidden hunger, affects more than one-half of the world's population, especially women and preschool children in developing countries. Despite past progress in controlling micronutrient decencies through supplementation and food fortification, new approaches are needed to expand the reach of food-based interventions. Biofortification, a new approach that relies on conventional plant breeding and modern biotechnology to increase the micronutrient density of staple crops, holds great promise for improving the nutritional status and health of poor populations in both rural and urban areas of the developing world. HarvestPlus, a research program implemented with the international research institutes of the CGIAR, targets a multitude of crops that are a regular part of the staple-based diets of the poor and breeds them to be rich in iron, zinc, and provitamin A. This paper emphasizes the need for interdisciplinary research and addresses the key research issues and methodological considerations for success. The major activities to be undertaken are broadly grouped into research related to nutrition research and impact analysis, and research considerations for delivering biofortified crops to end-users effectively. The paper places particular emphasis on the activities of the plant breeding and genetics component of this multidisciplinary program. The authors argue that for biofortification to succeed, product profiles developed by plant breeders must be driven by nutrition research and impact objectives and that nutrition research must understand that the probability of success for biofortified crops increases substantially when product concepts consider farmer adoption and, hence, agronomic superiority.

Phattarakul N, Cakmak I, Boonchuay P, Wongmo J, Rerkasem B (2009). Role of zinc fertilizers in increasing grain zinc concentration and improving grain yield of rice. Paper 1213, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1213

Iron (Fe) toxicity is a widespread nutrient disorder and limit to grain yield in lowland rice. As it is, however, sometimes associated with deficiency of other nutrients, Fe toxicity might be also managed and alleviated by applications of concerned nutrients such as potassium (K) and zinc (Zn). However, the information on this topic available in literature is very limited, especially in the case of Zn. The objective of this study was to evaluate the effects of soil and foliar Zn applications on severity of Fe toxicity and grain concentrations of Zn in rice grown on a Fe-toxic soil in Laos under field conditions. Soil Zn applications have been realized in 2 forms: 1.5 % Zn-containing KCl (KCl-Zn) and ZnSO4. The results with soil Zn applications showed that plant growth at early growth stage was increased by both forms of Zn applications which in turn contributed to final grain yield. The increases in grain yield resulted from the KCl-Zn and ZnSO4 applications were similar and were around 35 % compared to the control treatment without any Zn application. Leaf Zn concentrations were also increased by Zn applications while Fe concentrations tended to decrease. In a separate experiment soil and foliar applications of ZnSO4 were examined for their effectiveness in affecting plant Zn concentration. Soil Zn application was not affective in increasing grain Zn concentration, but foliar-applied Zn increased Zn concentration of brown rice up to 34 %. This study suggested that Zn fertilizer strategy is a promising approach to contribute to both grain yield and grain Zn concentrations in rice under Fe toxic soil conditions.

Pinstrup-Andersen P (2006). Agricultural research and policy to achieve nutrition goals. In: de Janvry A, Kanbur R (eds). Poverty, inequality and development. 353-370. New York, NY: Springer Science+Business Media. http://dx.doi.org/10.1007/0-387-29748-0_17

Poverty causes hunger and malnutrition and hunger and malnutrition contributes to poverty. While strong links exist with poverty and inequality, hunger and malnutrition are serious public health and development problems in their own right. Agriculture is essential to achieve nutrition goals in the most fundamental sense; it makes the food available without which nutrition goals could not be achieved. This paper goes beyond this fundamental relationship by exploring five related questions: 1. How could agricultural research and policy improve nutrition? 2. Should nutrition goals guide agricultural research and policy? 3. What policy measures are likely to be effective? 4. Are nutrition goals best achieved through pre- or post-harvest changes? 5. Would consumer behavior enhance or reduce the intended effect? Each of these five questions will be reviewed in turn but first it may be useful to provide a brief overview of the nature and magnitude of the nutrition problems.

Popham HJR, Shelby KS (2006). Uptake of dietary micronutrients from artificial diets by larval Heliothis virescens. Journal of Insect Physiology 52: 771-777. http://dx.doi.org/10.1016/j.jinsphys.2006.04.005

Micronutrient assimilation from artificial diet by larvae of Heliothis virescens during selenium (Se) supplementation was studied. The metal content of pupae and plugs of the artificial diet on which they had developed from hatching was analyzed by inductively coupled plasma-mass spectrometry. Levels of the metals Cr, Co, Fe, Mg, Mn, Ni, Se, Na, and Zn were not bioaccumulated from the diet regardless of the amount of Se added to the diet. Only pupal Cu and Mo bioaccumulation were found to be altered significantly by dietary Se supplementation. Larvae fed Zn, which was found in higher levels in pupae than diet, had a deleterious response to increasing levels of dietary Zn. Larvae fed Cr, found in higher levels in diet than in pupae, were not adversely affected when increasing levels of Cr were added to the diet. Based on this analysis, metals were identified that might well impact the fitness of a given colony of insects in relation to their diet.

Potrykus I (2005). GMO-technology and malnutrition: public sector responsibility and failure. Electronic Journal of Biotechnology 8: 3. http://dx.doi.org/10.4067/S0717-34582005000300001

Micronutrient malnutrition is the source of severe medical problems in developing countries. Of the 24'000 deaths per day attributed to this problem, probably 6'000 are due to vitamin A malnutrition. Traditional interventions do not reach the majority of the needy and, therefore, alternative interventions are required. Biofortification – improvement of the micronutrient content of crops on a genetic basis - has been recognized as a cost-effective, sustainable, complementary intervention. Golden Rice represents the first case of GM-based biofortification. In Golden Rice genes have been introduced to activate the biochemical pathway leading to the synthesis and accumulation of carotenoids (pro-vitamin A) in the rice endosperm, the edible part of the rice seed. Scientific proof-of-concept was completed in spring 1999 (Ye et al. 2000). The motivation for this 'scientific tour de force' was from the onset a humanitarian one: to contribute to a reduction in vitamin A malnutrition in developing countries. The scientists involved did not expect that transferring the benefits of the scientific breakthrough to the needy would constitute such a complex and time-consuming task. And in view of the problem it is difficult to accept that it is taking at least ten years, to deliver a deregulated product.

Potrykus I (2009). Lessons from Golden Rice on public sector responsibility and failure. New Biotechnology 25: S321-S322. http://dx.doi.org/10.1016/j.nbt.2009.06.542

The following remarks are based on the practical experience with the public sector humanitarian Golden Rice project. The lessons learned are however, probably, representative for any public sector altruistic initiative. 'Golden Rice' was developed in the public domain, with public funding and with the goal, to contribute to a reduction in vitamin A-malnutrition in rice-dependent poor societies. Proof-of-concept for the engineered biosynthetic pathway was completed by February 1999. Product development beyond basic research did not find any support from the public domain. The project was rescued only because of support from the private sector. Problems related to intellectual property rights involved with the basic technology were solved within half a year. Product optimisation by the private sector was donated to the humanitarian project. The putative impact of Golden Rice was calculated to up to 40,000 lives saved per year for India alone. Development of locally adapted varieties for target countries such as The Philippines, India, Vietnam, Bangladesh, Indonesia, China is by public national and international rice research institutes, with financial support from national governments and altruistic organisations. Despite of all this substantial support Golden Rice will not reach the farmer before 2012. If Golden Rice were not a GMO but a mutation, variety development and registration would have been completed by 2002. The difference in time between traditional variety development and that of a GMO-based variety of ten years is due to nothing else but routine, regulatory requirements.

Prakash R (2006). The acute and chronic toxic effects of vitamin A. American Journal of Clinical Nutrition 84: 462. http://www.ajcn.org/cgi/content/short/84/2/462

The review by Penniston and Tanumihardjo (1) in a recent issue of the Journal highlights the important issue of adverse affects associated with supplementation with preformed vitamin A. The fact that excess supplementation of preformed vitaminAcan lead to adverse effects in both the acute and chronic settings (2, 3) is well known, but the issue of subtoxicity without overt signs of toxicity requires more study. This lack of knowledge about subtoxicity has serious implications, particularly in developing countries, where vitaminAsupplementation programs for young children and lactating mothers are in vogue and subtoxic effects may occur in many recipients of preformed vitamin A.

Pray C, Huang J (2007). Biofortification for China: political responses to food fortification and GM technology, interest groups, and possible strategies. AgBioForum 10: 161-169. http://www.agbioforum.org/v10n3/v10n3a05-pray.htm

Despite making enormous strides in reducing poverty, hunger, and malnutrition, China still has large numbers of people who do not consume sufficient micronutrients such as iron, zinc and Vitamin A. To meet this need, government agencies in China are supporting programs in industrial fortification and vitamin supplements. In recent years the government has also supported research on biofortification of major grain crops using both conventional plant breeding and transgenic techniques. The article assesses the potential political barriers to the acceptance of biofortified crops and concludes that biofortification using non-transgenic techniques would probably not face much opposition, while biofortification with transgenic techniques might have a more difficult time. The article then assesses which groups in China are likely to support or oppose biofortification and then proposes some strategies that the government and international agencies might use if they decide to support biofortification.

Pray C, Paarlberg R, Unnevehr L (2007). Patterns of political response to biofortified varieties of crops produced with different breeding techniques and agronomic traits. AgBioForum 10: 135-143. http://www.agbioforum.org/v10n3/v10n3a02-pray.htm

This article first examines the political response to two crops that were nutritionally enhanced through conventional breeding - Quality Protein Maize (QPM) and orange-fleshed sweet potatoes. In the next section, the political response to food crops - maize, potato, and papaya - which have improved agronomic traits through genetic engineering is described. Finally, we mention briefly the initial political responses to biofortified GMO rice, potatoes, cassava, and sorghum. To gain political support as well as extensive adoption by farmers, biofortification needs to be combined with attractive agronomic traits. These case studies also show that only GMOs have elicited a strong negative political response and that the consumer trait, biofortification, is not likely to make GMOs more appealing to activists and politicians. However, political opposition to GMOs can be outweighed by well-organized, politically powerful interest groups.

Qaim M (2009). The economics of genetically modified crops. Annual Review of Resource Economics 1: 3.1-3.29. http://dx.doi.org/10.1146/annurev.resource.050708.144203

Genetically modified (GM) crops have been used commercially for more than 10 years. Available impact studies of insect-resistant and herbicide-tolerant crops show that these technologies are beneficial to farmers and consumers, producing large aggregate welfare gains as well as positive effects for the environment and human health. The advantages of future applications could even be much bigger. Given a conducive institutional framework, GM crops can contribute significantly to global food security and poverty reduction. Nonetheless, widespread public reservations have led to a complex system of regulations. Overregulation has become a real threat for the further development and use of GM crops. The costs in terms of foregone benefits may be large, especially for developing countries. Economics research has an important role to play in designing efficient regulatory mechanisms and agricultural innovation systems.

Qaim M, Stein AJ (2006). Wie satt macht Pflanzenzüchtung? Die Rolle der Agrarforschung bei der Bekämpfung von Hunger und Armut. eins Entwicklungspolitik 15-16: 49-52. http://www.entwicklungspolitik.org/fruehere-hefte/2006/15-16-2006/

In der öffentlichen Debatte wird Agrartechnologie oftmals lediglich mit Steigerungen der Nahrungsproduktion in Verbindung gebracht. Da der Hunger von Vielen in erster Linie als Verteilungsproblem gesehen wird, wäre die Rolle von Agrartechnologie in der Hungerbekämpfung demnach sehr begrenzt. Diese Sichtweise greift jedoch zu kurz. Auch in Zukunft werden Produktionssteigerungen erforderlich sein. Darüber hinaus kann Agrarforschung dazu beitragen, Einkommen im Kleinbauernsektor zu steigern – also dort wo Hunger und Armut am größten sind.

Qaim M, Stein AJ (2009). Biologische Anreicherung von Grundnahrungspflanzen: Wirksamkeit und Wirtschaftlichkeit. Ernährungs Umschau 56: 274-280. http://www.ernaehrungs-umschau.de/archiv/summaries/?id=3858

Biologische Anreicherung von Grundnahrungspflanzen ist ein neuer Ansatz zur Bekämpfung von Mikronährstoffmangel. Hierbei werden Pflanzen so gezüchtet, dass sie höhere Mengen an Mikronährstoffen enthalten. Dieser Ansatz zielt vor allem auf Entwicklungsländer ab, wo viele Menschen in abgelegenen ländlichen Gebieten kaum von anderen Mikronährstoffprogrammen erreicht werden. Bisherige Studien zeigen, dass dieser Ansatz sowohl wirksam als auch wirtschaftlich sein kann.

Qaim M, Stein AJ, Meenakshi JV (2007). Economics of biofortification. Agricultural Economics 37: 119-133. http://dx.doi.org/10.1111/j.1574-0862.2007.00239.x

Micronutrient malnutrition is a serious public health problem in many developing countries. Different interventions are currently used, but their overall coverage is relatively limited. Biofortification – that is, breeding staple food crops for higher micronutrient contents – is a new agriculture-based approach, but relatively little is known about its ramifications. Here, the main factors influencing success are discussed and a methodology for economic impact assessment is presented. Ex ante studies from India and other countries suggest that biofortified crops can reduce the problem of micronutrient malnutrition in a cost-effective way, when targeted to specific situations. Further research is needed to corroborate these findings and address certain issues still unresolved.

Qin Y, Kim S-M, An G, Sohn J-K (2008). Comparison and evaluation on the chemical constituents of progeny in T-DNA inserted rice. Korean Society of Crop Science 53: 131-163. http://www.koreascience.or.kr/article/articleresultdetail.jsp?no=47486613&searchtype=JSB&listlen=16&listno=3

With the development of diverse agricultures worldwide, biofortified rice noted for its preferable marketability and palatability plays an important role in the world's agricultural economics and rice breeding programs. In this report, several M5 of T-DNA inserted lines derived from the donor cultivars, 'Hwayong' and 'Dongjin', were selected for high or low protein, high lipid and low amylose content, respectively. The coefficients and ranges of variation for the chemical constituents between M4 and M5 TDNA inserted lines were evaluated in comparison with those of the donor varieties. Results indicated that T-DNA insertion might be an effective way to generate useful variations for chemical composition of rice grains which could be used for the development of biofortified rice cultivars.

Ramakrishnan U (2002). Prevalence of micronutrient malnutrition worldwide. Nutrition Reviews 60: S46-S52. http://dx.doi.org/10.1301/00296640260130731

Ramakrishnan U, Huffman SL (2008). Multiple micronutrient malnutrition: what can be done? In: Semba RD, Bloem MW, Piot P (eds). Nutrition and health in developing countries, second edition. Totowa, NJ: Humana Press, pp. 531-576. http://dx.doi.org/10.1007/978-1-59745-464-3_18

Ramaswami B (2007). Biofortified crops and biotechnology: a political economy landscape for India. AgBioForum 10: 170-177. http://www.agbioforum.org/v10n3/v10n3a06-ramaswami.htm

Micronutrient deficiencies are responsible for major health problems among the poor in India. Biofortification promises to be a cost-effective approach in enhancing the intake of micronutrients. However, it requires government support in terms of resources and regulatory climate. This paper assesses the political receptivity to biofortification especially when it may involve genetic engineering. The paper draws on an understanding of political economy of pro-poor policies as well as the political responses to Bt cotton - the only GM crop that has received regulatory approval. The paper argues that mainstream political parties are unlikely to take strong positions on biofortified crops - whether in favor or in opposition - unless it affords an opportunity to politically mobilize farmers. If it involves genetic modification, biofortified crops will certainly be opposed by NGOs opposed to biotechnology. The extent of support from the scientific community will depend on whether the health and nutrition community is involved.

Rébeillé F, Ravanel S, Jabrin S, Douce R, Storozhenko S, Van Der Straeten D (2006). Folates in plants: biosynthesis, distribution, and enhancement. Physiologia Plantarum 126: 330-342. http://dx.doi.org/10.1111/j.1399-3054.2005.00587.x

Folates are crucial intermediates for a set of reactions that involve the transfer of single-carbon units (C1 metabolism). They are directly involved in the synthesis of nucleic acids, methionine, pantothenate, glycine and serine, and indirectly, through S-adenosyl methionine, in all methylation reactions. Humans cannot synthesize folates de novo. In these organisms, folate deficiency has severe effects on health and affects large population groups around the world. Because plants are the main source of dietary folates, there are great concerns to select plant food having high concentrations of folates or to engineer their folate metabolism to increase the initial amount. All these attempts rely on what we know about the metabolism of folates. During these last 10 years, the complex pathway leading to the synthesis of folates has been deciphered. Our knowledge about folate synthesis and distribution during plant growth and development also increased substantially. However, important aspects of folate metabolism remain unclear, such as catabolism, transport and regulation of the homeostasis. The aim of this review was to summarize our recent findings, to describe the few attempts reported in the literature to engineer folate level in plants, and to discuss potential strategies that could be used for enhancement.

Ríos JJ, Blasco B, Cervilla LM, Rubio-Wilhelmi MM, Ruiz JM, Romero L (2008). Regulation of sulphur assimilation in lettuce plants in the presence of selenium. Plant Growth Regulation 56: 43-51. http://dx.doi.org/10.1007/s10725-008-9282-7

Selenium (Se) is considered an essential trace element for animals because of its nutritional and clinical value, including its special relevance in cancer prevention, and thus Se is at present used in biofortification programmes. However, possible effects of Se application on S metabolism and plant growth are still not clear. Thus, we analysed the effect that Se application in two different forms (selenate versus selenite) exerts on the S metabolism in lettuce plants grown for 66 days. Our results indicate that the application of selenite as opposed to selenate does not affect the foliar concentration of S. With respect to different enzymes in charge of sulphate (SO42−) assimilation, the ATP-sulphurylase activity varies only with the application of different rates of selenate, while the activity of O-acetylserine (thiol)lyase (OAS-TL) and serine-acetyltransferase (SAT) increase in activity mainly when selenite is applied. Finally, the concentration of cysteine (Cys) and total thiols (SH-total), fundamentally in the selenate treatments, increased with shoot biomass. In conclusion, this study confirms that the form and application rate of Se affects S assimilation, selenate being the more suitable form to improve effectiveness of the biofortification programme with this trace element.

Ríos JJ, Rosales MA, Blasco B, Cervilla LM, Romero L, Ruiz JM (2008). Biofortification of Se and induction of the antioxidant capacity in lettuce plants. Scientia Horticulturae 116: 248-255. http://dx.doi.org/10.1016/j.scienta.2008.01.008

The aim of the present work is to analyse the way in which Se fertilization in both Se forms applied at different rates can affect the production and accumulation of Se and the foliar antioxidant capacity in lettuce plants Lactuca sativa L. cv Philipus. After different rates of sodium selenate and selenite were applied (5, 10, 20, 40, 60, 80, 120 μmol L−1), the foliar biomass, lipid peroxidation, Se accumulation, antioxidant compounds, and the antioxidant capacity were analysed. Our results indicate that the less toxic form was selenate, as it induced greater biomass, higher Se accumulation, and more antioxidant compounds than did selenite. The treatment of 40 μmol L−1 proved the most suitable for lettuce plants, as the antioxidant capacity and Se accumulation augmented without diminishing biomass, and making the two these lettuce plants healthier than control plants for human consumption, in comparison to control. Finally, regarding the antioxidant capacity test used (the ferric reducing ability of plasma [FRAP], 2,2-diphenyl-1-picryl-hydrazyl [DPPH] and reducing power), only FRAP showed a significant relationship with the different antioxidant compounds, while ascorbate best reflected the effect of Se on the antioxidant capacity under our experimental conditions.

Rosado JL, Hambidge KM, Miller LV, Garcia OP, Westcott J, Gonzalez K, Conde J, Hotz C, Pfeiffer W, Ortiz-Monasterio I, Krebs NF (2009). The quantity of zinc absorbed from wheat in adult women is enhanced by biofortification. Journal of Nutrition 139: 1920-1925. http://dx.doi.org/10.3945/jn.109.107755

Biofortification of crops that provide major food staples to large, poor rural populations offers an appealing strategy for diminishing public health problems attributable to micronutrient deficiencies. The objective of this first-stage human study was to determine the increase in quantity of zinc (Zn) absorbed achieved by biofortifying wheat with Zn. Secondary objectives included evaluating the magnitude of the measured increases in Zn absorption as a function of dietary Zn and phytate. The biofortified and control wheats were extracted at high (95%) and moderate (80%) levels and Zn and phytate concentrations measured. Adult women with habitual diets high in phytate consumed 300 g of 95 or 80% extracted wheat as tortillas for 2 consecutive days using either biofortified (41 mg Zn/g) or control (24 mg Zn/g) wheat. All meals for the 2-d experiment were extrinsically labeled with Zn stable isotopes and fractional absorption of Zn determined by a dual isotope tracer ratio technique. Zn intake from the biofortified wheat diet was 5.7 mg/d (72%) higher at 95% extraction ($P < 0.001$) and 2.7 mg/d (68%) higher at 80% extraction compared with the corresponding control wheat ($P = 0.007$). Zn absorption from biofortified wheat meals was (mean ± SD) 2.1 ± 0.7 and 2.0 ± 0.4 mg/d for 95 and 80% extraction, respectively, both of which were 0.5 mg/d higher than for the corresponding control wheat ($P < 0.05$). Results were consistent with those predicted by a trivariate model of Zn absorption as a function of dietary Zn and phytate. Potentially valuable increases in Zn absorption can be achieved from biofortification of wheat with Zn.

Rose D, Burgos G, Bonierbale M, Thiele G (2009). Understanding the role of potatoes in the Peruvian diet: an approach that combines food composition with household expenditure data. Journal of Food Composition and Analysis 22: 525-532. http://dx.doi.org/10.1016/j.jfca.2008.10.002

Agricultural research in developing countries has increasingly focused on meeting nutritional objectives. Biofortified varieties and increased use of fertilizers have been studied to improve the nutrient profile of staple foods and thereby reduce micronutrient malnutrition. To understand where and for which crops this is appropriate, a better understanding of population-level consumption patterns is needed. In this paper, we demonstrate an approach to understanding the role of the potato in the Peruvian diet, and how it varies by geographic and socio-economic group. We combine readily available data on household expenditures from a Peruvian living conditions survey (ENAHO) with food composition data to derive estimates on the amount of potatoes consumed per adult equivalent, and the contribution of potatoes to meeting the energy, protein, calcium, iron, and vitamin C needs of Peruvians. Households in the highlands, where potatoes are often the basis of cropping systems, consume the greatest quantities of potatoes, averaging 421 g/adult equivalent/day (g/ae/d). In this region, potatoes contribute 18%, 16%, 17%, and 97% of the recommended needs for energy, protein, iron, and vitamin C, respectively. Sensitivity testing using different cultivars previously examined from the Peruvian highlands shows that potatoes could supply a range from 7-31% of the

recommended intakes for iron in this population. This work gives support for continuing agricultural research to reduce micronutrient malnutrition and provides guidance for where and with whom such research might have the greatest impact.

Salas Fernandez MG, Kapran I, Souley S, Abdou M, Maiga IH, Acharya CB, Hamblin MT, Kresovich S (2009). Collection and characterization of yellow endosperm sorghums from West Africa for biofortification. Genetic Resources and Crop Evolution online 27 March. http://dx.doi.org/10.1007/s10722-009-9417-3

Sorghum is a good candidate crop for breeding to increase provitamin A, i.e., biofortification. Yellow endosperm sorghums contain carotenoids, including precursors of vitamin A, and sorghum is a major staple crop in areas of Asia and Africa where vitamin A deficiency is prevalent. Our objective was to collect and characterize yellow endosperm sorghums as a potential new source of genetic diversity to increase provitamin A content. A set of 164 landraces were collected from southern Niger and northern Nigeria. The most important use of these cultivars was as food. The endosperm exhibited a significant variation in yellow intensity. Lutein, zeaxanthin and β-carotene were the most abundant carotenoids in the ten landraces with the most intense yellow color. Cluster analysis, principal coordinate analysis and population differentiation test revealed that this set of 164 landraces represent a new genetic pool that might increase the genetic diversity of yellow endosperm sorghums in applied breeding programs.

Sanchez P, Swaminathan MS, Dobie P, Yuksel N (2005). Halving hunger: it can be done. UN Millennium Project, Task Force on Hunger. London: Earthscan. http://www.unmillenniumproject.org/reports/tf_hunger.htm

Over the past 20 years, the proportion of the world's people who are hungry has declined from one-fifth to one-sixth, and the absolute number of hungry people has fallen slightly. But 852 million people are still chronically or acutely malnourished. Most of them are in Asia, particularly India (221 million) and China (142 million). Sub-Saharan Africa has 204 million hungry and is the only region of the world where the prevalence of both general undernourishment and children's underweight status are increasing. If current trends continue, this region will not only fail to achieve the hunger Goal, but it is likely to suffer from increasing numbers of hungry people. That is why this report emphasizes the needs of Sub-Saharan Africa while addressing global hunger. Hunger continues to be a global tragedy. It requires a concerted and persistent worldwide effort to eliminate it. The Task Force on Hunger is convinced that hunger can be halved by 2015. Indeed, the task force will not be satisfied with the mere attainment of that goal. It sees reaching the hunger Goal as a milestone in the global effort to eliminate hunger.

Sandler, BJ (2005). Biofortification to reduce vitamin A deficiency: a comparative cost-benefit analysis of Golden Rice and orange-fleshed sweet potato. Thesis. Stanford, CA: Stanford University.

This study analyzes the potential costs and benefits of the biofortification of orange-fleshed sweet potato in Uganda and golden rice in Bangladesh for the reduction of vitamin A deficiency using a framework of DALYs (disability-adjusted life years). Vitamin A deficiency (VAD) afflicts millions worldwide whose diets primarily consist of starchy staple crops; women and children in South and Southeast Asia and Sub-Saharan Africa are at greatest risk. VAD can lead to severe ocular disorders and blindness, as well as immune system effects that predispose children under five to measles, malaria, and premature mortality. Vitamin A capsule supplementation has been a successful intervention to reduce vitamin A deficiency, but food-based strategies are important for a number of reasons. Results indicate that β-carotene biofortification of rice ('golden rice') can result in a 30% decrease in the burden of vitamin A deficiency in Bangladesh, and the biofortification of orange-fleshed sweet potatoes can decrease the burden of vitamin A deficiency in Uganda by nearly 40%. Biofortification scenarios resulted in a 110% increase in vitamin A consumption, but as current levels of intake are around 1-15% of recommended daily levels, biofortification alone will not be enough to eliminate vitamin A deficiency. Regardless, any increase above current low levels will have positive health benefits. Results also indicate that orange-fleshed sweet potatoes will be a substantially more cost-effective intervention (in terms of cost per year of life saved) in the reduction of VAD than golden rice, though both interventions have high internal rates of return and benefit-cost ratios greater than one. Numerous technical and legal issues surround the development and large-scale deployment of transgenic golden rice that do not affect the conventionally-bred and traditionally under-researched sweet potato. Regardless of the differences between these two scenarios, it is concluded that biofortification has the potential to be an additional cost-effective intervention to reduce vitamin A deficiency.

Sands DC, Morris CE, Dratz EA, Pilgeram AL (2009). Elevating optimal human nutrition to a central goal of plant breeding and production of plant-based foods. Plant Science 177: 377-389. http://dx.doi.org/10.1016/j.plantsci.2009.07.011

High-yielding cereals and other staples have produced adequate calories to ward off starvation for much of the world over several decades. However, deficiencies in certain amino acids, minerals, vitamins and fatty acids in staple crops, and animal diets derived from them, have aggravated the problem of malnutrition and the increasing incidence of certain chronic diseases in nominally well-nourished people (the so-called diseases of civilization). Enhanced global nutrition has great potential to reduce acute and chronic disease, the need for health care, the cost of health care, and to increase educational attainment, economic productivity and the quality of life. However, nutrition is currently not an important driver of most plant breeding efforts, and there are only a few well-known efforts to breed crops that are adapted to the needs of optimal human nutrition. Technological tools are available to greatly enhance the nutritional value of our staple crops. However, enhanced nutrition in major crops might only be achieved if nutritional traits are introduced in tandem with important agronomic yield drivers, such as resistance to emerging pests or diseases, to drought and salinity, to herbicides, parasitic plants, frost or heat. In this way we might circumvent a natural tendency for high yield and low production cost to effectively select against the best human nutrition. Here we discuss the need and means for agriculture, food processing, food transport, sociology, nutrition and medicine to be integrated into new approaches to food production with optimal human nutrition as a principle goal.

Sasson A (2005). Food and nutrition biotechnology: achievements, prospects, and perceptions. UNU-IAS Report. Yokohama: United Nations University Institute of Advanced Studies. http://www.ias.unu.edu/sub_page.aspx?catID=111&ddlID=169

The health of populations depend largely on what they eat; and what and how much populations eat concerns consumers, governments, food manufacturers, consumer advocates, and environmentalists alike. These concerns revolve around issues of their safety, their origins, their health effects – both preventive and therapeutic, their novelty and taste and their adequacy to feed growing populations particularly in developing countries where large portions are either under or malnourished. Current forms of biotechnologies bring enormous potential to addressing these concerns. It can now help not just in growing more varieties of foodstuffs but also in the production of functional foodstuffs, i.e. foods with therapeutic properties; correct some vitamin and micronutrient deficiencies; offer healthier versions of popular foodstuffs without affecting the taste, e.g. sweeteners, bitter or acid suppressors; and can also help trace food origin and authenticity through correlating genetic markers with meat quality, genetic tagging of aquacultural species and even DNA fingerprinting of grapevine varieties. In the areas mentioned, biotechnology has already been making significant inroads in delivering the potential to address the fundamental food and health concerns of a growing world population. Social acceptance for biotechnologies by the public has yet to solidify and spread to reach the acceptance other technologies in other sectors enjoy but the signs are encouraging and industry has so far held on to the current level of reception and acceptance from consumers, while urging governments to give more incentives to help it further.

Sautter C, Poletti S, Zhang P, Gruissem W (2006). Biofortification of essential nutritional compounds and trace elements in rice and cassava. Proceedings of the Nutrition Society 65: 153-159. http://dx.doi.org/10.1079/PNS2006488

Plant biotechnology can make important contributions to food security and nutritional improvement. For example, the development of 'Golden Rice' by Professor Ingo Potrykus was a milestone in the application of gene technology to deliver both increased nutritional qualities and health improvement to wide sections of the human population. Mineral nutrient and protein deficiency as well as food security remain the most important challenges for developing countries. Current projects are addressing these issues in two major staple crops, cassava (Manihot esculenta Crantz) and rice. The tropical root crop cassava is a major source of food for approximately 600 million of the population worldwide. In sub-Saharan Africa >200 million of the population rely on cassava as their major source of dietary energy. The nutritional quality of the cassava root is not sufficient to meet all dietary needs. Rice is the staple food for half the world population, providing approximately 20% of the per capita energy and 13% of the protein for human consumption worldwide. In many developing countries the dietary contributions of rice are substantially greater (29·3% dietary energy and 29·1% dietary protein). The current six most popular 'mega' rice varieties (in terms of popularity and acreage), including Chinese hybrid rice, have an incomplete amino acid profile and contain limited amounts of essential micronutrients. Rice lines with improved Fe contents have been developed using genes that have functions in Fe absorption, translocation and accumulation in the plant, as well as improved Fe bioavailability in the human intestine. Current developments in biotechnology-assisted plant improvement are reviewed and the potential of the technology in addressing human nutrition and health are discussed.

Schneeman BO (2005). Biotechnology-derived nutritious foods for developing countries: needs, opportunities, and barriers - an overview. Food and Nutrition Bulletin 26: 410. http://foodandnutritionbulletin.org/FNB/index.php/FNB/issue/view/13

The first workshop on biotechnology-derived nutritious foods, which was held in January 2002 in Mexico [1], was one of the first attempts to bring together a balanced group of nutrition, agriculture, and biotechnology scientists to engage in a multidisciplinary dialogue about the nature of nutrition problems in developing countries and potential strategies to address the challenges. The goal of the workshop was to ensure that the issues and the challenges were defined by the experts in the field so that the cross-disciplinary dialogue among participants would be meaningful to each area of expertise (i.e., nutrition, agriculture, and biotechnology). With regard to nutritional status, the groups focused on problems of undernutrition, and the nutrition experts cautioned against focusing on single nutrient problems and illustrated the need to consider the potential impact of multiple nutrient inadequacies. The workshop identified four primary strategies to improve nutritional status: supplementation, fortification, diversification of the food supply, and biofortification. The groups viewed these strategies as a portfolio of tools that are available and discouraged focusing on the comparative advantages of each approach. They instead emphasized the importance of selecting the most appropriate strategy for the prevailing conditions.

Sekimoto H (2009). Higher plants have the ability to reduce iodate to iodide. Paper 1092, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1092

To avoid iodine toxicity in crops and to make iodine-biofortified crops, it is important to study iodine uptake and metabolism in plant depending on its chemical forms. Using ion chromatography and inductively coupled plasma mass spectrometry system (IC-ICP-MS) for the determination of form of iodine, plant uptake and metabolism of inorganic iodine and the behavior in the rhizosphere were studied. Iodide was detected in plant body, xylem sap and culture media of Iodate treated plants. Iodate would be reduced to Iodide by roots or in the rhizoshere readily, and rice plants would absorb the reduced Iodide. Higher plants would have the ability to reduce iodate to iodide.

Shekhar Gautam C, Saha L, Sekhri K, Kumar Saha P (2008). Iron deficiency in pregnancy and the rationality of iron supplements prescribed during pregnancy. Medscape Journal of Medicine 10: 283. http://www.medscape.com/viewarticle/583028

Iron deficiency with its resultant anemia is probably the most widespread micronutrient deficiency in the world. Women who are pregnant or lactating and young children are the most affected, especially in the developing world. Despite that only 1 to 3 mg of absorbed iron is required daily at different stages of life, most diets remain deficient. Failure to include iron-rich foods in the diet and inappropriate dietary intake coupled with wide variation in bioavailability (based on the presence of iron absorption inhibitors in the diet) are some of the important factors responsible for iron deficiency. Iron supplementation can be targeted to high-risk groups (eg, pregnant women) and can be cost-effective. Iron fortification of food can prevent iron deficiency in at-risk populations. Selective plant breeding and genetic engineering are promising new approaches to improve dietary iron nutrition quality.

Shi R, Li H, Tong Y, Jing R, Zhang F, Zou C (2008). Identification of quantitative trait locus of zinc and phosphorus density in wheat (Triticum aestivum L.) grain. Plant and Soil 306: 95-104. http://dx.doi.org/10.1007/s11104-007-9483-2

Zinc (Zn) is an essential micronutrient for human beings. However, Zn malnutrition has become a major problem throughout the world. Wheat is the most important food crop in the world, therefore, developing Zn-enriched wheat varieties provides an effective approach to reduce Zn malnutrition in human beings. The aim of this study was to understand the genetic control of grain Zn density in wheat and hence, to provide genetic basis for breeding wheat with high grain Zn density using molecular approach. A doubled haploid (DH) population developed from a cross between winter wheat varieties Hanxuan10 and Lumai 14 was used to identify quantitative trait loci (QTLs) for Zn concentration and content in wheat grains. In addition, phosphorus (P) concentration and content in wheat grain were also investigated to examine possible interactions between these two nutrients. The wheat grains used in this study were harvested from the plants grown under normal condition in a field trial. We found the grain Zn concentrations of the DH population varied from 25.9 to 50.5 mg/kg and the Zn content varied from 0.90 to 2.21 µg/seed. The grain P concentrations of the DH population varied from 0.258 to 0.429 mg/kg, and the P contents varied from 0.083 to 0.186 mg/seed. A significant positive correlation was observed between Zn and P density in this experiment. The results showed that both grain Zn and P densities were controlled by polygenes. Four and seven QTLs for Zn concentration and Zn content were detected, respectively. All the four QTLs for Zn concentration co-located with the QTLs for Zn content, suggesting a possibility to improve both grain Zn concentration and content simultaneously. Four and six QTLs for P concentration and P content were detected, respectively. The two QTLs for grain Zn concentration on chromosomes 4A and 4D co-located with the QTLs for P concentration. The four QTLs for grain Zn content on chromosome 2D, 3A and 4A co-located with the QTLs for P contents, reflecting the positive correlations between the grain Zn and P density, and providing possibility of improving grain micro- and macronutrient density simultaneously in wheat. In order to improve human health, the effect of P-Zn relation in grain on the Zn bioavailability should also be considered in the future work.

Šimić D, Sudar R, Ledenčan T, Jambrović A, Zdunić Z, Brkić I, Kovačević V (2009). Genetic variation of bioavailable iron and zinc in grain of a maize population. Journal of Cereal Science in press: 6p. http://dx.doi.org/10.1016/j.jcs.2009.06.014

More than one-third of the world's population is afflicted by iron (Fe) and zinc (Zn) deficiencies, since cereal grain as a staple food of the people contains low levels or low bioavailability of Fe and Zn because of phytate. In maize, 80% of grain phosphorus (P) is in the form of phytate, and P could be an indicator of phytate content. The objectives of this study were (1) to estimate genetic variation of Fe and Zn in a maize population including P/Fe and P/Zn molar ratios as quantitative traits; (2) to determine relations among yield, P, Fe, Zn, P/Fe and P/Zn molar ratios; and (3) to define the implications of those on biofortification (breeding) programmes. There were significant genetic variations and workable heritabilities for Fe, Zn, P/Fe and P/Zn estimated in 294 F4 lines of a maize population, but there were no associations among six traits according to both simple correlations and principal component analysis. Weak correlations between P and Fe and between P and Zn indicated feasibility of breeding non lowphytic acid maize genotypes with more appropriate phytate/Fe and phytate/Zn relations. Bioavailability of iron and zinc varied substantially in a maize population justifying utilisation of these unique parameters in biofortification programmes.

Singh MV (2009). Micronutrient nutritional problems in soils of India and improvement for human and animal health. Indian Journal of Fertilisers 5: 11-16. http://www.zinc-crops.org/Documents/singharticle.pdf (1.5 MB)

An article by M.V. Singh entitled, "Micronutrient Nutritional Problems in Soils of India and Improvement for Human and Animal Health" focuses on how zinc deficiency affects human health and how the ongoing increase of zinc deficiency in India greatly increases the need for zinc in fertilizers. His suggested strategies for correction include biofortification of micronutrients in seed through improved agricultural practices, micronutrient supplementation and improving bioavailability through dietary modifications.

Singh Y, Sharma HC, Singh K, Singh UN, Singh AK, Singh CS, Singh KK (2005). Rice yield as affected by use of biofortified straw compost combined with NPK fertilizer. International Rice Research Notes 30: 47-48. http://www.irri.org/publications/irrn/irrn30-1.asp

To fully exploit the yield potential of input-responsive, high-yielding rice cultivars, agronomists generally consider improving the management of essential macro mineral elements only (NPK) while ignoring the rest. Rice straw as farm waste was found useful for sustaining rice productivity and soil health in a pollution-free environment when used either alone or in combination with mineral fertilizers (macro- and micronutrients) or bioactivators or both (Gaur 1999). This study was conducted during the 2002 and 2003 rainy seasons at the BHU Research Farm to find the efficiency of bio-fortified rice straw compost in combination with NPK in transplanted rice.

Slingerland MA, Traore K, Kayodé APP, Mitchikpe CES (2006). Fighting Fe deficiency malnutrition in West Africa: an interdisciplinary programme on a food chain approach. NJAS Wageningen Journal of Life Sciences 53: 253-279. http://library.wur.nl/ojs/index.php/njas/article/viewArticle/647

About 2 billion people, mainly women and young children, suffer from iron deficiency. The supply of iron (Fe) falls short when consumed foods have a low Fe content or when absorption of Fe is inhibited by the presence of phytic acid and polyphenols in the diet. Current interventions are dietary diversification, supplementation, fortification and biofortification. In West Africa these interventions have only moderate chances of success due to low purchasing power of households, lack of elementary logistics, lack of central processing of food and the high heterogeneity in production and consumption conditions. A staple food chain approach, integrating parts of current interventions was proposed as an alternative. The research was carried out in several villages in Benin and Burkina Faso to take ecological, cultural and socio-economic diversity into account. The interdisciplinary approach aimed at elaborating interventions in soil fertility management, improvement and choice of sorghum varieties and food processing, to increase Fe and decrease the phytic acid-Fe molar ratio in sorghum-based foods. The phytic acid-Fe molar ratio was used as a proxy for Fe bioavailability in food. Synergy and trade-offs resulting from the integrated approach showed its added value. P fertilization and soil organic amendments applied to increase yield were found to also increase phytic acid content of the grain and thus to decrease its nutritional value. Amounts of Fe and phytic acid and their ratio in the grain differed among sorghum varieties, illustrating the presence of genetic variation for Fe bioavailability. The current local food preparation method for one of the main sorghum-based foods (dibou) in northern Benin did not include processing steps that remove or de-activate anti-nutritional factors reducing Fe bioavailability. The preliminary results suggest that a feasible chain solution consists of breeding for high Fe and moderate phytic acid contents and using soil organic amendments and P fertilization to increase yields but that this needs to be followed by improved food processing to remove phytic acid. Further research on timing of application of phosphate, Fe fertilizer and soil organic amendments is needed to improve phytic acid-Fe molar ratios in the grain. Research on the exact distribution of Fe, phosphate, phytic acid and tannins within the sorghum grain is needed to enable the development of more effective combinations of food processing methods aiming for more favourable phytic acid-Fe molar ratios in sorghum-based food.

Smale M, Zambrano P, Gruère G, Falck-Zepeda J, Matuschke I, Horna D, Nagarajan L, Yerramareddy I, Jones H (2009). Measuring the economic impacts of transgenic crops in developing agriculture during the first decade approaches, findings, and future directions. Food Policy Review 10. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/publication/measuring-economic-impacts-transgenic-crops-developing-agriculture-during-first-decade

In the debate over biotech crops, differentiating fact from fiction is not easy. The debate has been confused by the influence of rigid, absolutist views (both supportive of and opposed to biotech crops) about the role of science in society, combined with a general ignorance of science. On the one hand, we hear that transgenic methods offer the chance to overcome some of the most intractable problems faced by poor farmers in harsh growing environments, such as drought. On the other, we hear concerns about the risks to human health and threats to biodiversity. Concentration of advanced scientific knowledge and market share in life-science corporations has provoked suspicion that poor farmers may have no say in the matter and cannot afford to purchase biotech seed anyway. Profound ethical issues, and skepticism about the benefits of transgenic crops, have led consumers and advocacy groups to vigorously resist adoption of biotech crops. While we cannot claim objectivity on a topic fraught with such strongly held views, this systematic review represents our best effort to disentangle from the controversy some facts about the economic impacts of biotech crops on farmers in developing economies during the first decade of their use, 1997-2007.

Solomons NW (2008). National food fortification: a dialogue with reference to Asia: balanced advocacy. Asia Pacific Journal of Clinical Nutrition 17: S20-S23. http://apjcn.nhri.org.tw/server/APJCN/Volume17/vol17suppl.1/abstracts.php

The vulnerability of large segments of Asia's population to micronutrient deficiency is more a consequence of cultural evolution and demography than of economic inequities. We evolved in a hunter-gatherer lifestyle with vigorous energy expenditure, wide dietary variety and a nutrient-dense diet (meat, viscera), and wound up 10,000 years ago as agriculturalists cultivating cereal and tuber crops for 70% of our dietary calories. Obtaining rice, maize and wheat is less energy intensive than needed for hunters' fare, while grains are distinctly less rich in available vitamins and minerals. Recurrent infectious episodes, transmitted in crowded societies, further deplete micronutrient nutriture. A fast-track option to address historically unprecedented life conditions includes chemical- or bio-fortification of ubiquitous condiments or widely consumed staples. With little or no change in habitual eating individuals will consume recommended micronutrient intakes and uptakes. Generous intakes of nutrients such as vitamin A and zinc counteract the adverse environmental effects on quality of life and survival in poverty situations. One size may not fit all, and over-consumption of certain micronutrients in heterogeneous societies is to be avoided. For the rice bowl to support the descendants of the caveman in the third millennium requires both imagination and technological ingenuity.

Sparvoli F, Campion B, Doria E, Fileppi M, Galasso I, Tagliabue G, Daminati MG, Rasmussen S, Bollini R, Nielsen E (2007). Improving bean seeds for micronutrient bioavailability: isolation and characterisation of a LPA (low phytic acid) mutant. Paper 2.04, 51st Annual Congress, 23-26 September. Riva del Garda: Italian Society of Agricultural Genetics. http://www.siga.unina.it/SIGA2007/Legumes.html

One of the major challenges in improving seed nutritional quality traits, is the production of biofortified crops in which micronutrients, such as iron, zinc and phosphorous, are more bioavailable for human and animal nutrition. Phytic acid, that in the seed represent the major form of P storage, is one of the major constraint to micronutrient bioavailability. In fact, this compound binds mineral cations, such as Fe, Zn and Ca, forming mixed salts (phytin) that are largely excreted by humans and other non ruminant animals, since they have no or limited phytase activity in their digestive tract. Therefore, phytin excretion, besides contributing to nutritional micronutrient deficiencies, has also a significant impact on water pollution (eutrophication). The development of low phytic acid (lpa) grains is considered an useful goal to obtain nutritionally improved food and feed as well as environment friendly and sustainable productions.

Sreenivasulu K, Raghu P, Ravinder P, Nair KM (2008). Effect of dietary ligands and food matrices on zinc uptake in Caco-2 cells: implications in assessing zinc bioavailability. Journal of Agricultural and Food Chemistry 56: 10967-10972. http://dx.doi.org/10.1021/jf802060q

The kinetics, depletion/repletion of zinc, and effects of dietary ligands/food matrices on 65Zn uptake was studied in Caco-2 cells. The uptake of zinc showed a saturable and nonsaturable component, depending upon the media zinc concentrations. Intracellular depletion increased zinc uptake, whereas zinc loading did not. Phytic acid and histidine inhibited zinc uptake, while tannic acid, tartaric acid, arginine, and methionine increased zinc uptake. Tannic acid at a 1:50 molar ratio promoted zinc uptake from wheat- and rice-based food matrices. Further, Caco-2 cells responded similarly with zinc and iron uptake when fed Indian bread prepared from low- and high-extraction wheat flour, representing low and high phytate content. However, inclusion of tea extract or red grape juice as a source of polyphenols enhanced the uptake of zinc while decreasing that of iron. These results suggest that the Caco-2 cells predict the correct direction of response to dietary ligands even from complex foods.

Ssemakula G, Dixon A (2007). Genotype X environment interaction, stability and agronomic performance of carotenoid-rich cassava clones. Scientific Research and Essay 2: 390-399. http://www.academicjournals.org/SRE/abstracts/abstracts/abstracts2007/Sep/Ssemakula%20and%20Dixon.htm

Cassava is widely consumed in Africa where malnutrition is rampant; there is, therefore, a major effort to produce micronutrient biofortified cassava. Adoption of such cassava genotypes will largely depend on their agronomic performance, resistance to biotic stresses, and the stability of these traits. The objectives of this study were to (i) evaluate the influence of genotype (G) environment (E), and G x E interaction on fresh root yield (FRY), dry root yield (DRY), dry matter content (DM), cassava mosaic disease (CMD), bacterial blight (CBB), cassava anthracnose diseases (CAD), and cassava green mite (CGM) in carotenoid-rich cassava, (ii) evaluate performance of the selected clones for the traits and establish any linear relationships between them, and (iii) determine the most stable clones for FRY, DRY, and DM. Genotypes were evaluated over two years (2004/2005, 2005/2006) at five locations in Nigeria. All clones expressed mild CBB and CAD symptoms; eleven clones did not have CMD symptoms, while CGM was the most severe biotic stress. There were significant negative correlations between CMD and CBB, CBB and CAD, CBB and FRY, CBB and DRY, CAD and CGM, and CGM and FRY. This implies that selecting for one trait in a pair may be indirectly selecting against the other. There were significant positive correlations between CMD and CAD, CMD and FRY, CMD and DRY, CBB and CGM, CAD and FRY, and CAD and DRY. This implies that improving one trait in a pair may indirectly improve the other. G effects had the largest impact on CMD, CGM, and DM; location effect (L) had largest impact on CBB, CAD, FRY and DRY. Effects of L, G x L and G x year x L interaction were significant for all traits. The high influence of E on FRY, DRY, CBB, and CAD, will limit progress in breeding and selection for these traits in carotenoid-rich cassava. The substantial E and G x E effects on CMD, CGM, and DM, albeit with high G effects, suggest prospects for advance in breeding for these traits though the extent may be limited by the failure of some genotypes to respond. Clones 01/1235, 94/0006, 01/1206, 01/1412 and 91/2324 (check) were stable with relatively high FRY; 01/1380, 94/0006, and 30572 were stable with high DRY; 94/0330, 01/1646, 01/1277, and 95/0379 were stable with relatively high DM.

Stein AJ (2006). Micronutrient malnutrition and the impact of modern plant breeding on public health in India: how cost-effective is biofortification? Göttingen: Cuvillier Verlag. http://www.ajstein.de/cv/biofortification.htm

Millions of people worldwide suffer from micronutrient malnutrition or "hidden hunger"; and it is mostly women and children in poor households who suffer from a lack of essential minerals and vitamins in their daily diets. These deficiencies can have devastating consequences for the life, health and well-being of the affected individuals, but they may also perpetuate a vicious circle of undernutrition, low economic productivity and poverty. Hence, in many developing countries vitamin and mineral deficiencies are public health problems of primary concern. Economic development and rising incomes can only address undernutrition in the long run, but conventional approaches also have weaknesses that limit the overall progress in controlling micronutrient deficiencies. Therefore, "biofortification" may be a promising complementary intervention. The idea is to breed food crops for higher micronutrient content, which can be done through cross-breeding or genetic engineering. Targeting staple crops that fortify themselves already on the farmers' fields has several advantages: the enriched crops simply follow the normal food chain and they are eaten by the poor in bigger quantities. Moreover, the underlying germplasm of micronutrient-rich crops only needs to be developed once and can then be used around the world - and farmers can grow and reproduce biofortified crops year on year and share the micronutrient-dense seeds. Therefore, the initial investments in research and development (R&D) of biofortification can be followed by a continuous stream of benefits that accumulates over time and space, which suggests that biofortification can be a very cost-effective intervention. Apart from two more limited studies that focused on "Golden Rice", which has been genetically engineered to produce beta-carotene, a more rigorous and comprehensive assessment of biofortification is still outstanding.

Stein AJ (2009). Global impacts of human mineral malnutrition. Plant and Soil, online 25 November. http://dx.doi.org/10.1007/s11104-009-0228-2

Background: Malnutrition – in the form of insufficient energy intakes – affects millions of people worldwide and the negative impact of this kind of hunger is well acknowledged, not least by agronomists trying to increase yields to ensure a sufficient supply of food. Scope: This review focuses on another, more particular and "hidden" form of malnutrition, namely mineral malnutrition. It illustrates the burden of disease that is caused by mineral deficiencies and the social and economic consequences they bring about. Conclusions: Mineral malnutrition has a considerable negative impact on individual well-being, social welfare and economic productivity. Agricultural scientists should keep the nutritional qualities of food in mind and – next to optimizing the agricultural properties of crops that are paramount for their adoption by farmers – in particular try to increase the micronutrient content in major staple crops as one way to address vitamin and mineral malnutrition in humans; especially plant breeding approaches promise to be very cost-effective.

Stein AJ, Matuschke I, Qaim M (2008). Grüne Gentechnik' für eine arme Landbevölkerung: Erfahrungen aus Indien. Geographische Rundschau 4: 36-41. http://www.geographischerundschau.de/aktuell_inhalt-aktuelles-heft.php?bestellnr=51080400

In Entwicklungs- und Schwellenländern lebt die Mehrheit der Bevölkerung auf dem Land und ist dort zum Großteil von der Landwirtschaft abhängig. Ein in diesem Zusammenhang viel diskutiertes Thema ist der mögliche Beitrag moderner Agrartechnologien zur Hunger- und Armutsbekämpfung im ländlichen Raum, wo die Bevölkerung zumeist traditionell geprägt und wenig gebildet ist. Die „Grüne Revolution" – die u.a. neues Hochertragssaatgut mit sich brachte – hat den Armen in Indien z.B. insofern genützt, dass akute Hungerkrisen vermieden werden konnten. Dennoch steht Indien weiterhin vor der Herausforderung, Millionen von Menschen aus der Armut zu führen. Mit der Grünen Gentechnik wird in Indien eine andere agrartechnologische Neuerung weiterentwickelt und genutzt, um die Einkommens- und Ernährungssituation der armen Landbevölkerung zu verbessern.

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2008). Potential impacts of iron biofortification in India. Social Science & Medicine 66: 1797-1808. http://dx.doi.org/10.1016/j.socscimed.2008.01.006

Iron deficiency is a widespread nutrition and health problem in developing countries, causing impairments in physical activity and cognitive development, as well as maternal mortality. Although food fortification and supplementation programmes have been effective in some countries, their overall success remains limited. Biofortification, that is, breeding food crops for higher micronutrient content, is a relatively new approach, which has been gaining international attention recently. We propose a methodology for ex ante impact assessment of iron biofortification, building on a disability-adjusted life years (DALYs) framework. This methodology is applied in an Indian context. Using a large and representative data set of household food consumption, the likely effects of iron-rich rice and wheat varieties are simulated for different target groups and regions. These varieties, which are being developed by an international public research consortium, based on conventional breeding techniques, might be ready for local distribution within the next couple of years. The results indicate sizeable potential health benefits. Depending on the underlying assumptions, the disease burden associated with iron deficiency could be reduced by 19-58%. Due to the relatively low institutional cost to reach the target population, the expected cost-effectiveness of iron biofortification compares favourably with other micronutrient interventions. Nonetheless, biofortification should not be seen as a substitute for other interventions. Each approach has its particular strengths, so they complement one another.

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2005). Health benefits of biofortification: an ex-ante analysis of iron-rich rice and wheat in India. Paper 132485, Annual Meeting, 24-27 July. Providence, RI: American Agricultural Economics Association. http://purl.umn.edu/19468

Hunger is acknowledged to impose a heavy burden on humankind with severe negative health consequences. Micronutrient malnutrition, or "hidden hunger", is an even more widespread problem, to which economic development and income growth alone are not expected to provide a solution any time soon. Existing micronutrient interventions like pharmaceutical supplementation or industrial fortification have their limitations and can be complemented by a new approach: breeding food crops for higher micronutrient densities. Knowledge about the cost-effectiveness of this new tool, also termed biofortification, is scarce. In this study, a framework for economic impact analysis is developed, which is then used for evaluation of iron-rich rice and wheat in India. Health benefits are measured and quantified using "disability-adjusted life years" (DALYs). The impact of biofortification is based on a representative data set of food consumption at the household level. Juxtaposing imputed health benefits with research and development costs proves the cost-effectiveness of the intervention; under pessimistic assumptions saving one healthy life year through biofortification only costs US$ 1.90, a cost which even declines to 36 Cents under optimistic assumptions. Extending the study to include a cost-benefit analysis shows that iron biofortification, with an internal rate of return of 74-152%, can also be a worthwhile public investment.

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2005). Analyzing the health benefits of biofortified staple crops by means of the Disability-Adjusted Life Years approach: a handbook focusing on iron, zinc and vitamin A. HarvestPlus Technical Monograph 4. Washington, DC: International Food Policy Research Institute. http://www.harvestplus.org/content/analyzing-health-benefits-biofortified-staple-crops-means-disability-adjusted-life-years-app

Biofortified staple crops – food crops bred for higher micronutrient content – are expected to reduce micronutrient deficiency and its accompanying adverse health outcomes. Health benefits can be measured and expressed in terms of the number of "disability-adjusted life years" (DALYs) saved due to the intervention. This quantification of health benefits can be used in cost-effectiveness and in cost-benefit analyses, by attributing a monetary value to DALYs and juxtaposing this benefit and the research and development costs of the biofortified crop. This handbook describes how to conduct these impact analyses for staple crops biofortified with iron, zinc or beta-carotene. It outlines the underlying method, explains the individual steps of the analysis, and details information and data requirements. The results of analyses of the type described here should prove useful for demonstrating the economic feasibility of biofortification, estimating its impact, creating awareness of this new intervention, directing research priorities, and identifying constraints early on.

Stein AJ, Nestel P, Meenakshi JV, Qaim M, Sachdev HPS, Bhutta ZA (2007). Plant breeding to control zinc deficiency in India: how cost-effective is biofortification? Public Health Nutrition 10: 492-501. http://dx.doi.org/10.1017/S1368980007223857

Objective: To estimate the potential impact of zinc biofortification of rice and wheat on public health in India and to evaluate its cost-effectiveness compared with alternative interventions and international standards. Design: The burden of zinc deficiency (ZnD) in India was expressed in disability-adjusted life years (DALYs) lost. Current zinc intakes were derived from a nationally representative household food consumption survey (30-day recall) and attributed to household members based on adult equivalent weights. Using a dose-response function, projected increased zinc intakes from biofortified rice and wheat were translated into potential health improvements for pessimistic and optimistic scenarios. After estimating the costs of developing and disseminating the new varieties, the cost-effectiveness of zinc biofortification was calculated for both scenarios and compared with alternative micronutrient interventions and international reference standards.Setting: India. Subjects: Representative household survey (n = 119 554). Results: The calculated annual burden of ZnD in India is 2.8 million DALYs lost. Zinc biofortification of rice and wheat may reduce this burden by 20-51% and save 0.6-1.4 million DALYs each year, depending on the scenario. The cost for saving one DALY amounts to $US 0.73-7.31, which is very cost-effective by standards of the World Bank and the World Health Organization, and is lower than that of most other micronutrient interventions. Conclusions: Not only may zinc biofortification save lives and prevent morbidity among millions of people, it may also help accommodate the need to economise and to allocate resources more efficiently. Further research is needed to corroborate these findings.

Stein AJ, Qaim M (2007). The human and economic cost of hidden hunger. Food and Nutrition Bulletin 28: 125-134. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/1841

Stein AJ, Sachdev HPS, Qaim M (2006). Can genetic engineering for the poor pay off? An ex-ante evaluation of Golden Rice in India. Research in Development Economics and Policy 5: 33p. http://purl.umn.edu/8534

Genetic engineering (GE) in agriculture is a controversial topic in science and society at large. While some oppose genetically modified crops as proxy of an agricultural system they consider unsustainable and inequitable, the question remains whether GE can benefit the poor within the existing system and what needs to be done to deliver these benefits? Golden Rice has been ge-netically engineered to produce provitamin A. The technology is still in the testing phase, but, once released, it is expected to address one consequence of poverty – vitamin A deficiency (VAD) – and its health implications. Current interventions to combat VAD rely mainly on phar-maceutical supplementation, which is costly in the long run and only partially successful. We develop a methodology for ex-ante evaluation, taking into account the whole sequence of effects between the cultivation of the crop and its ultimate health impacts. In doing so we build on a comprehensive, nationally representative data set of household food consumption in India. Using a refined disability-adjusted life year (DALY) framework and detailed health data, this study shows for India that under optimistic assumptions this country's annual burden of VAD of 2.3 million DALYs lost can be reduced by 59.4% hence 1.4 million healthy life years could be saved each year if Golden Rice would be consumed widely. In a low impact scenario, where Golden Rice is consumed less frequently and produces less provitamin A, the burden of VAD could be reduced by 8.8%. However, in both scenarios the cost per DALY saved through Golden Rice (US$3.06-19.40) is lower than the cost of current supplementation efforts, and it outperforms international cost-effectiveness thresholds. Golden Rice should therefore be considered seriously as a complementary intervention to fight VAD in rice-eating populations in the medium term.

Stein AJ, Sachdev HPS, Qaim M (2006). Potential impact and cost-effectiveness of Golden Rice. Nature Biotechnology 24: 1200-1201. http://dx.doi.org/10.1038/nbt1006-1200b

A News & Views article by Michael Grusak in last year's April issue (Nat. Biotechnol. 23, 429-430, 2005) highlighted the unresolved debate concerning the efficacy of Golden Rice in addressing the problem of vitamin A deficiency (VAD). He pointed out that an assessment of the potential impact of Golden Rice on this type of malnutrition requires the consideration of multiple variables, including the target individuals' life stages, the average amount of rice consumed daily by these individuals and the percentage of β-carotene that would be absorbed from rice. He further explains how early critics of the original Golden Rice technology had used simple estimates of these variables to suggest that unrealistic amounts of the transgenic rice would need to be consumed to satisfy the recommended dietary intakes of vitamin A equivalents (exclusively) through rice consumption. By replacing the daffodil phytoene synthase gene with the equivalent gene from maize, researchers have managed to increase the amount of β-carotene that accumulates in rice considerably1. However, a sound impact analysis of this new Golden Rice 2 variety, based on a solid methodological framework, is still outstanding.

Stein AJ, Sachdev HPS, Qaim M (2006). Potential impacts of Golden Rice on public health in India. Annual Meeting, 12-18 August. Gold Coast: International Association of Agricultural Economists. http://purl.umn.edu/25381

Vitamin A deficiency (VAD) affects millions of people world-wide, causing serious health problems. Golden Rice (GR), which has been genetically engineered to produce beta-carotene, is being proposed as a remedy. While this new technology has aroused controversial debates, its nutritional impact and cost-effectiveness remain unclear. We determine the current burden of VAD in India from a public health perspective, and simulate the potential alleviating impact of GR using representative household food consumption data. Given broad public support, GR could more than halve the overall burden of VAD. Juxtaposing health benefits and overall costs suggests that GR is very costeffective.

Stein AJ, Sachdev HPS, Qaim M (2007). What we know and don't know about Golden Rice. Nature Biotechnology 25: 624. http://dx.doi.org/10.1038/nbt0607-624a

Michael Krawinkel raises three issues in his comment to our economic analysis of Golden Rice1. First, he questions the scientific basis of the assumptions that we have used in our impact assessment. Second, he claims that the development of Golden Rice costs "a lot of money" and would mainly benefit "agrochemistry" companies. And third, he states that biofortification in general and Golden Rice in particular cannot replace any of the established micronutrient interventions for the forseeable future.

Stein AJ, Sachdev HPS, Qaim M (2008). Genetic engineering for the poor: Golden Rice and public health in India. World Development 36: 144-158. http://dx.doi.org/10.1016/j.worlddev.2007.02.013

Vitamin A deficiency (VAD) affects millions of people, causing serious health problems. Golden Rice (GR), which has been genetically engineered to produce b-carotene, is being proposed as a remedy. While this new technology has aroused controversial debates, its actual impact remains unclear. We develop a methodology for ex ante evaluation, taking into account health and nutrition details, as well as socioeconomic and policy factors. The framework is used for empirical analyses in India. Given broad public support, GR could more than halve the disease burden of VAD. Juxtaposing health benefits and overall costs suggests that GR could be very cost-effective.

Stevens R, Winter-Nelson A (2008). Consumer acceptance of provitamin A-biofortified maize in Maputo, Mozambique. Food Policy 33: 341-351. http://dx.doi.org/10.1016/j.foodpol.2007.12.003

Biofortified staple foods hold the potential to alleviate micronutrient malnutrition in many impoverished regions of the world. However, biofortification often alters the flavor, appearance, and other features of foods in ways that may limit consumer acceptance of the new varieties and diminish their impact. This research examined the acceptance of provitamin A-biofortified maize through taste tests and a trading experiment conducted in Maputo, Mozambique. On average, participants ranked the taste, texture, and appearance of their local white maize over an orange, biofortified variety and over a white variety with similar texture and flavor as the biofortified maize. Nonetheless, a large share of participants in a framed experiment accepted offers to trade local white maize meal for meal from the biofortified maize. Household size, the presence of small children, dietary diversity, and perceived taste were statistically significant determinants of acceptance. Results suggest that existing preferences for white maize do not preclude acceptance of orange, biofortified varieties and that provitamin A-biofortified maize may be a self-targeting nutritional intervention.

Stomph T, Slingerland MA, Hoffland E, Nout R (2006). Does a food chain approach help to target zinc bio-fortification efforts in cereal crops? Paper 24-3, 18th World Congress of Soil Science, 9-15 July. Philadelphia, PA: International Union of Soil Sciences. http://crops.confex.com/crops/wc2006/techprogram/P17189.HTM

Worldwide it has been estimated that 2 billion people suffer from iron and zinc deficiency-related health problems. For zinc the attained population is mainly situated in developing countries. A food chain approach is proposed to improve the density of bio-available zinc in the cereal crops sorghum and rice, being staple foods in West Africa and China respectively. This coherent integrated approach combines soil science, soil-plant interactions, crop physiology, post-harvest handling, food technology and human nutrition epidemiology. The ultimate challenge of the program is to improve human uptake of zinc by the poor from their mainly plant-derived foods. In Africa agronomic measures are proposed to enhance zinc and to keep phytic acid/zinc ratios moderate followed by processing to decrease phytic acid/zinc ratios further. Results from the program show that enhancement of zinc through improved soil management is possible as this goes together with improved productivity. The current trend in soil management recommendations, though, would rather lead to a decreased nutritional quality through lower bio-availability of zinc from cereals in the diet. The food chain approach has helped to highlight how a broader view is needed to avoid choices in soil management that will show counterproductive in the longer term. The food technology work has highlighted how the enhanced phytic acid accumulation in cereal seeds as a consequence of the need to fertilize with phosphorus can be coped with at later stages during the food chain. In China the possibilities to enhance zinc through agronomic measures currently seem too limited. Without genetic improvements the levels of zinc that seem attainable are insufficient. When rice production systems change from flooded to aerobic conditions the problem probably even becomes more acute. Reducing phytic acid/zinc ratios in order to improve zinc bio-availability could be attained both through improved agronomic measures. The need for this though is low as there are ample possibilities to counter the negative effect of phytic acid during processing. The comparison of the two productions chains show how answers are context specific. It also shows how the food chain approach.

Stomph Tj, Jiang W, Struik PC (2009). Zinc biofortification of cereals: rice differs from wheat and barley. Trends in Plant Science 14: 123-124. http://dx.doi.org/10.1016/j.tplants.2009.01.001

In their review, mainly focused on bread wheat (Triticum aestivum), durum wheat (Triticum durum) and barley (Hordeum vulgare), Palmgren et al. suggested two major bottlenecks in zinc biofortification in cereals: the root-shoot barrier and the process of grain filling. ... However, from our own work on zinc accumulation, we surmise that the bottlenecks are different in rice (Oryza sativa). These three aspects do not seem to apply to rice; therefore, zinc biofortification in rice differs from that in wheat and barley.

Storozhenko S, Ravanel S, Zhang G-F, Rébeillé F, Lambert W, Van Der Straeten D (2005). Folate enhancement in staple crops by metabolic engineering. Trends in Food Science & Technology 16: 271-281. http://dx.doi.org/10.1016/j.tifs.2005.03.007

Folate deficiency has profound effects on human health and affects large population groups around the world. Plants are the main source of dietary folate, therefore, the creation of genetically modified crops with higher folate content may contribute to solve the global folate deficiency problem. Current approaches, which have been successfully used for the enhancement of other micronutrients in plants and their potential applicability for folate enhancement, are reviewed. Folate biosynthesis in plants as well as recent advances in methods for folate detection are also discussed.

Storozhenko S, Veerle De Brouwer V, Volckaert M, Navarrete O, Blancquaert D, Zhang G-F, Lambert W, Van Der Straeten D (2007). Folate fortification of rice by metabolic engineering. Nature Biotechnology 25: 1277-1279. http://dx.doi.org/10.1038/nbt1351

Rice, the world's major staple crop, is a poor source of essential micronutrients, including folates (vitamin B9). We report folate biofortification of rice seeds achieved by overexpressing two Arabidopsis thaliana genes of the pterin and para-aminobenzoate branches of the folate biosynthetic pathway from a single locus. We obtained a maximal enhancement as high as 100 times above wild type, with 100 g of polished raw grains containing up to four times the adult daily folate requirement.

Stupak M, Vanderschuren H, Gruissem W, Zhang P (2006). Biotechnological approaches to cassava protein improvement. Trends in Food Science & Technology 17: 634-641. http://dx.doi.org/10.1016/j.tifs.2006.06.004

Cassava starchy storage roots are an excellent source of carbohydrates but lacking in protein. To enhance their nutritional quality, here we discuss several biotechnological strategies that might be used to increase protein levels as well as improved essential amino acid content in transgenic cassava. Application of such strategies in this major crop could, in the long term, help to fight against malnutrition in those regions which depend heavily on cassava consumption.

Sun T, Simon PW, Tanumihardjo SA (2009). Antioxidant phytochemicals and antioxidant capacity of biofortified carrots (Daucus carota L.) of various colors. Journal of Agricultural and Food Chemistry 57: 4142-4147. http://dx.doi.org/10.1021/jf9001044

Antioxidants and antioxidant capacity of seven colored carrots were determined. Five anthocyanins, chlorogenic acid, caffeic acid, and four carotenoids were quantified by HPLC. Total phenolic content was determined according to the Folin-Ciocalteu method. Antioxidant capacities of the hydrophilic and hydrophobic fractions were determined by using the 2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and 2,2'-diphenyl-1-picrylhydrazyl (DPPH) methods. The relative antioxidant capacity index was determined. Anthocyanins were the major antioxidants in purple-yellow and purple-orange carrots, and chlorogenic acid was a major antioxidant in all carrots. Carotenoids did not contribute to total antioxidant capacity, but correlated with antioxidant capacity of hydrophobic extracts. Both the DPPH and ABTS assays showed that the hydrophilic extract had higher antioxidant capacity than the hydrophobic extract. Purple-yellow carrots had the highest antioxidant capacity, followed by purple-orange carrots, and the other carrots did not significantly differ. This information is useful for consumers and may help horticulturists develop carrots with higher antioxidant capacity.

Tako E, Laparra JM, Glahn RP, Welch RM, Gen Lei X, Beebe S, Miller DD (2008). Biofortified black beans in a maize and bean diet provide more bioavailable iron to piglets than standard black beans. Journal of Nutrition 139: 305-309. http://dx.doi.org/10.3945/jn.108.098657

Our objective was to compare the capacities of biofortified and standard black beans (Phaseolus vulgaris L.) to deliver iron (Fe) for hemoglobin (Hb) synthesis. Two lines of black beans, one standard and the other biofortified (high) in Fe (71 and 106 μg Fe/g, respectively), were used. Maize-based diets containing the beans were formulated to meet the nutrient requirements for swine except for Fe (Fe concentrations in the 2 diets were 42.9 ± 1.2 and 54.6 ± 0.9 mg/kg). At birth, pigs were injected with 50 mg of Fe as Fe dextran. At age 28 d, pigs were allocated to the experimental diets (n = 10). They were fed 2 times per day for 5 wk and given free access to water at all times. Body weights and Hb concentrations were measured weekly. Hb repletion efficiencies (means ± SEM) did not differ between groups and, after 5 wk, were 20.8 ± 2.1% for the standard Fe group and 20.9 ± 2.1% for the high Fe group. Final total body Hb Fe contents did not differ between the standard [539 ± 39 mg (9.7 ± 0.7 μmol)] and high Fe [592 ± 28 mg (10.6 ± 0.5 μmol)] bean groups (P = 0.15). The increase in total body Hb Fe over the 5-wk feeding period was greater in the high Fe bean group [429 ± 24 mg (7.7 ± 0.4 μmol)] than in the standard Fe bean group [361 ± 23 mg (6.4 ± 0.4 μmol)] (P = 0.034). We conclude that the biofortified beans are a promising vehicle for increasing intakes of bioavailable Fe in human populations that consume beans as a dietary staple.

Tang G, Qin J, Dolnikowski GG, Russell RM, Grusak MA (2009). Golden Rice is an effective source of vitamin A. American Journal of Clinical Nutrition 89: 1176-1183. http://dx.doi.org/10.3945/ajcn.2008.27119

Background: Genetically engineered "Golden Rice" contains up to 35 lg b-carotene per gram of rice. It is important to determine the vitamin A equivalency of Golden Rice b-carotene to project the potential effect of this biofortified grain in rice-consuming populations that commonly exhibit low vitamin A status. Objective: The objective was to determine the vitamin A value of intrinsically labeled dietary Golden Rice in humans. Design: Golden Rice plants were grown hydroponically with heavy water (deuterium oxide) to generate deuterium-labeled [2H]b-carotene in the rice grains. Golden Rice servings of 65-98 g (130-200 g cooked rice) containing 0.99-1.53 mg b-carotene were fed to 5 healthy adult volunteers (3 women and 2 men) with 10 g butter. A reference dose of [13C10]retinyl acetate (0.4-1.0 mg) in oil was given to each volunteer 1 wk before ingestion of the Golden Rice dose. Blood samples were collected over 36 d. Results: Our results showed that the mean (+-SD) area under the curve for the total serum response to [2H]retinol was 39.9 +- 20.7 lg -d after the Golden Rice dose. Compared with that of the [13C10]retinyl acetate reference dose (84.7 +- 34.6 lg - d), Golden Rice b-carotene provided 0.24-0.94 mg retinol. Thus, the conversion factor of Golden Rice b-carotene to retinol is 3.8 +- 1.7 to 1 with a range of 1.9-6.4 to 1 by weight, or 2.0 +- 0.9 to 1 with a range of 1.0-3.4 to 1 by moles. Conclusion: b-Carotene derived from Golden Rice is effectively converted to vitaminA in humans. This trial was registered at clinicaltrials.gov as NCT00680355.

Tang G, Russell RM, Qin J, Dolnikowski GG, Grusak MA (2009). Reply to MB Krawinkel. American Journal of Clinical Nutrition 90: 696-697. http://dx.doi.org/10.3945/ajcn.2009.28268

We appreciate the interest from Krawinkel in our recent publication on the vitamin A equivalency of Golden Rice (1), in which we used stable isotope methodologies and a single serving (per subject) of Golden Rice (a transgenic rice that produces b-carotene in the grain) to study b-carotene absorption and bioconversion to vitamin A in 5 healthy adult subjects in Boston, Massachusetts. We showed that Golden Rice b-carotene in the dose provided (~1 mg) was effectively converted to vitamin A. Although Krawinkel acknowledges that our study provides evidence for b-carotene uptake, he raises 2 concerns about the bioconversion results

Tanumihardjo SA (2007). HarvestPlus: breeding for nutritional aspects. Paper 167-3, ASA-CSSA-SSSA International Annual Meetings, 4-8 November. New Orleans, LA: ASA-CSSA-SSSA. http://a-c-s.confex.com/crops/2007am/techprogram/P34115.HTM

Traditional breeding techniques have been used for centuries to improve the color and organoleptic qualities of carrots. Biofortification of staple crops with provitamin A carotenoids has emerged rather recently and is a potential long-term, sustainable approach to improve vitamin A status in groups at risk of vitamin A deficiency. Unlike current fortification and supplementation efforts which largely use preformed vitamin A, biofortification through enhancing provitamin A carotenoids offers a natural approach to improving vitamin A status without the risk of hypervitaminosis A. Globally, less emphasis has been placed on dietary diversification because of the difficulties in persuading people to change their diets. While biofortication could be considered a form of dietary diversification, it differs in that it nutritionally improves the main energy sources of the diet without the addition of complementary foods. Nutritionists do not dispute the benefits of a diversified diet, but it is often difficult to achieve this idealized diet in resource-poor areas of the world. Crops that have been targeted for biofortification with provitamin A carotenoids include maize, cassava, sweet potato, and rice. After successfully showing that biofortified maize can maintain the vitamin A status of Mongolian gerbils, we have simulated how biofortified maize will improve the vitamin A status of children from infancy through adolescence. Unlike periodic supplementation that results in oscillation of liver vitamin A reserves or the potential for hypervitaminosis A with food fortification, biofortified maize results in a steady increase in liver concentrations and a plateau once liver reserves are high. Biofortification of staple crops with provitamin A carotenoids should continue and efforts need to focus on familiarizing consumers with the nutritional benefits of deeper colored foods to build awareness and demand.

Tanumihardjo SA, Anderson C, Kaufer-Horwitz M, Bode L, Emenaker NJ, Haqq AM, Satia JA, Silver HJ, Stadler DD (2007). Poverty, obesity, and malnutrition: an international perspective recognizing the paradox. Journal of the American Dietetic Association 107: 1966-1972. http://dx.doi.org/10.1016/j.jada.2007.08.007

In the year 2000, multiple global health agencies and stakeholders convened and established eight tenets that, if followed, would make our world a vastly better place. These tenets are called the Millennium Development Goals. Most of these goals are either directly or indirectly related to nutrition. The United Nations has led an evaluation team to monitor and assess the progress toward achieving these goals until 2015. We are midway between when the goals were set and the year 2015. The first goal is to "eradicate extreme poverty and hunger." Our greatest responsibility as nutrition professionals is to understand the ramifications of poverty, chronic hunger, and food insecurity. Food insecurity is complex, and the paradox is that not only can it lead to undernutrition and recurring hunger, but also to overnutrition, which can lead to overweight and obesity. It is estimated that by the year 2015 noncommunicable diseases associated with overnutrition will surpass undernutrition as the leading causes of death in low-income communities. Therefore, we need to take heed of the double burden of malnutrition caused by poverty, hunger, and food insecurity. Informing current practitioners, educators, and policymakers and passing this information on to future generations of nutrition students is of paramount importance.

Tanumihardjo SA, Bouis H, Hotz C, Meenakshi JV, McClafferty B (2008). Biofortification of staple crops: an emerging strategy to combat hidden hunger. Comprehensive Reviews in Food Science and Food Safety 7: 329-373. http://dx.doi.org/10.1111/j.1541-4337.2008.00049.x

Diverse diets rich in micronutrients offer the ultimate sustainable solution to undernutrition. Unfortunately, poverty drives food consumption habits. For the poor, a simple meal consisting mostly of staple foods make up the daily diet. A diet based predominantly on staple food lacks adequate essential nutrients and thus can lead to hidden hunger. The biofortification strategy targets the poor by naturally adding nutrients to these staple foods through plant breeding. Biofortified crops offer a rural-based intervention that, by design, initially reach these more remote populations, which comprise a majority of the undernourished in many countries, and then extend to urban populations as production surpluses are marketed. In this way, biofortification complements fortification and supplementation programs, which currently work best in centralized urban and peri-urban areas and then reach into rural areas only with good infrastructure. Initial investments in agricultural research at a central location can generate high recurrent benefits at low cost as adapted biofortified varieties become available in country after country across time at low recurrent costs. HarvestPlus is working to develop and distribute varieties of food staples that are high in iron, zinc, and provitamin A through an interdisciplinary, global alliance of scientific institutions and implementing agencies in developing and developed countries. HarvestPlus, comanaged by the International Center for Tropical Agriculture and the International Food Policy Research Institute, collaborates with the India Biofortification Project to develop biofortified varieties of rice, wheat, and maize for India.

Thavarajah D, Ruszkowski J, Vandenberg A (2008). High potential for selenium biofortification of lentils (Lens culinaris L.) Journal of Agricultural and Food Chemistry 56: 10747-10753. http://dx.doi.org/10.1021/jf802307h

Beneficial forms of selenium (Se) and their impact on human health are a global topic of interest in public health. We are studying the genetic potential for Se biofortification of pulse crops to improve human nutrition. Lentils (Lens culinaris L.) are an important protein and carbohydrate food and are a valuable source of essential dietary components and trace elements. We analyzed the total Se concentration of 19 lentil genotypes grown at eight locations for two years in Saskatchewan, Canada. We observed significant genotypic and environmental variation in total Se concentration in lentils and that total Se concentration in lentils ranged between 425 and 673 μg kg−1, providing 77−122% of the recommended daily intake in 100 g of dry lentils. Over 70% of the Se was present as selenomethionine (SeMet) with a smaller fraction (<20%) as inorganic Se and very small amounts as selenocysteine (SeCys). We found that soils from the locations where the lentils were grown were rich in Se (37−301 μg kg−1) and that lentils grown in Saskatchewan have the potential to provide an excellent natural source of this essential element. Our analyses gave us a preliminary understanding of the genetic basis of Se uptake in lentil and indicated that any potential strategy for micronutrient biofortification in lentil will require choice of field locations that minimize the spatial variability of soil Se content.

Thavarajah D, Thavarajah P, Sarker A, Vandenberg A (2009). Lentils (Lens culinaris Medikus subspecies culinaris): a whole food for increased iron and zinc intake. Journal of Agricultural and Food Chemistry 57: 5413-5419. http://dx.doi.org/10.1021/jf900786e

Micronutrient malnutrition, the hidden hunger, affects more than 40% of the world's population, and a majority of them are in South and South East Asia and Africa. This study was carried out to determine the potential for iron (Fe) and zinc (Zn) biofortification of lentils (Lens culinaris Medikus subsp. culinaris) to improve human nutrition. Lentils are a common and quick-cooking nutritious staple pulse in many developing countries. We analyzed the total Fe and Zn concentrations of 19 lentil genotypes grown at eight locations for 2 years in Saskatchewan, Canada. It was observed that some genetic variation exists for Fe and Zn concentrations among the lentil lines tested. The total Fe and Zn concentrations ranged from 73 to 90 mg of Fe kg−1 and from 44 to 54 mg of Zn kg−1. The calculated percentages of the recommended daily allowance (RDA) for Fe and Zn were within the RDA ranges from a 100 g serving of dry lentils. Broad-sense heritability estimates for Fe and Zn concentrations in lentil seed were 64 and 68%, respectively. It was concluded that lentils have great potential as a whole food source of Fe and Zn for people affected by these nutrient deficiencies. This is the first report on the genetic basis for Fe and Zn micronutrient content in lentils. These results provide some understanding of the genetic basis of Fe and Zn concentrations and will allow for the development of potential strategies for genetic biofortification.

Thinley LJY (1999). Values and development: "Gross National Happiness". In: Kinga S, Galay K, Rapten P, Pain A (eds). Gross National Happiness: a set of discussion papers, Centre for Bhutan Studies, Thimpbu, pp. 12-23. http://www.bhutanstudies.org.bt/main/pub_detail.php?pubid=65

Tiong J, Genc Y, McDonald GK, Langridge P, Huang CY (2009). Over-expressing a barley ZIP gene doubles grain zinc content in barley (Hordeum vulgare). Paper 1326, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1326

More than half the world's population is at moderate to high risk of zinc (Zn) deficiency, and biofortification has become an important strategy to alleviate the problem. Grain loading is likely to be a major bottleneck in cereal biofortification. However, very little is known about the transporters involved in this process. We have used barley as a model system to study the transporter genes which are potentially important in grain Zn loading. Here we report effect of over-expressing a barley ZIP gene in barley on grain Zn content. Our results showed that when the transgenic plants were grown at low Zn supply, grain Zn concentrations of transgenic lines were not different from those of the null lines, but with a low dose of Zn supplement during anthesis grain Zn content in transgenic lines increased by 50%. When plants were grown at a high Zn supply, grain Zn concentration of the transgenic lines was doubled relative to the null lines and wildtype. The enhanced concentration of Zn in the grain of the transgenic plants did not alter concentrations of other micronutrients. These results indicate that the constitutive expression of HvZIP7 could specifically increase grain Zn content.

Tiwari VK, Rawat N, Chhuneja P, Neelam K, Aggarwal R, Randhawa GS, Dhaliwal HS, Keller B, Singh K (2009). Mapping of quantitative trait loci for grain iron and zinc concentration in diploid A genome wheat. Journal of Heredity Advance online 11 June. http://dx.doi.org/10.1093/jhered/esp030

Micronutrients, especially iron (Fe) and zinc (Zn), are deficient in the diets of people in underdeveloped countries. Biofortification of food crops is the best approach for alleviating the micronutrient deficiencies. Identification of germplasm with high grain Fe and Zn and understanding the genetic basis of their accumulation are the prerequisites for manipulation of these micronutrients. Some wild relatives of wheat were found to have higher grain Fe and Zn concentrations compared with the cultivated bread wheat germplasm. One accession of Triticum boeoticum (pau5088) that had relatively higher grain Fe and Zn was crossed with Triticum monococcum (pau14087), and a recombinant inbred line (RIL) population generated from this cross was grown at 2 locations over 2 years. The grains of the RIL population were evaluated for Fe and Zn concentration using atomic absorption spectrophotometer. The grain Fe and Zn concentrations in the RIL population ranged from 17.8 to 69.7 and 19.9 to 64.2 mg/kg, respectively. A linkage map available for the population was used for mapping quantitative trait loci (QTL) for grain Fe and Zn accumulation. The QTL analysis led to identification of 2 QTL for grain Fe on chromosomes 2A and 7A and 1 QTL for grain Zn on chromosome 7A. The grain Fe QTL were mapped in marker interval Xwmc382-Xbarc124 and Xgwm473-Xbarc29, respectively, each explaining 12.6% and 11.7% of the total phenotypic variation and were designated as QFe.pau-2A and QFe.pau-7A. The QTL for grain Zn, which mapped in marker interval Xcfd31-Xcfa2049, was designated as QZn.pau-7A and explained 18.8% of the total phenotypic variation.

Tiwari VK, Rawat N, Neelam K, Randhawa GS, Singh K, Chhuneja P, Dhaliwal HS (2008). Development of Triticum turgidum subsp. durum - Aegilops longissima amphiploids with high iron and zinc content through unreduced gamete formation in F1 hybrids. Genome 51: 757-766. http://www.ingentaconnect.com/content/nrc/gen/2008/00000051/00000009/art00012

Four different interspecific hybrids involving three different accessions of Aegilops longissima Schweinf. & Muschl. with high grain iron and zinc content and three Triticum turgidum L. subsp. durum (Desf.) Husn. cultivars with low micronutrient content were made for durum wheat biofortification and investigated for chromosome pairing, fertility, putative amphiploidy, and micronutrient content. The chromosome pairing in the 21-chromosome F1 hybrids (ABSl) consisted of 0-6 rod bivalents and occasionally 1 trivalent. All the F1 hybrids, however, unexpectedly showed partial but variable fertility. The detailed meiotic investigation indicated the simultaneous occurrence of two types of aberrant meiotic divisions, namely first-division restitution and single-division meiosis, leading to regular dyads and unreduced gamete formation and fertility. The F2 seeds, being putative amphiploids (AABBSlSl), had nearly double the chromosome number (40-42) and regular meiosis and fertility. The F1 hybrids were intermediate between the two parents for different morphological traits. The putative amphiploids with bold seed size had higher grain ash content and ash iron and zinc content than durum wheat cultivars, suggesting that Ae. longissima possesses a better genetic system (s) for uptake and seed sequestration of iron and zinc, which could be transferred to elite durum and bread wheat cultivars and exploited.

Tothova M, Meyers WH (2006). Modelling the acceptance of high beta-carotene maize. Annual Meeting, 23-26 July. Long Beach, CA: American Agricultural Economics Association. http://purl.umn.edu/21457

In the development of high beta carotene (HBC) maize, the focus is on subsistence farms which do not get any (or at least very little) benefit from commercial fortification programs. The technology can be considered to be primarily for the small-scale subsistence farmer. The paper postulates a household decision model that takes into account the production and consumption tradeoffs between traditional and biofortified seed. The objective is to understand the effect of these differing traits on the adoption decision when white maize is preferred by the consumers.

Tuberosa R (2008). Biotechnological approaches to improve food quality. Journal of Biotechnology 136: S712. http://dx.doi.org/10.1016/j.jbiotec.2008.07.1694

Food quality is of paramount importance to the agro-food industry and for the health of farm animals and humans. More than half theworld's people, particularly in developing countries, suffer from vitamin A, zinc and iron deficiency due to a poor diet. Biotechnology offers great potential to improve food quality through forwardand reverse-genetics approaches that enable us to clone the relevant genes and QTLs.

UN (1970). International Development Strategy for the Second United Nations Development Decade, UN General Assembly, 25th Session, 24 October, Resolution 2626 (XXV), para. 43. New York, NY: United Nations, p. 43. http://www.un.org/documents/ga/res/25/ares25.htm

UN (2000). United Nations Millennium Declaration. General Assembly Resolution 55/2, 8 September. New York, NY: United Nations. http://www.un.org/millennium/declaration/ares552e.htm; für eine deutsche Version siehe UNRIC (2000).

UN (2009). The Millennium Development Goals Report. New York, NY: United Nations. http://www.un.org/millenniumgoals/reports.shtml

UNDP (2009). The human development concept. Web page of the Human Development Report Office. New York, NY: United Nations Development Programme. http://hdr.undp.org/en/humandev/

Unnevehr L, Pray C, Paarlberg R (2007). Addressing micronutrient deficiencies: alternative interventions and technologies. AgBioForum 10: 124-134. http://www.agbioforum.org/v10n3/v10n3a01-unnevehr.htm

Market failure for nutritional attributes of foods leads to underinvestment in crop breeding to enhance nutritional content of foods. As awareness of the importance of micronutrient deficiencies in the diets of poor people has grown, public investments in research to create biofortified staple crops have increased. The potential for this new approach is assessed in two ways. First, an examination of lessons from established interventions to address micronutrient deficiencies shows where and how biofortification can complement existing interventions and provides guidance regarding potential hurdles to successful implementation. Second, the potential for different crop-breeding technologies to biofortify crops is examined, and the advances that can only be achieved through application of modern biotechnology are identified.

UNRIC (2000). Millenniums-Erklärung der Vereinten Nationen. Brussels: United Nations Regional Information Centre. http://www.unric.org/de/wirtschaftliche-und-soziale-entwicklung/99?start=2

Vallabhaneni R, Gallagher CE, Licciardello N, Cuttriss AJ, Quinlan RF, Wurtzel ET (2009). Metabolite sorting of a germplasm collection reveals the Hydroxylase3 locus as a new target for maize provitamin A biofortification. Plant Physiology Preview, online September 18. http://dx.doi.org/10.1104/pp.109.145177

Vitamin A deficiency, a global health burden, can be alleviated through provitamin A carotenoid biofortification of major crop staples such as maize and other grasses in the Poaceae. If regulation of carotenoid biosynthesis was better understood, enhancement could be controlled by limiting beta-carotene hydroxylation to compounds with lower or no nonprovitamin A activity. Natural maize genetic diversity enabled identification of hydroxylation genes associated with reduced endosperm provitamin A content. A novel approach was used to capture the genetic and biochemical diversity of a large germplasm collection, representing 80% of maize genetic diversity, without having to sample the entire collection. Metabolite data-sorting was applied to select a 10 line genetically diverse subset representing biochemical extremes for maize kernel carotenoids. Transcript profiling led to discovery of the Hydroxylase3 locus that coincidently mapped to a carotene QTL, thereby prompting investigation of allelic variation in a broader collection. Three natural alleles in 51 maize lines explained 78% of variation and 11-fold difference in beta-carotene relative to beta-cryptoxanthin and 36% of the variation and 4-fold difference in absolute levels of beta-carotene. A simple PCR assay to track and identify HYD3 alleles will be valuable for predicting nutritional content in genetically diverse cultivars found world-wide.

Van Montagu M (2005). Technological milestones from plant science to agricultural biotechnology. Trends in Plant Science 10: 559-560. http://dx.doi.org/10.1016/j.tplants.2005.10.013

Reading through the past ten years of Trends in Plant Science, we can see impressive progress in our understanding of plant science. Focusing on the model plant Arabidopsis was crucial for this progress, but we need to keep the momentum going. The molecular plant community is still small compared with other life science disciplines, and funding remains problematic in many countries. The research is time consuming and so the need for cooperation and exchange of materials and experience remains high. In spite of all the progress we have made, many questions still remain. In particular, we need better in vitro systems to study cell biology and to gain a deeper understanding of epigenetics, hybrid vigor, the dynamics of the chromatin domains, and the flow and function of microRNA. However, some of the most riveting aspects of modern plant science are plant biotechnology and molecular breeding. Many new tools have helped to unravel the molecular basis of plant genetics, heredity, and growth and development, which has led to high expectations among consumers. Now we are faced with the challenge of applying this knowledge to improve crop plants used in food, feed and industrial production.

Velu G, Rai KN, Muralidharan V, Kulkarni VN, Longvah T, Raveendran TS (2007). Prospects of breeding biofortified pearl millet with high grain iron and zinc content. Plant Breeding 126: 182-185. http://dx.doi.org/10.1111/j.1439-0523.2007.01322.x

Development of crop cultivars with elevated levels of micronutrients is being increasingly recognized as one of the approaches to provide sustainable solutions to various health problems associated with micronutrient malnutrition, especially in developing countries. To assess the prospects of this approach in pearl millet (Pennisetum glaucum), a diverse range of genetic materials, consisting of 40 hybrid parents, 30 each of population progenies and improved populations, and 20 germplasm accessions, was analysed for grain iron (Fe) and zinc (Zn) content, deficiencies of which adversely affect human health. Based on the mean performance in two seasons at ICRISAT, Patancheru, India, large variability among the entries was found, both for Fe (30.1-75.7 mg/kg on dry weight basis) and Zn (24.5-64.8 mg/kg). The highest levels of grain Fe and Zn were observed in well-adapted commercial varieties and their progenies, and in the parental lines of hybrids, which were either entirely based on iniari germplasm, or had large components of it in their parentage. There were indications of large within-population genetic variability for both Fe and Zn. The correlation between Fe and Zn content was positive and highly significant ($r = 0.84$; $P < 0.01$). These results indicate that there are good prospects of simultaneous selection for both micronutrients, and that selection within populations, especially those with the predominantly iniari germplasm, is likely to provide good opportunities for developing pearl millet varieties and hybrid parents with significantly improved grain Fe and Zn content in pearl millet.

von Braun J, Ruel M, Gulati A (2008). Accelerating progress toward reducing child malnutrition in India. IFPRI Brief 12. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/publication/accelerating-progress-toward-reducing-child-malnutrition-india

India is home to 40 percent of the world's malnourished children and 35 percent of the developing world's low-birth-weight infants; every year 2.5 million children die in India, accounting for one in five deaths in the world. More than half of these deaths could be prevented if children were well nourished. India's progress in reducing child malnutrition has been slow. The prevalence of child malnutrition in India deviates further from the expected level at the country's per capita income than in any other large developing country. India has many nutrition and social safety net programs, some of which (such as Integrated Child Development Services [ICDS] and the Public Distribution System [PDS]) have had success in several states in addressing the needs of poor households. All of these programs have potential, but they do not form a comprehensive nutrition strategy, and they have not addressed the nutrition problem effectively so far.

Walker EL, Connolly EL (2008). Time to pump iron: iron-deficiency-signaling mechanisms of higher plants. Current Opinion in Plant Biology 11: 530-535. http://dx.doi.org/10.1016/j.pbi.2008.06.013

Iron is an essential nutrient for plants, yet it often limits plant growth. On the contrary, overaccumulation of iron within plant cells leads to oxidative stress. As a consequence, iron-uptake systems are carefully regulated to ensure that iron homeostasis is maintained. In response to iron limitation, plants induce expression of sets of activities that function at the root-soil interface to solubilize iron and subsequently transfer it across the plasma membrane of root cells. Recent advances have revealed key players in the signaling pathways that function to induce these iron-uptake responses. Transcription factors belonging to the basic helix-loop-helix, ABI3/VP1 (B3), and NAC families appear to function either directly or indirectly in the upregulation of iron deficiency responses.

Waters BM, Grusak MA (2008). Quantitative trait locus mapping for seed mineral concentrations in two Arabidopsis thaliana recombinant inbred populations. New Phytologist 179: 1033-1047. http://dx.doi.org/10.1111/j.1469-8137.2008.02544.x

Biofortification of foods, achieved by increasing the concentrations of minerals such as iron (Fe) and zinc (Zn), is a goal of plant scientists. Understanding genes that influence seed mineral concentration in a model plant such as Arabidopsis could help in the development of nutritionally enhanced crop cultivars. • Quantitative trait locus (QTL) mapping for seed concentrations of calcium (Ca), copper (Cu), Fe, potassium (K), magnesium (Mg), manganese (Mn), phosphorus (P), sulfur (S), and Zn was performed using two recombinant inbred line (RIL) populations, Columbia (Col) × Landsberg erecta (Ler) and Cape Verde Islands (Cvi) × Ler, grown on multiple occasions. QTL mapping was also performed using data from silique hulls and the ratio of seed:hull mineral concentration of the Cvi × Ler population. • Over 100 QTLs that affected seed mineral concentration were identified. Twenty-nine seed QTLs were found in

more than one experiment, and several QTLs were found for both seed and hull mineral traits. A number of candidate genes affecting seed mineral concentration are discussed. • These results indicate that A. thaliana is a suitable and convenient model for discovery of genes that affect seed mineral concentration. Some strong QTLs had no obvious candidate genes, offering the possibility of identifying unknown genes that affect mineral uptake and translocation to seeds.

Waters BM, Grusak MA (2008). Whole-plant mineral partitioning throughout the life cycle in Arabidopsis thaliana ecotypes Columbia, Landsberg erecta, Cape Verde Islands, and the mutant line ysl1ysl3. New Phytologist 177: 389-405. http://dx.doi.org/10.1111/j.1469-8137.2007.02288.x

Minimal information exists on whole-plant dynamics of mineral flow through Arabidopsis thaliana or on the source tissues responsible for mineral export to developing seeds. Understanding these phenomena in a model plant could help in the development of nutritionally enhanced crop cultivars. • A whole-plant partitioning study, using sequential harvests, was conducted to characterize growth and mineral concentrations and contents of rosettes, cauline leaves, stems, immature fruit, mature fruit hulls, and seeds of three WT lines (Col-0, Ler, and Cvi) and one mutant line (Col-0::ysl1ysl3). • Shoot mineral content increased throughout the life cycle for all minerals, although tissue-specific mineral partitioning differed between genotypes. In particular, iron (Fe), zinc (Zn), and copper (Cu) were aberrantly distributed in ysl1ysl3. Remobilization was observed for several minerals from various tissues, including cauline leaves and silique hulls, but the amounts were generally far below the total mineral accretion observed in seeds. • When YSL1 and YSL3 are nonfunctional, Cu, Fe, and Zn are not effectively remobilized from, or do not effectively pass through, leaf and maternal fruit tissues. With respect to seed mineral accretion in Arabidopsis, continued uptake and translocation of minerals to source tissues during seed fill are as important, if not more important, than remobilization of previously stored minerals.

Waters BM, Pedersen JF (2009). Sorghum germplasm profiling to assist breeding and gene identification for biofortification of grain mineral and protein concentrations. Paper 1228, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1228

Sorghum (Sorghum bicolor) is the world's fifth most important grain crop, and is a widely consumed staple in subtropical semi-arid regions of Africa and Asia. Biofortification of sorghum by increasing mineral micronutrient (especially iron and zinc) and protein concentration is of widespread interest. Here, we report profiling of a panel of 95 sorghum accessions of wide diversity for concentration of eight minerals (Cu, Fe, K, Mg, Mn, P, S, and Zn), crude protein, and digestibility. Accessions were chosen from a prior large-scale screen for protein concentration (2882 accessions). The extreme high (10 accessions) and low (19 accessions) protein lines were selected, and 66 accessions also included that are in an association mapping panel. We observed a normal distribution of grain size, digestibility, and mineral concentrations, in most cases with a range of >2-fold. Several minerals showed strong positive correlations with protein concentration, suggesting that mineral and protein density in grain can be improved together. Several minerals were positively correlated, (i.e. Fe and Zn), suggesting that improving accumulation of one of these minerals might also result in increases in others. None of the mineral or protein concentrations were correlated with digestibility. Therefore, sorghum breeders can likely select for improved digestibility independently of mineral or crude protein concentration. Sufficient diversity is present in sorghum germplasm to breed for increased seed mineral and protein. Association mapping may allow identification of specific genes that can be used in transgenic approaches to develop lines with higher accumulation of nutrients in grain.

Waters BM, Wang D, Grusak M (2009). Defining the NAM regulon for gene targets to biofortify crop iron, zinc, and protein concentrations. Paper 1232, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1232

Approximately half of the world population suffers from iron and/or zinc deficiency, and millions suffer from protein-energy malnutrition, primarily from reliance on plant based staple foods. These foods are low in iron, zinc, and protein density relative to animal based foods. We and others are interested in genetic improvement of plants to increase the nutritional value of plants, a strategy termed biofortification. In previous work, the NAM transcription factor genes of wheat were shown to regulate leaf senescence and iron, zinc, and nitrogen remobilization and translocation from vegetative tissues to grain. Thus, genes of the NAM transcription factor regulon are potential targets for nutritional improvement of cereal or other seed crops. As a first step to identify NAM regulated genes, we used the Affymetrix Wheat Genome microarray to profile genes that are differentially regulated in flag leaf tissue at mid-grain fill relative to anthesis, and that are also differentially regulated between control and NAM RNAi knockdown lines. Over three hundred genes met the criteria to be potential NAM targets, several of which are annotated as coding for proteins that could be involved in nutrient transport or protein metabolism. A highly homologous NAM gene with developmentally regulated leaf expression similar to wheat NAM genes was cloned from Sorghum bicolor. Results of genome-wide bioinformatic and molecular screens to identify potential NAM regulated genes and putative NAM response elements in gene promoters will be presented.

Welch RM (2005). Biotechnology, biofortification, and global health. Food and Nutrition Bulletin 26: 419-421. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/1132

Deficiencies of micronutrients such as iron, zinc, and vitamin A afflict over three billion people (more than 50% of the world's population), most of them women, infants, and children in resource-poor families in the developing world. This global crisis in nutritional health is the result of dysfunctional food systems that do not consistently supply enough of these essential nutrients to meet the nutritional requirements of high-risk groups. Deficiencies of micronutrients result in increased morbidity and mortality rates, lost worker productivity, stagnated national development, permanent impairment of cognitive development in infants and children, and large economic costs and suffering to those societies affected. Because agricultural systems are the primary source of all micronutrients for all people, changes in agricultural policies and systems must be made that will ensure consistent and adequate supplies of all essential nutrients to all people. Additionally, the nutrition and health sectors must turn to agricultural interventions as a primary tool in their efforts to eliminate malnutrition from the world if they want to ensure sustainability. Biotechnological advances show great promise for improving the output of bioavailable micronutrients from agricultural systems that feed the poor. This paper reviews some of these opportunities and discusses the questions and concerns that should be raised when these technologies are used to improve the micronutrient status of vast numbers of people who are dependent on staple food crops for their sustenance. Further, important issues surrounding micronutrient bioavailability and plant food factors that affect it are discussed.

Welch RM (2009). A systems approach to optimizing plant nutrition for human health. Paper 1438, Proceedings of the International Plant Nutrition Colloquium XVI, 26-30 August. Sacramento, CA: University of California, Davis. http://repositories.cdlib.org/ipnc/xvi/1438

Malnutrition is the leading cause of death globally. Both overt nutrient deficiencies and diet-related chronic diseases account for over 20 million deaths a year. The causes of malnutrition are complex and many but are rooted in dysfunctional food systems dependent on agricultural systems that have never had an explicit goal of improving human nutrition and health. These deaths are preventable. Closely linking agricultural systems to human health could provide sustainable tools needed to address this global crisis of malnutrition. Various agricultural tools including plant nutrition can be used to improve the health of resource-poor people in the developing world afflicted with malnutrition. Biofortification is one tool that is currently being used to address micronutrient malnutrition among resource-poor families in the developing world. Fertilizers (a agronomic biofortification strategy) are another tool that has been used successfully to address selenium, iodine and zinc deficiencies in several nations. There are numerous other agricultural tools that could be used to improve the nutrient output of farming systems and improve the health all people dependent on agricultural systems for their sustenance. These include: designing cropping systems to maximize nutrient output, using agronomic practices to improve the nutritional and health promoting quality of food crops, re-diversifying cropping systems, and genetically modifying crops to be more nutritious. This can only be accomplished if explicit links are made between the agriculture, nutrition and health communities. Further, government policies should be reoriented to reflect the important roles that agriculture plays in the nutritional health of all people. We need to closely link agriculture to our nutrition and health goals if we want to find sustainable solutions to malnutrition globally.

Welch RM, Graham RD (2000). A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. Food and Nutrition Bulletin 21: 361-366. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/322

Welch RM, Graham RD (2005). Agriculture: the real nexus for enhancing bioavailable micronutrients in food crops. Journal of Trace Elements in Medicine and Biology 18: 299-307. http://dx.doi.org/10.1016/j.jtemb.2005.03.001

Human existence requires that agriculture provide at least 50 nutrients (e.g., vitamins, minerals, trace elements, amino acids, essential fatty acids) in amounts needed to meet metabolic demands during all seasons. If national food systems do not meet these demands, mortality and morbidity rates increase, worker productivity declines, livelihoods are diminished and societies suffer. Today, many food systems within the developing world cannot meet the nutritional needs of the societies they support mostly due to farming systems that cannot produce enough micronutrients to meet human needs throughout the year. Nutrition transitions are also occurring in many rapidly developing countries that are causing chronic disease (e.g., cancer, heart disease, stroke, diabetes, and osteoporosis) rates to increase substantially. These global developments point to the need to explicitly link agricultural technologies to human health. This paper reviews some ways in which agriculture can contribute significantly to reducing micronutrient malnutrition globally. It concludes that it is imperative that close linkages be forged between the agriculture, nutrition and health arenas in order to find sustainable solutions to micronutrient malnutrition with agriculture becoming the primary intervention tool to use in this fight.

Welch RM, House WA, Ortiz-Monasterio I, Cheng Z (2005). Potential for improving bioavailable zinc in wheat grain (Triticum species) through plant breeding. Journal of Agricultural and Food Chemistry 53: 2176-2180. http://dx.doi.org/10.1021/jf040238x

A "whole-body" radioassay procedure was used to assess retention and absorption by rats of Zn in mature kernels of whole grain wheat harvested from 28 genotypes (Triticum spp.) grown in nutrient solution supplied with 2 uM ZnSO4 radiolabeled with 65Zn. Grain-Zn concentration differed among genotypes and ranged from 33 to 149 ug g-1 of dry weight (DW); similarly, grain-Fe concentration varied ~4-fold, from 80 to 368 ug g-1 of DW. Concentrations of Zn and Fe in the grain were positively correlated. Therefore, selecting genotypes high in grain-Zn also tends to increase grain-Fe concentration. Concentrations of myo-inositolhexaphosphate (phytate) in the wheat grain varied from 8.6 to 26.1 umol g-1 of DW. Grain intrinsically labeled with 65Zn was incorporated into test meals fed to Zn-depleted rats. All rats readily ate the test meals, so that Zn intake varied directly with grain-Zn concentration. As determined by the percentage of 65Zn absorbed from the test meal, the bioavailability to rats of Zn in the wheat genotypes ranged from about 60 to 82%. The amount of bioavailable Zn (micrograms) in the grain was positively correlated to the amount of Zn accumulated in the grain. There was a significant negative correlation between grain-phytate levels and percentage of Zn absorbed from the wheat grain, but the effect was not large. These results demonstrate that concentrations of Zn in whole-wheat grain, as well as amounts of bioavailable Zn in the grain, can be increased significantly by using traditional plant-breeding programs to select genotypes with high grain-Zn levels. Increasing the amount of Zn in wheat grain through plant-breeding contrivances may contribute significantly to improving the Zn status of individuals dependent on whole grain wheat as a staple food.

White PJ, Broadley MR (2005). Biofortifying crops with essential mineral elements. Trends in Plant Science 10: 586-593. http://dx.doi.org/10.1016/j.tplants.2005.10.001

Humans require more than 22 mineral elements, which can all be supplied by an appropriate diet. However, the diets of populations subsisting on cereals, or inhabiting regions where soil mineral imbalances occur, often lack Fe, Zn, Ca, Mg, Cu, I or Se. Traditional strategies to deliver these minerals to susceptible populations have relied on supplementation or food fortification programs. Unfortunately, these interventions have not always been successful. An alternative solution is to increase mineral concentrations in edible crops. This is termed 'biofortification'. It can be achieved by mineral fertilization or plant breeding. There is considerable genetic variation in crop species that can be harnessed for sustainable biofortification strategies. Varieties with increased mineral concentrations in their edible portions are already available, and new genotypes with higher mineral densities are being developed.

White PJ, Broadley MR (2007). Genetic aspects of mineral biofortification. Comparative Biochemistry and Physiology, Part A 146: S246. http://dx.doi.org/10.1016/j.cbpa.2007.01.572

Humans require at least 22 mineral elements. These can all be supplied by an appropriate diet. Nevertheless, over 60% of the world's 6 billion people are Fe deficient, over 30% are Zn deficient, 30% are I deficient and about 15% are Se deficient. Deficiencies of Ca, Mg and Cu are also common. Mineral malnutrition can be addressed through supplementation, food fortification or dietary diversification, but these interventions have had limited success. 'Biofortification' is a complimentary strategy that aims to increase bioavailable concentrations of essential elements in edible portions of crop plants by applying mineral fertilizers and/ or growing crops that accumulate minerals more effectively. Since fertilisers impose a financial and environmental burden, and many infertile soils contain sufficient minerals to support mineral-dense crops if they became phytoavailable, there is considerable interest in breeding for mineral-dense crops that produce high yields on infertile soils. This presentation will first describe the contrasting mineralogies of angiosperm orders and quantify the phylogenetic impacts on species' mineral composition.

White PJ, Broadley MR (2009). Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium, selenium and iodineNew Phytologist 182: 49-84. http://dx.doi.org/10.1111/j.1469-8137.2008.02738.x

The diets of over two-thirds of the world's population lack one or more essential mineral elements. This can be remedied through dietary diversification, mineral supplementation, food fortification, or increasing the concentrations and/or bioavailability of mineral elements in produce (biofortification). This article reviews aspects of soil science, plant physiology and genetics underpinning crop biofortification strategies, as well as agronomic and genetic approaches currently taken to biofortify food crops with the mineral elements most commonly lacking in human diets: iron (Fe), zinc (Zn), copper (Cu), calcium (Ca), magnesium (Mg), iodine (I) and selenium (Se). Two complementary approaches have been successfully adopted to increase the concentrations of bioavailable mineral elements in food crops. First, agronomic approaches optimizing the application of mineral fertilizers and/or improving the solubilization and mobilization of mineral elements in the soil have been implemented. Secondly, crops have been developed with: increased abilities to acquire mineral elements and accumulate them in edible tissues; increased concentrations of 'promoter' substances, such as ascorbate, beta-carotene and cysteine-rich polypeptides which stimulate the absorption of essential mineral elements by the gut; and reduced concentrations of 'antinutrients', such as oxalate, polyphenolics or phytate, which interfere with their absorption. These approaches are addressing mineral malnutrition in humans globally.

WHO (2002). The World Health Report 2002. Geneva: World Health Organization. http://www.who.int/whr/2002/

WHO (2009a). Micronutrient deficiencies: iron deficiency anaemia. Web page. Geneva: World Health Organization. http://www.who.int/nutrition/topics/ida/

WHO (2009b). Global prevalence of vitamin A deficiency in populations at risk 1995-2005: WHO global database on vitamin A deficiency. Geneva: World Health Organization. http://www.who.int/vmnis/vitamina/prevalence/report/

Wirth J, Poletti S, Aeschlimann B, Yakandawala N, Drosse B, Osorio S, Tohge T, Fernie AR, Günther D, Gruissem W, Sautter C (2009). Rice endosperm iron biofortification by targeted and synergistic action of nicotianamine synthase and ferritin. Plant Biotechnology Journal 7: 631-644. http://dx.doi.org/10.1111/j.1467-7652.2009.00430.x

Nearly one-third of the world's population, mostly women and children, suffer from iron malnutrition and its consequences, such as anaemia or impaired mental development. Iron fortification of food is difficult because soluble iron is either unstable or unpalatable, and non-soluble iron is not bioavailable. Genetic engineering of crop plants to increase iron content has therefore emerged as an alternative for iron biofortification. To date, strategies to increase iron content have relied on single genes, with limited success. Our work focuses on rice as a model plant, because it feeds one-half of the world's population, including the majority of the iron-malnourished population. Using the targeted expression of two transgenes, nicotianamine synthase and ferritin, we increased the iron content of rice endosperm by more than six-fold. Analysis of transgenic rice lines confirmed that, in combination, they provide a synergistic effect on iron uptake and storage. Laser ablation-inductively coupled plasma-mass spectrometry showed that the iron in the endosperm of the transgenic rice lines accumulated in spots, most probably as a consequence of spatially restricted ferritin accumulation. Agronomic evaluation of the high-iron rice lines did not reveal a yield penalty or significant changes in trait characters, except for a tendency to earlier flowering. Overall, we have demonstrated that rice can be engineered with a small number of genes to achieve iron biofortification at a dietary significant level.

Wissuwa M, Ismail AM, Graham RD (2008). Rice grain zinc concentrations as affected by genotype, native soil-zinc availability, and zinc fertilization. Plant and Soil 306: 37-48. http://dx.doi.org/10.1007/s11104-007-9368-4

The development of rice (Oryza sativa L.) cultivars with a higher Zn content in their grains has been suggested as a way to alleviate Zn malnutrition in human populations subsisting on rice in their daily diets. This study was conducted to evaluate the effects of native soil Zn status and fertilizer application on Zn concentrations in grains of five rice genotypes that had previously been identified as either high or low in grain Zn. Genotypes were grown in field trials at four sites ranging in native soil-Zn status from severely deficient to high in plant available Zn. At each site a −Zn plot was compared to a +Zn plot fertilized with 15 kg Zn ha−1. Results showed that native soil Zn status was the dominant factor to determine grain Zn concentrations followed by genotype and fertilizer. Depending on soil-Zn status, grain Zn concentrations could range from 8 mg kg−1 to 47 mg kg−1 in a single genotype. This strong location effect will need to be considered in estimating potential benefits of Zn biofortification. Our data furthermore showed that it was not possible to simply compensate for low soil Zn availability by fertilizer applications. In all soils fertilizer Zn was taken up as seen by a 50-200% increase in total plant Zn content. However, in more Zn deficient soils this additional Zn supply improved straw and grain yield and increased straw Zn concentrations by 43-95% but grain Zn concentrations remained largely unchanged with a maximum increase of 6%. Even in soils with high Zn status fertilizer Zn was predominantly stored in vegetative tissue. Genotypic differences in grain Zn concentrations were significant in all but the severely Zn deficient soil, with genotypic means ranging from 11 to 24 mg kg−1 in a Zn deficient soil and from 34 to 46 mg kg−1 in a high Zn upland soil. Rankings of genotypes remained largely unchanged from Zn deficient to high Zn soils, which suggests that developing high Zn cultivars through conventional breeding is feasible for a range of environments. However, it may be a challenge to develop cultivars that respond to Zn fertilizer with higher grain yield and higher grain Zn concentrations when grown in soils with low native Zn status.

Wolson R (2007). Assessing the prospects for the adoption of biofortified crops in South Africa. AgBioForum 10: 184-191. http://www.agbioforum.org/v10n3/v10n3a08-wolson.htm

South Africa was an early adopter of GM crops and, more recently, introduced a national food-fortification program. This article discusses the country's experiences in developing an appropriate regulatory framework and the responses of key stakeholders. In addition, an assessment is presented of the prospects for the adoption of biofortified crops in South Africa.

World Bank (1994). Enriching lives: overcoming vitamin and mineral malnutrition in developing countries. Washington, DC: World Bank. http://go.worldbank.org/N8B0YJMVB0

World Bank (2006). Repositioning nutrition as central to development: a strategy for large-scale action. Directions in Development. Washington, DC: The World Bank. http://go.worldbank.org/UGPWFYHNU0

Persistent malnutrition contributes not only to widespread failure to meet the first Millennium Development Goal – to halve poverty and hunger – but also to meet other goals related to maternal and child health, HIV/AIDS, education, and gender equity. Underweight prevalence among children is the key indicator for measuring progress on nonincome poverty, and malnutrition remains the world's most serious health problem – as well as the single largest contributor to child mortality. Nearly one-third of children in the developing world are underweight or stunted, and more than 30 percent of the developing world's population suffers from micronutrient deficiencies. Moreover, new malnutrition problems are emerging: the epidemic of obesity and diet-related noncommunicable diseases is spreading to the developing world, and malnutrition is linked to the HIV/AIDS pandemic. Repositioning Nutrition as Central to Development: A Strategy for Large-Scale Action makes the case that development partners and developing countries must increase investment in nutrition programs. This case is based on evidence that the scale of the problem is very large and that nutrition interventions are essential for speeding poverty reduction, have high benefit-cost ratios, and can improve nutrition much faster than reliance on economic growth alone. Moreover, improved nutrition can drive economic growth. The report proposes to the international development community and national governments a global strategy for accelerated action in nutrition.

World Bank (2008). Agriculture for development. World Development Report 2008. Washington, DC: The World Bank. http://go.worldbank.org/ZJIAOSUFU0

An African woman bent under the sun, weeding sorghum in an arid field with a hoe, a child strapped on her back - a vivid image of rural poverty. For her large family and millions like her, the meager bounty of subsistence farming is the only chance to survive. But others, women and men, have pursued different options to escape poverty. Some smallholders join producer organizations and contract with exporters and supermarkets to sell the vegetables they produce under irrigation. Some work as laborers for larger farmers who meet the scale economies required to supply modern food markets. Still others, move into the rural nonfarm economy, starting small enterprises selling processed foods. While the worlds of agriculture are vast, varied, and rapidly changing, with the right policies and supportive investments at local, national, and global levels, today's agriculture offers new opportunities to hundreds of millions of rural poor to move out of poverty. Pathways out of poverty open to them by agriculture include smallholder farming and animal husbandry, employment in the "new agriculture" of high-value products, and entrepreneurship and jobs in the emerging rural, nonfarm economy. In the 21st century, agriculture continues to be a fundamental instrument for sustainable development and poverty reduction. Three of every four poor people in developing countries live in rural areas - 2.1 billion living on less than $2 a day and 880 million on less than $1 a day - and most depend on agriculture for their livelihoods. Given where they are and what they do best, promoting agriculture is imperative for meeting the Millennium Development Goal of halving poverty and hunger by 2015.

Wu J, Salisbury C, Graham R, Lyons G, Fenech M (2009). Increased consumption of wheat biofortified with selenium does not modify biomarkers of cancer risk, oxidative stress, or immune function in healthy Australian males. Environmental and MolecularMutagenesis 50: 489-501. http://dx.doi.org/10.1002/em.20490

Increased intake of selenium (Se) may reduce the risk of degenerative diseases including cancer but excessive intake may be toxic. Wheat is a major source of dietary Se in humans. However, the effect of Se from wheat that is agronomically biofortified with Se on biomarkers of human health status is unknown. This study aimed to investigate whether improving Se status, by increased dietary intake of Se-biofortified wheat, affects biomarkers of cancer risk, cardiovascular disease risk, oxidative stress, and immune function in healthy South Australian men. A 24-week placebo-controlled double-blind intervention was performed in healthy older men (n = 62), with increased dose of Se intake every 8 weeks. Wheat was provided as 1, 2, and 3 puffed wheat biscuits, during weeks 1-8, 9-16, and 17-24, respectively. Blood was collected to measure a wide range of disease risk biomarkers. Consumption of Se-biofortified wheat was found to increase plasma Se concentration from a baseline level of 122 to 192 microg/L following intake of three biscuits/day, which provided 267 microg Se. Platelet glutathione peroxidase, chromosome aberrations, and DNA damage in lymphocytes measured using the cytokinesis-block micronucleus cytome assay and with the Comet assay, plasma F2-isoprostanes, protein carbonyls, plasma C-reactive protein, and leukocyte number were unaffected by the improved Se status. Improvement of Se status by consumption of Se-biofortified wheat did not substantially modify the selected biomarkers of degenerative disease risk and health status in this apparently selenium-replete cohort of healthy older men in South Australia.

Wu X, Sun C, Yang L, Zeng G, Liu Z, Li Y (2008). β-carotene content in sweet potato varieties from China and the effect of preparation on β-carotene retention in the Yanshu No. 5. Innovative Food Science and Emerging Technologies 9: 581-586. http://dx.doi.org/10.1016/j.ifset.2008.06.002

To compare the β-carotene contents in different Chinese sweet potato (SP) varieties and to choose a variety of SP rich in β-carotene for the study of the effect of processing methods on β-carotene retention, β-carotene in thirteen varieties of sweet potato from China was measured by HPLC. The results showed that β-carotene contents were significantly correlated with SP flesh colours, with the orange-red fleshed SP varieties being higher in β-carotene. β-carotene contents in SP were affected by many factors, and this was demonstrated using the variety of Yanshu No.5, showing that the β-carotene contents in SP grown in different farming sites in the same area ranged from 53.2 to 84.3 mg kg−1 fresh weight. Moreover, β-carotene distributes unevenly in one SP root, with highest concentrations in the core. The β-carotene content was positively related to the root size. Five processing methods including boiling, steaming, microwave cooking, frying, and post steam-drying were simulated in the study to check their effects on the true retention of β-carotene in SP. Compared to boiling, steaming resulted in much more loss of β-carotene and microwave cooking resulted in the biggest loss of β- carotene among the five processing methods. Industrial relevance: Orange-fleshed sweet potato can be prepared for sale and consumption, using methods that protect the β-carotene content. This can aid in promoting sweet potato as a staple food as well as a snack food for supplying vitamin A for both rural and urban populations. Prepared orange-fleshed sweet potato can contribute to alleviating vitamin A deficiency in China as well as other low-income countries.

Yang X-E Chen W-R, Feng Y (2007). Improving human micronutrient nutrition through biofortification in the soil-plant system: China as a case study. Environmental Geochemistry and Health 29: 413-428. http://dx.doi.org/10.1007/s10653-007-9086-0

Micronutrient malnutrition is a major health problem in China. According to a national nutritional survey, approximately 24% of all Chinese children suffer from a serious deficiency of iron (Fe) (anemia), while over 50% show a sub-clinical level of zinc (Zn) deficiency. More than 374 million people in China suffer from goiter disease, which is related to iodine (I) deficiency, and approximately 20% of the Chinese population are affected by selenium (Se) deficiency. Micronutrient malnutrition in humans is derived from deficiencies of these elements in soils and foods. In China, approximately 40% of the total land area is deficient in Fe and Zn. Keshan and Kaschin-Beck diseases always appear in regions where the soil content of Se in low. The soil-plant system is instrumental to human nutrition and forms the basis of the "food chain" in which there is micronutrient cycling, resulting in an ecologically sound and sustainable flow of micronutrients. Soil-plant system strategies that have been adopted to improve human micronutrient nutrition mainly include: (1) exploiting micronutrient-dense crop genotypes by studying the physiology and genetics of micronutrient flow from soils to the edible parts of crops; (2) improving micronutrient bioavailability through a better knowledge of the mechanisms of the enhancers' production and accumulation in edible parts and its regulation through soil-plant system; (3) improving our knowledge of the relationship between the content and bioavailability of micronutrients in soils and those in edible crop products for better human nutrition; (4) developing special micronutrient fertilizers and integrated nutrient management technologies for increasing both the density of the micronutrients in the edible parts of plants and their bioavailability to humans.

Yasuda K, Roneker KR, Miller DD, Welch RM, Gen Lei X (2006). Supplemental dietary inulin affects the bioavailability of iron in corn and soybean meal to young pigs. Journal of Nutrition 136: 3033-3038. http://jn.nutrition.org/cgi/content/abstract/136/12/3033

Iron deficiency represents one of the most common global nutritional disorders in humans. Our objective was to determine whether and how supplemental inulin improved utilization of iron intrinsically present in a corn and soybean meal diet by young pigs for hemoglobin repletion. In Expt. 1, 3 groups (n = 8/group) of pigs were fed a corn and soybean meal-based diet (BD, without inorganic iron addition) or BD + 2 or 4% inulin (Synergy 1: a mixture of oligofructose and long-chain inulin HP, Orafti) for 5 wk. Final blood hemoglobin concentrations and the overall hemoglobin repletion efficiency of pigs were positively (r = 0.55 and 0.69, P < 0.01) correlated with dietary inulin concentrations. Compared with pigs fed the BD, those fed 4% inulin demonstrated a 28% improvement (P < 0.01) in hemoglobin repletion efficiency and 15% (P < 0.01) improvement in the final blood hemoglobin concentration. In Expt. 2, 12 weanling pigs (n = 6/group) were fed the BD or the BD14% inulin for 6 wk. Pigs fed4% inulin had higher (P < 0.05) soluble Fe concentrations in the digesta of the proximal, mid, and distal colon, and lower (P< 0.05) sulfide concentrations in the digesta of the distal colon. Supplemental inulin had virtually no effect on pH or phytase activity of digesta from any of the tested segments. In conclusion, supplementing 4% inulin improved utilization of intrinsic iron in the corn and soybean meal diet by young pigs, and this benefit was associated with soluble Fe and sulfide concentrations but not pH or phytase activity in the digesta.

Yuan YX, Zhang J, Wang DW, Ling HQ (2005). AtbHLH29 of Arabidopsis thaliana is a functional ortholog of tomato FER involved in controlling iron acquisition in strategy I plants. Cell Research 15: 613-621. http://dx.doi.org/10.1038/sj.cr.7290331

AtbHLH29 of Arabidopsis, encoding a bHLH protein, reveals a high similarity to the tomato FER which is proposed as a transcriptional regulator involved in controlling the iron deficiency responses and the iron uptake in tomato. For identification of its biological functions, AtbHLH29 was introduced into the genome of the tomato FER mutant T3238fer mediated by Agrobacterium tumefaciencs. Transgenic plants were regenerated and the stable integration of AtbHLH29 into their genomes was confirmed by Southern hybridization. Molecular analysis demonstrated that expression of the exogenous AtbHLH29 of Arabidopsis in roots of the FER mutant T3238fer enabled to complement the defect functions of FER. The transgenic plants regained the ability to activate the whole iron deficiency responses and showed normal growth as the wild type under iron-limiting stress. Our transformation data demonstrate that AtbHLH29 is a functional ortholog of the tomato FER and can completely replace FER in controlling the effective iron acquisition in tomato. Except of iron, FER protein was directly or indirectly involved in manganese homeostasis due to that loss functions of FER in T3238fer resulted in strong reduction of Mn content in leaves and the defect function on Mn accumulation in leaves was complemented by expression of AtbHLH29 in the transgenic plants. Identification of the similar biological functions of FER and AtbHLH29, which isolated from two systematically wide-diverged "strategy I" plants, suggests that FER might be a universal gene presented in all strategy I plants in controlling effective iron acquisition system in roots.

Zapata-Caldas E, Hyman G, Pachón H, Monserrate FA, Vesga Varela L (2009). Identifying candidate sites for crop biofortification in Latin America: case studies in Colombia, Nicaragua and Bolivia. International Journal of Health Geographics 8: 29. http://dx.doi.org/10.1186/1476-072X-8-29

Background: Agricultural science can address a population's vitamin, amino acid and mineral malnutrition through biofortification - agronomy, plant breeding and biotechnology to develop crops with high nutrient contents. Biofortified crop varieties should be grown in areas with populations at risk of nutrient deficiency and in areas where the same crop is already grown and consumed. Information on the population at risk of nutrient deficiency is rarely available for sub-national administrative units, such as provinces, districts, and municipalities. Nor is this type of information commonly analyzed with data on agricultural production. This project developed a method to identify populations at risk of nutrient deficiency in zones with high crop production, places where biofortification interventions could be targeted. Results: Nutrient deficiency risk data were combined with crop production and socioeconomic data to assess the suitability of establishing an intervention. Our analysis developed maps of candidate sites for biofortification interventions for nine countries in Latin America and the Caribbean. Results for Colombia, Nicaragua, and Bolivia are presented in this paper. Interventions in northern Colombia appear promising for all crops, while sites for bean biofortification are widely scattered throughout the country. The most promising sites in Nicaragua are found in the center-north region. Candidate sites for biofortification in Bolivia are found in the central part of the country, in the Andes Mountains. The availability and resolution of data limits the analysis. Some areas show opportunities for biofortification of several crops, taking advantage of their spatial coincidence. Results from this analysis should be confirmed by experts or through field visits. Conclusion: This study demonstrates a method for identifying candidate sites for biofortification interventions. The method evaluates populations at risk of nutrient deficiencies for sub-national administrative regions, and provides a reasonable alternative to more costly, information-intensive approaches.

Zhang J, Wu L, Wang M (2008). Can iron and zinc in rice grains (Oryza sativa L.) be biofortified with nitrogen fertilisation under pot conditions? Journal of the Science of Food and Agriculture 88: 1172-1177. http://dx.doi.org/10.1002/jsfa.3194

BACKGROUND: Because only grain yield has been investigated, the influence of fertilisation by N on the concentration of Fe and Zn in polished rice has been overlooked in China. So, using the rice cultivars of the indica Zhenong 952 and the japonica Bing 98110, pot experiments were conducted to investigate the amounts of N fertiliser (applied as urea at rates of 0, 0.50, 1.00 and 1.50 g N pot-1) that would lead to the optimum Fe and Zn concentrations in polished rice as well as grain yield. RESULTS: For Zhenong 952, the optimal Fe and Zn concentration as well as grain yield was attained at a N application of 1.00 g pot-1; for Bing 98110 the optimum N was 1.50 g pot-1. The ratio of Zn deposited in brown rice was about 40% of the total Zn in the

plant irrespective of N application. However, Fe was only about 3%. Fe concentration in brown rice was approximately one-half of the rice husk, one-fifth of the peduncles, and one-tenth of the leaves, and a little more than 1% of the root. CONCLUSION: The optimum N application, alone, on rice crops could increase Fe concentration in polished rice, but had an adverse effect for Zn. Fe appeared not to be as easily accumulated into rice seeds as was Zn.

Zhang J, Wu LH, Wang MY (2008). Iron and zinc biofortification in polished rice and accumulation in rice plant (Oryza sativa L.) as affected by nitrogen fertilization. Acta Agriculturae Scandinavica, B 58: 267-272. http://dx.doi.org/10.1080/09064710701628982

With focus on maximizing grain yield in rice (Oryza sativa L.) production, especially in China, information available in the literature on how nitrogen (N) fertilization of rice crops affects biofortification of iron (Fe) and (Zn) in grains is limited. The objective of the experiment was to investigate to what degree application of N fertilizer attained the optimum Fe and Zn concentration in rice grains as well as grain yield under pot conditions. Two rice cultivars of the indica 'Zhenong 952' and the japonica 'Bing 98110', grown widely in the area of the Yangtse River Delta in southern China, and fertilized with four rates of urea (0, 0.50, 1.00 and 1.50 g N pot-1), were investigated. The results showed that, in the pot trails, the optimum application of N alone on rice crops could increase the concentration of Fe in the polished rice. By considering both health and commercial reasons, when N application reached 1.00 g pot-1, the optimal Fe and Zn concentrations were attained as well as grain yield for 'Zhenong 952', and for 'Bing 98110' the optimum N application was 1.50 g pot-1. Fe appeared not to be so easily mobilized as Zn in the plant. The ratio of Zn deposited in the brown rice was about 40% of total Zn in the plant, irrespective of N application. However, deposited Fe was only about 3% of total Fe. Fe concentration in brown rice was only about ½ that in rice husk, 1/5 that in peduncles, 1/10 that in leaves, and only a little more than 1% of that in roots. These results suggested if we wanted to increase the amount of Fe in grains the translocation mechanism of Fe in rice plant must be clearly understood first.

Zhao F, McGrath S, Gray C, Lopez-Bellido J (2007). Selenium concentrations in UK wheat and biofortification strategies. Comparative Biochemistry and Physiology, Part A 146: S246. http://dx.doi.org/10.1016/j.cbpa.2007.01.571

Selenium is essential for humans and animals but has no known function in plants. Dietary intake of selenium is low in a large number of people worldwide. In some European countries, dietary Se intakes have decreased significantly in recent decades. For example, average Se intake of UK adults has decreased by more than 40% from the mid 1970s to 1995. The main reason for this trend is the decreased importation of breadmaking wheat from North America, which generally contains much more Se than European wheat. Our survey of 452 grain samples of bread-making wheat produced in the UK shows a range of 6-858 µg Se/kg dry weight with a mean and median of 32 and 22 µg Se/kg, respectively. Furthermore, 91% of the samples contained <50 µg Se/kg, which is considered to be insufficient for the requirements of humans and animals.

Zhao F-J, McGrath SP (2009). Biofortification and phytoremediation. Current Opinion in Plant Biology 12: 373-380. http://dx.doi.org/10.1016/j.pbi.2009.04.005

Producing nutritious and safe foods sufficiently and sustainably is the ultimate goal of modern agriculture. Past efforts have focused on increasing crop yields, but enhancing the concentrations of mineral micronutrients has become an urgent task because about half of the world population suffers from the malnutrition of iron, zinc, and selenium. Biofortification of these trace elements can be achieved through fertilization, crop breeding or biotechnology. On the other hand, soils contaminated with metals or metalloids may be cleaned up by phytoextraction that combines hyperaccumulation with high biomass production. Progress has been made in identifying inter-species and intra-species variation in trace element accumulation, and mechanistic understanding of some aspects of trace element transport and homeostasis in plants, but much remains to be elucidated.

Zhao FJ, Y.H. Su YH, Dunham SJ, Rakszegi M, Bedo Z, McGrath SP, Shewry PR (2009). Variation in mineral micronutrient concentrations in grain of wheat lines of diverse origin. Journal of Cereal Science 49: 290-295. http://dx.doi.org/10.1016/j.jcs.2008.11.007

150 lines of bread wheat representing diverse origin and 25 lines of durum, spelt, einkorn and emmer wheat species were analysed for variation in micronutrient concentrations in grain. A subset of 26 bread wheat lines was grown at six sites or seasons to identify genetically determined differences in micronutrient concentrations. Substantial variation among the 175 lines existed in grain Fe, Zn and Se concentrations. Spelt, einkorn and emmer wheats appeared to contain higher Se concentration in grain than bread and durum wheats. Significant differences between bread wheat genotypes were found for grain Fe and Zn, but not Se concentration; the latter was influenced more by the soil supply. Grain Zn, but not Fe, concentration correlated negatively with grain yield, and there was a significant decreasing trend in grain Zn concentration with the date of variety release, suggesting that genetic improvement in yield has resulted in a dilution of Zn concentration in grain. Both grain Zn and Fe concentrations also correlated positively and significantly with grain protein content and P concentration, but the correlations with kernel size, kernel weight or bran yield were weak. The results from this study are useful for developing micronutrient biofortification strategies.

Zhu C, Naqvi S, Gomez-Galera S, Pelacho AM, Capell T, Christou P (2007). Transgenic strategies for the nutritional enhancement of plants. Trends in Plant Science 12: 548-555. http://dx.doi.org/10.1016/j.tplants.2007.09.007

The nutrients in the human diet ultimately come from plants. However, all our major food crops lack certain essential vitamins and minerals. Although a varied diet provides adequate nutrition, much of the human population, particularly in developing countries, relies on staple crops, suchas riceormaize,whichdoesnotprovide the full complement of essential nutrients. Malnutrition is a significant public health issue in most of the developing world. One way to address this problem is through the enhancement of staple crops to increase their essential nutrient content. Here, we review the current strategies for the biofortification of crops, including mineral fertilization and conventional breeding but focusing on transgenic approaches which offer the most rapid way to develop high-nutrient commercial cultivars.

Zhu Y-G, Pilon-Smits EAH, Zhao F-J, Williams PN, Meharg AA (2009). Selenium in higher plants: understanding mechanisms for biofortification and phytoremediation Trends in Plant Science 14: 436-442. http://dx.doi.org/10.1016/j.tplants.2009.06.006

Selenium (Se) is an essential micronutrient for many organisms, including plants, animals and humans. As plants are the main source of dietary Se, plant Se metabolism is therefore important for Se nutrition of humans and other animals. However, the concentration of Se in plant foods varies between areas, and too much Se can lead to toxicity. As we discuss here, plant Se uptake and metabolism can be exploited for the purposes of developing high-Se crop cultivars and for plant-mediated removal of excess Se from soil or water. Here, we review key developments in the current understanding of Se in higher plants. We also discuss recent advances in the genetic engineering of Se metabolism, particularly for biofortification and phytoremediation of Se-contaminated environments.

Zimmermann MB, Hurrell RF (2007). Nutritional iron deficiency. Lancet 370: 511-520. http://dx.doi.org/10.1016/S0140-6736(07)61235-5

Iron deficiency is one of the leading risk factors for disability and death worldwide, affecting an estimated 2 billion people. Nutritional iron deficiency arises when physiological requirements cannot be met by iron absorption from diet. Dietary iron bioavailability is low in populations consuming monotonous plant-based diets. The high prevalence of iron deficiency in the developing world has substantial health and economic costs, including poor pregnancy outcome, impaired school performance, and decreased productivity. Recent studies have reported how the body regulates iron absorption and metabolism in response to changing iron status by upregulation or downregulation of key intestinal and hepatic proteins. Targeted iron supplementation, iron fortification of foods, or both, can control iron deficiency in populations. Although technical challenges limit the amount of bioavailable iron compounds that can be used in food fortification, studies show that iron fortification can be an effective strategy against nutritional iron deficiency. Specific laboratory measures of iron status should be used to assess the need for fortification and to monitor these interventions. Selective plant breeding and genetic engineering are promising new approaches to improve dietary iron nutritional quality.

Zuo Y, Zhang F (2009). Iron and zinc biofortification strategies in dicot plants by intercropping with gramineous species. A review. Agronomy for Sustainable Development 29: 63-71. http://dx.doi.org/10.1051/agro:2008055

The lack of micronutrients such as iron and zinc is a widespread nutrition and health problem in developing countries. Biofortification is the process of enriching the nutrient content of staple crops. Biofortification provides a sustainable solution to iron and zinc deficiency in food around the world. Reports have highlighted the current strategies for the biofortification of crops, including mineral fertilization, conventional breeding and transgenic approaches. Any approach which could increase root growth and result in a high transfer of Fe and Zn from the soil to the plant is crucial for biofortification. In addition to these approaches, we draw attention to another important aspect of Fe and Zn biofortification: intercropping between dicots and gramineous species. Intercropping, in which at least two crop species are grown on the same plot of land simultaneously, can improve utilization of resources while significantly enhancing crop productivity, whereas monocropping is a traditional cropping system of only one crop growth. Monocropping has maintained crop productivity through heavy chemical inputs including the application of fertilizers and pesticides. Monocropping has therefore resulted in substantial eutrophication, environmental pollution, a food security crisis and economic burdens on farmers. Monocropping has also reduced the plant and microorganism diversity in the ecosystem. Compared with monocropped plants, intercropped plants can use nutrients, water and light better due to the spatial and temporal differences in the growth factors and a variety of species-specific mechanisms of physiological response to environmental stress. Intercropping is common in developing countries such as China, India, Southeast Asia, Latin America and Africa. In particular, interspecific interaction facilitates the iron and zinc nutrition of intercropping systems such as peanut/maize, wheat/chickpea and guava/sorghum or maize. Intercropping also increases iron and zinc content in the seeds. In a peanut/maize case study, the Fe concentrations in peanut shoots and seed were 1.47-2.28 and 1.43 times higher than those of peanut in monocropping, respectively. In intercropping of chickpea and wheat, the Fe contents in wheat and chickpea seed were increased 1.26 and 1.21 times, respectively, and Zn concentration in chickpea seed was 2.82 times higher than that in monocropping. In this review, we focus on exemplary cases of dicot/gramineous species intercropping that result in improved iron and zinc nutrition of the plants. We present the current understanding of the mechanisms of improvement of iron and zinc in intercropping. The available literature shows that a reasonable intercropping system of nutrient-efficient species could prevent or mitigate iron and zinc deficiency of plants. Here, we propose that intercropping can potentially offer an effective and sustainable pathway to iron and zinc biofortification.

Anhang

Kurzvitae der Autoren

Dr. Alexander J. Stein

Alexander J. Stein ist unabhängiger Experte für Agrar-, Gesundheits- und Entwicklungsökonomie. Er arbeitet hauptsächlich zu Themen im Ernährungsbereich sowie zu Fragestellungen der grünen Gentechnik – Themen, zu denen er zahlreiche Artikel in Fachzeitschriften, Diskussionsbeiträge und wissenschaftliche Berichte erstellt hat. Alexander Stein studierte Volkswirtschaftslehre an den Universitäten Würzburg, Münster und Montpellier (Frankreich), machte einen Masters in Entwicklungsökonomie an der Universität von Nottingham (England), nahm am Doktorandenprogramm des Zentrums für Entwicklungsforschung der Universität Bonn teil und promovierte 2006 in Agrarökonomie mit summa cum laude an der Universität Hohenheim. Seine Doktorarbeit zu "Micronutrient malnutrition and the impact of modern plant breeding on public health in India: how cost-effective is biofortification?" wurde mit zwei Preisen ausgezeichnet. Neben weiteren Tätigkeiten arbeitete Alexander Stein als Berater für Projekte der internationalen Entwicklungszusammenarbeit, als wissenschaftlicher Mitarbeiter am Zentrum für Entwicklungsforschung in Bonn und am Lehrstuhl für Internationalen Agrarhandel und Welternährungswirtschaft der Universität Hohenheim in Stuttgart, sowie zuletzt als wissenschaftlicher Referent in der Abteilung für Wirtschaft, Landwirtschaft und Lebenswissenschaften am Institut für technologische Zukunftsforschung der Europäische Kommission in Sevilla (Spanien). Weitere Informationen sind seiner Webseite unter http://www.AJStein.de zu entnehmen.

Prof. Dr. Matin Qaim

Matin Qaim ist Professor für Welternährungswirtschaft und Rurale Entwicklung and der Georg-August-Universität Göttingen. Seine Forschungsschwerpunkte sind die Ökonomik von Biotechnologie und Agrarforschungssystemen, Welternährungsfragen und nachhaltige Entwicklung, Ernährungs- und Gesundheitsökonomik sowie Märkte für hochwertige Agrarprodukte in Entwicklungsländern – wozu er über 120 Veröffentlichungen geschrieben hat. Matin Qaim studierte Agrarwissenschaften an den Universitäten Bonn und Kiel. Er promovierte an der Universität Bonn, wo er sich im Jahr 2003 auch im Fach Agrar- und Entwicklungsökonomie habilitierte. Für seine Forschungsarbeiten hat er mehrere nationale und internationale Ehrungen und Preise erhalten. Vor seiner Professur an der Universität Göttingen war Matin Qaim Professor für Internationalen Agrarhandel und Welternährungswirtschaft an der Universität Hohenheim, Forschungsgruppenleiter am Zentrum für Entwicklungsforschung der Universität Bonn, Visiting Research Fellow an der Universität von Kalifornien in Berkeley (USA) sowie wissenschaftlicher Mitarbeiter an den Universitäten Bonn und Kiel. Derzeit hat Matin Qaim außerdem mehrere außeruniversitäre Ämter inne, so ist er u.a. im wissenschaftlichen Beirat für Agrarpolitik des BMELV, im Aufsichtsrat des International Maize and Wheat Improvement Center (CIMMYT), im Aufsichtsrat von Africa Harvest, Vorsitzender des External Advisory Board des Africa Biofortified Sorghum Projects, Mitglied des Golden Rice Humanitarian Board sowie Mitherausgeber verschiedener internationaler Zeitschriften.

Expertenbefragung

Zur Ergänzung der Literaturübersicht und um aktuell und aus der Praxis zu erfahren, welche Hindernisse es bei der Weiterentwicklung und Umsetzung der biologischen Anreicherung gibt, haben wir 50 deutsche und internationale Experten im Bereich der Pflanzenzüchtung und der biologischen Anreicherung einzeln per E-Mail angeschrieben, um Ihnen einen Fragebogen zuzuschicken (siehe im Folgenden). Nach einer persönlichen Begrüßung und einem kurzen, auf die einzelnen Experten zugeschnittenen Absatz, folgte das hier aufgeführten Anschreiben:

Dear Colleague,

We are writing a report for the **German Parliament** on "Strategies for the elimination of micronutrient deficiencies" (in the context of a bigger project of the Parliament's Office of Technology Assessment (TAB) about the potential contribution of research and technology to solving the **world food problem**). The focus of our report will be on **biofortification** – and on **potential barriers** and restrictions that must be overcome for a successful implementation of this novel micronutrient intervention.

Given your involvement in current biofortification efforts we would be very much obliged if you could answer **six questions** we are sending you in the attachment. As one objective of the TAB project is to identify those fields in science and R&D where more intensive support (in the form of **research funding and international coordination**) promises to be particularly relevant for helping solve the world food problem, answering the questions may also be in the interest of your work. For further details (in English) on the TAB project, please see: http://www.tab.fzk.de/en/projekt/skizze/welternaehrung.htm

Of course you are welcome to discuss the questions with colleagues within your project or organisation, but we would be grateful to receive a response that reflects **your personal views** on the issues. (By specifically contacting various experts with different backgrounds we hope to obtain a comprehensive picture of the way biofortification is taking and of the restrictions for its development.) Overall, answering all questions need not take more than 10-15 minutes of your precious time; **short answers** are sufficient. Please type directly into the attached document.

Looking forward to receiving your response soon (to integrate your answers in a meaningful way into the report we would need to receive them by the end of the **first week of November**). You are also more than welcome to share with us any new or forthcoming article you may have on the topic of biofortification.

Please do not hesitate to get back to us if you have questions. Only in case you cannot respond yourself, please forward the questionnaire to a member of your staff who is closely collaborating with you on biofortification and who is familiar with the restrictions you face in your work.

Thank you very much!

Kind regards,
Alexander Stein
Matin Qaim

Von den 50 angeschriebenen Experten antworteten 24, wovon wiederum 18 Experten der Veröffentlichung ihrer Antworten zustimmten (6 Experten wollten nicht namentlich genannt werden oder antworteten nur auf informeller Basis). Zudem wurde mit Prof. Dr. Peter Beyer von der Universität Freiburg, dem wohl am meisten in biologische Anreicherung involvierten deutschen Wissenschaftler, ein ergänzendes Telefoninterview durchgeführt. Auf der nächsten Seite ist der Original-Fragebogen wiedergegeben; die Antworten der Experten folgen im Anschluss – geordnet anhand des Datums ihrer Rücksendung. Aus Platzgründen wurden die Fragen auf den beantworteten Fragebögen z.T. etwas gekürzt (für die vollständigen Fragen siehe das Original), die beantworteten Fragebögen wurden neu formatiert, und nicht beantwortete Felder wurden ausgelassen. Außerdem wurden Tippfehler korrigiert und Abkürzungen verwendet bzw. ausgeschrieben.

Fragebogen

----- Anfang des Original-Fragebogens -----

Restrictions to overcome for successful biofortification

(Please type directly into the boxes)

1.) Your professional background

Your name

Your training or academic background

Your affiliation

The biofortification project you are involved in

Your role within the project

Nutrient(s) you are working on

Crop(s) you are working on

Approaches you are using (conventional, GM, etc.)

(Additional information)

2.) Privacy and use of information (check one)

My answer can be printed in the annex of the report ☐

The essence of the information can be referred to as "personal communication" ☐

The answer is informal and for information only and should not be attributed to me ☐

3.) Definition of "biofortification" (check all that apply)

Conventional breeding for higher micronutrient content in crops ☐

Genetic engineering for higher micronutrient content in crops ☐

Introduction of different (colour, taste, etc.) crop varieties with higher micronutrient content ☐

Optimisation of fertiliser use for higher micronutrient content in crops ☐

Fortification of food with natural substances with a high micronutrient content ☐

Efforts to increase the amount or quality of *macro*nutrients in crops ☐

(Other definitions)

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research

... development

... regulation	
... commercialisation	
... dissemination	
... farmer adoption	
... consumer acceptance	
Other	

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation?
What kind of support? And at which levels?

Basic research (*Which disciplines? At international or country level?*)	
Applied research (*Which disciplines? At international or country level?*)	
Knowledge transfer, collaboration & coordination (*In which disciplines? At international or country level?*)	
Physical infrastructure & facilities (*In which areas?*)	
Institutions, legislation & politics (*In which areas? At international or country level?*)	
Other	

6.) Where do you see the biggest potential contribution of Germany (and more generally European actors) to addressing micronutrient malnutrition?

International collaborations (*In which fields? Between whom?*)	
Capacity building (*In which fields? Of whom?)*	
Targeted funding (*In which fields? Of whom or what?*)	
Political support (*In which areas? At which levels?*)	
Other	

Thank you very much for your help!

----- Ende des Original-Fragebogens -----

Antworten im Detail

De Groote H – CIMMYT – HarvestPlus

1.) Your professional background

Your name	Hugo De Groote
Training or academic background	PhD agricultural economics
Your affiliation	CIMMYT
The biofort. project you are involved in	HarvestPlus – vitamin A biofortified maize
Your role within the project	Economist – impact assessment and consumer acceptance
Nutrient(s) you are working on	Vitamin A (Zn, Iron), lysine
Crop(s) you are working on	Maize
Approaches you are using	Conventional
Additional info	I work on Quality Protein Maize (QPM), fortified with higher lysine and tryptophan content

2.) Privacy and use of information

My answer can be printed in the annex of the report	Y

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	X
Genetic engineering for higher micronutrient content in crops	X
Optimisation of fertiliser use for higher micronutrient content in crops	X
Efforts to increase the amount or quality of *macro*nutrients in crops	X
Other def.	Breeding for increased nutritional quality, (so QPM should be included)

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	Impact assessment, consumer acceptance (especially yellow maize in Africa)
... regulation	GM regulation in Africa
... consumer acceptance	Need to map where yellow maize is currently used in Africa

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Applied research	Impact assessment, consumer studies, improving agronomic performance of YFSP
Infrastructure & facilities	Labs to measure micronutrient and amino acid content
Institutions, legislation etc.	Setting quality standards for biofortified crops, labels

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

Funding	More support for CIMMYT

N1 (Name nicht zur Veröffentlichung)

2.) Privacy and use of information

My answer can be printed in the annex of the report	yes
The answer is informal and for information only and should not be attributed to me	yes

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	X
Genetic engineering for higher micronutrient content in crops	X
Optimisation of fertiliser use for higher micronutrient content in crops	X
Efforts to increase the amount or quality of *macro*nutrients in crops	X

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	Limited funding sources are available
... regulation	Very difficult to get through all of the regulatory barriers [...] to perform this type of research
... consumer acceptance	So much misinformation and fear generation has been put out that consumers and governments are confused about the safety of such crops. Millions of people who could truly benefit from the higher nutrient content (in terms of lower morbidity sand mortality) have been deprived of the nutritional advantages of these crops. WE are truly in need of an educational effort – both in developed and in economically deprived countries.
Other	Certain groups and organizations have tried to vilify work on GM crops with inflammatory language- they also try to intimidate investigators.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	Development of crops for nutritional enhancement and for drought resistance. An international effort should be made to develop such staple crops if we are to solve the world food problems, which we are currently encountering and will continue to encounter. 500 million dollars
Applied research	Ultimately, the nutritional impact of these crops on the nutritionally deprived human population is of the greatest interest. Again, this applied research should be done at the international, regional level. Initial efficacy testing of these crops should be done in the countries in which they were developed. 500 million dollars
Knowledge transfer, collaboration etc.	We need a massive educational effort on conventional breeding and GM development so that we have informed populations in both the developed and the developing world. Collaborations at the country level are especially needed to perform the applied aspects of this work.
Institutions, legislation etc.	We need to try to streamline the regulatory processes. This would need to be done at the country level with WHO guidance

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaboration	Target Africa—Collaboration with Gates Foundation should be sought
Capacity building	Develop local capacities for carrying out field studies— (crop growth as well as effectiveness studies)
Targeted funding	Development of key staple crops for Africa-for micronutrient enhancement and drought resistance

Political support	Political support is especially needed for education on conventional and GM crop production techniques, so that the population in truly informed of the advantages, risks (minimal as they are) and necessity of these crops.

Sayre R – Danforth Plant Science Center – BioCassava Plus

1.) Your professional background

Your name	Richard Sayre
Training or academic background	Ph. D. Biology, Univ. Iowa, USA; Postdoc, Molecular Biology, Harvard Univ.
Your affiliation	Donald Danforth Plant Science Center, St Louis, MO, USA
The biofort. project you are involved in	BioCassava Plus funded by BMGF
Your role within the project	Director and scientist for iron and protein biofortification, reduced cyanide content and extended shelf life.
Nutrient(s) you are working on	Pro-vitamin A, vitamin E, iron, zinc, protein
Crop(s) you are working on	Cassava
Approaches you are using	GM
Additional info	We are also working on reducing cyanide content, developing virus resistance and extending shelf life. Our ex ante studies indicate that The addition of these value-added traits will serve as economic drivers to promote adoption and acceptance of biofortified cassava that may be hard to distinguish between non-fortified cassava.

2.) Privacy and use of information

My answer can be printed in the annex of the report	X

3.) Definition of "biofortification"

Genetic engineering for higher micronutrient content in crops	X
Introduction of different crop varieties with higher micronutrient content	X
Efforts to increase the amount or quality of *macro*nutrients in crops	X

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	Need for funding to support efforts to do multi-gene stacking of traits and field trials.
... development	Need for funding to support for the development of extensive number of transgenic and biofortified farmer-preferred cultivars to achieve the highest impact. The science is ready to go.
... regulation	Need for national biosafety legislation for human consumption of transgenic crops.
... commercialisation	Need for funding to support national agricultural research organizations and NGOs to generate products for dissemination.
... dissemination	Identification of final partners and funding of dissemination programs
... farmer adoption	Need for funding to support for educational outreach
... consumer acceptance	Need for funding to support educational activities

Other	Overall, we have proof-of-principle for nearly all of our transgenic traits in the greenhouse and are limited in developing these products by the size of the continuing investment in our program. The financial crisis has lead to a 60% cut in BMGF programmatic funding for phase II starting in July 2010.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	At this stage we need investment in nutritional studies to determine the effectiveness of the biofortified food products to deliver sufficient nutrients in a normal sized meal. If we find we find we are not meeting our targets than additional funds will be needed to support basic research on nutrient retention strategies in prepared foods. Transgenic strategies to increase nutrient retention in prepared foods are under consideration as a contingency. We also need additional support to develop stacked trait (Fe, Zn, pro-vitamin A, protein) biofortified plants with traits (low CN, extended shelf life, virus resistance) that serve as economic drivers for adoption. Our *ex ante* studies indicate that the benefit/cost ratios for stacked trait (pro-vitamin A, Fe, and Zn) products are substantially higher (3-4X) than for single trait pro-vitamin A) plants. Furthermore, the cost per DALY (<$60/DALY in Nigeria) is also reduced (2-3 X) for multi-stacked traits. An additional interest currently outside the BMGF funding stream is the development of true seed for cassava. Currently cassava is cultivated as stem cuttings that have short life times and limited numbers of propagules (10) per plant. The development of true seeds (>200 seeds/plant) would make cassava a modern agricultural crop adaptable to mechanized seed planting, reduce virus transmission, and increase income and food security for farmers.
Applied research	Field and human feeding trials will be necessary to support efficacy.
Knowledge transfer, collaboration & coordination	We hope to transfer our molecular tool box of transgenic constructs and technologies to African scientists currently undergoing training in our advanced labs. The objective is to have African scientists develop the biofortified products in African labs using farmer-preferred cultivars. It is our expectation that this strategy will give Africans ownership and pride in the project. But, currently there is no financial support to make this a reality even after an extensive 1.5 year training program for future African scientists supported by the BMGF.
Physical infrastructure & facilities	Our current target countries are Nigeria (largest cassava consumer) and Kenya. In addition, we are building strong teams in Tanzania and Uganda. We also envision our products being developed for the DR Congo and Ghana. To make this a reality will require investments in laboratories, personnel, equipment and supplies in these target countries for at least 25 years. It is recommended that this program be co-developed with some level of buy in from the target country.
Institutions, legislation & politics	We achieved great success recently with the approval of the first ever confined field trail (CFT) for a transgenic organism (vitamin A biofortified cassava) in Nigeria. We expect an official announcement of approval of a CFT in Kenya at any moment. This is the first stage in the process of de-regulating the production and consumption of biofortified cassava in Africa. Legislation is also needed in each target country to permit testing and human consumption of the biofortified cassava. Additionally, it would be useful if there was international consensus that would allow certification of transgenic constructs rather than event-specific production of transgenics. This would greatly streamline the de-regulation process. We also need well recognized, respected and persons of high integrity to serve as local champions for the biofortified food products with value-added traits.
Other	It would also be valuable in the long term to develop national food and agricultural extension services that bring best practices to farmers.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	Need for funding to support the training of African scientists and the infra-structure and supplies needed to produce biofortified cassava in Africa. Additional support is needed to make stacked trait plants a reality. These tools can most efficiently be developed in advanced labs (US, Switzerland, UK).
Capacity building	See above. Where; Nigeria, Tanzania, Uganda, Kenya, Ghana and some day DR Congo.
Targeted funding	Gene stacking technologies, food nutrient retention studies, field and human feeding trials in Africa, product development and outreach to farmers and consumers
Political support	The development of a pan-African consensus and review committee focusing on the development and approval of GMO technologies for humanitarian purposes would streamline the approval process and reduce costs. It would also be incredibly valuable to get in-country buy in to support the projects.
Other	Thank you for your interest. It is most appreciated for this very valuable program. I am currently in Tanzania and spent yesterday visiting a remote cassava farmer who lives north of Dar-es-Salaam. His annual income is $200 from all farming activities (cassava, cashew, citrus, groundnuts on 4 hectares without land title). It costs $75/year to send a child to school. He has three children so this year, due to the drought, only one child will go to school. Cassava mosaic virus and short root shelf life in addition to the drought have severely impacted his food production and the well being of his family. His dream is to send all his children to school. I hope we can help him reach his dream.

Potrykus I – ETH Zürich (Emeritus) – Golden Rice

1.) Your professional background

Your name	Ingo Potrykus
Training or academic background	Professor Plant Sciences
Your affiliation	ETH Zürich, Emeritus
The biofort. project you are involved in	Golden Rice and follow-up
Your role within the project	Co-leader
Nutrient(s) you are working on	Provitamin A, iron, zinc, high quality protein
Crop(s) you are working on	Rice, cassava, sorghum, wheat
Approaches you are using	GM
Additional info	Retired, chairman of Humanitarian Golden Rice Board & Network

2.) Privacy and use of information

My answer can be printed in the annex of the report	**yes**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	**OK**
Genetic engineering for higher micronutrient content in crops	**OK**
Other def.	Optimisation of micronutrient content of crops in situ using the potential of genetic interventions.

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	Good potential in the public domain
... development	No potential and experience in the public domain
... regulation	The overwhelming hurdle: time and costs required to comply with regulatory requirements prevent use of GM-technology for public good projects
... dissemination	Can be organized
... farmer adoption	Can be encouraged by additional agronomic traits
... consumer acceptance	Can be encouraged by demonstration of benefits
Other	All problems are the consequence of regulation

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	Lack of financial support for projects addressing real world problems; waste of resources for "biosafety" research.
Applied research	"Applied" research lacks real world connection to "application". Academics often misunderstand "proof-of-concept" with application. There is a very long way from e.g. Arabidopsis to rice.
Knowledge transfer, collaboration etc.	Public-private-partnerships very helpful, but there must be mutual interest from both sides. Public good tasks seldom offer mutual interests to the private sector
Infrastructure & facilities	No infrastructure (and funding) for product development and deregulation in the public sector
Institutions, legislation & politics	Public institutions which could transfer scientific knowledge to application have changed to become institutions which compete in the academic arena (Max-Planck, John Innes, Wageningen, etc.)
Other	Public-private partnerships essential for public good projects because of total lack of knowledge with regards to product development and deregulation in the public sector.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	To be able to participate in international collaborations would require that scientists receive funding for positive research, not for pseudo-biosafety projects.
Capacity building	The political climate is increasingly discouraging students to join the field and professors do not receive the necessary funds to built and maintain functional teams.
Targeted funding	Golden Rice is the world-wide leading project in GM project addressing micronutrient malnutrition. Very effective varieties will be released in developing countries with severe public health problems from 2012 onwards. If Germany does not want to lose its only chance to be involved, it should substantially support Professor Peter Beyer, Freiburg.
Political support	There is no political support but obstruction.
Other	Germany was once **the** leading nation. It will require substantial efforts to approach this place again.

1.) Your professional background

Your name	Prof. Dr. Ute Krämer
Training or academic background	1996 D.Phil. Plant Sciences, Oxford Univ., UK; 2006 Habilitation Molecular Plant Physiology, Univ. Potsdam, Germany
Your affiliation	Chair of Plant Physiology, University of Bochum
The biofort. project you are involved in	EU InP "Public health impact of long-term low-level exposure to metallic elements in susceptible population strata (PHIME)";
Your role within the project	EU InP: partner
Nutrient(s) you are working on	Focus on Zn, Fe, Cu, Mn, Se; exclusion of Cd (toxic Zn/Ca analogue); analytically: all
Crop(s) you are working on	Barley (as model for cereal crops in general, PHIME), primarily other model plants *Arabidopsis thaliana* and *Arabidopsis halleri* (strongly modified metal handling) for a fundamental molecular understanding of metal handling and accumulation by plants
Approaches you are using	Conventional breeding (natural diversity, introgression lines) and GM

2.) Privacy and use of information

My answer can be printed in the annex of the report	X

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	X
Genetic engineering for higher micronutrient content in crops	X
Introduction of different crop varieties with higher micronutrient content	X
Efforts to increase the amount or quality of *macro*nutrients in crops	X

Other def.	One rationale is that fertilizer supplies will become more and more expensive and scarce. Fertilization can also endanger the environment. Thus, bio-fortification also means to obtain cultivars (by conventional breeding or GMO approaches) that accumulate higher concentrations of micronutrients with minimal fertilizer supply (→ goal: high efficiency of uptake and translocation systems). Most of the following refers to micronutrient elements. There is a large community working on organic biofortification (vitamins, omega-3, lycopenes, ...), which I know less well.

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	Existing natural diversity among different cultivars in crop micronutrient contents has not exhaustively been screened; genetic knowledge on which genes control crop micronutrient contents has not yet been developed yet; general and molecular physiology of nutrient accumulation pathways is not well understood. This has not so far been an area of intense research or research funding, and the research community working on this is very small. Company support has so far been minimal: current company focus is on yield increase, companies say that these quality issues will be an important goal in 10 or 20 years and are thus not interesting for them now. However, micronutrient efficiencies have an important impact on fertility, growth and yield – this knowledge is just being developed in "easy" models, i.e. *Arabidopsis thaliana*. It is possible to achieve micronutrient selectivity (Zn and Fe over Cd), but currently the fundamental scientific knowledge on how this can be reached is insufficient. There is insufficient knowledge on human

	micronutrient deficiencies: for example, there are no good markers for Zn status.
... development	Not currently a focus for breeding companies. Lack of fundamental knowledge. Lack of R&D funding. It is important that concentrations in biofortified crops don't reach toxic levels and micronutrient concentrations in the diet are well-balanced (e.g. excess Zn can cause Fe deficiency,...). Knowledge needs to be developed tin order to be able to control this (soil contents, soil properties, plant contents, to which extent do plant contents reflect soil contents, which regions are in danger of exceeding limits due to soil contents or high availability in the soil?)
... regulation	Conventional breeding strategies will take much longer until ready for the market than GMO strategies so that strong GMO restrictions are a hindrance, but not prohibitive.
... commercialisation	Countries where micronutrient deficiencies are a serious health problem (primarily staple diets, no meat) don't have much money. These crops could however also be interesting for sustainable agriculture (low-fertilizer use), and micronutrient deficiencies are also widespread in Europe (although there might be other ways such as meat consumption for Fe, seafood for Zn, etc.).
... dissemination	Judging from what's available in supermarkets and pharmacies, people take a lot of supplements as pills. Availability for intestinal absorption, and (compared to biofortification much more serious) issues of potential overdosing and balance between nutrients are important here.
... farmer adoption	I see no problem if there is a market. In addition, there might be yield benefits/reduced fertilizer expenses.
... consumer acceptance	Might be high (see dissemination), depending on information.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	1. Plant molecular physiology/molecular genetics: (international/national): Fundamental molecular and genetic understanding of micronutrient accumulation pathways, their regulation and selectivity in model and crop plants. 2. Crop physiology/genetics: Natural diversity of nutrient accumulation in crops (medium term) and genes/alleles governing it (long term: for use as breeding targets).
Applied research	3. Proof-of-concept 4. Generation of prototypes (GMO) and testing of specific alleles/genes for their effect on crop nutrient accumulation 5. Marker design for conventional breeding.
Knowledge transfer, collaboration etc.	Plant molecular genetics/molecular physiology (international and national level) in basic science and in the interaction of basic and applied science.
Infrastructure & facilities	Plant molecular biology, plant genotyping, plant growth in greenhouse or laboratory (controlled conditions), GMO generation

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	1. Basic science: Improvement of molecular-genetic understanding of plant micronutrient metal homeostasis networks, together with France (CNRS Montpellier, Gif-sur-Yvette), Spain (Univ. Valencia), UK (Univ. Nottingham, Univ. York), the Netherlands (Wageningen), Denmark (Univ. Kopenhagen) or Germany alone (IPK Gatersleben, Univ. Bochum, Bayreuth, Saarbrücken, Freiburg, Heidelberg). 2. Applied science: Screening of natural diversity in micronutrient contents/ accumulation in crops and identification of genes governing them. (Univ. Halle, Bochum, Bayreuth, IPK Gatersleben, Univ. Heidelberg, Univ. Nottingham UK, Univ. Wageningen The Netherlands, Flakkeberg Denmark)

Capacity building	Both above fields and their combination in the future. Germany has extensive germplasm resources for several crops (e.g. barley as a model for cereals, other cereals). These could be supplemented by ICARDA and the Spanish Core Collection. Concerning vegetables, Israel has generated great resources for genetic mapping in tomato, but nobody has looked at micronutrient metals/metalloids so far. Germany has internationally highly competitive groups in micronutrient metal homeostasis (basic science). Extension of current ionomics facilities would be important.
Targeted funding	1. Fundamental research in the model plant Arabidopsis: molecular physiology and molecular genetics of micronutrient accumulation pathways and their regulation; research on metal homeostasis networks including the development of a systems biology approach to metal homeostasis. 2. Natural diversity (ionomics) in crops where Germany has strong germplasm collections and genetics resources (barley, wheat,...); development of mapping populations and identification of genes/markers governing micronutrient concentrations in edible parts under field and a variety of other growth conditions (e.g. deficiencies, increased CO2)

N2 (Name nicht zur Veröffentlichung)

2.) Privacy and use of information

The answer is informal and for information only and should not be attributed to me ☒

Krawinkel M – Universität Gießen – kein Projekt

2.) Privacy and use of information

The essence of the information can be referred to as "personal communication" ☒

Gemeinsame Antwort von acht Experten – IFPRI & CIAT – HarvestPlus

1.) Your professional background

Die Antworten wurde von folgenden acht Experten von HarvestPlus gemeinsam gegeben:

Name	Disciplinary background	Institutional affiliation	Project involved in	Role within the project
Howarth Bouis	Agric. Economics	IFPRI	HarvestPlus	Director
Wolfgang Pfeiffer	Plant Breeding	CIAT		Head of Plant Breeding
Bonnie McClafferty	Communication	IFPRI		Head of Dvpmt & Communication
J.V. Meenakshi	Agric. Economics	IFPRI		Head of Impact & Policy
Erick Boy	Nutrition	IFPRI		Head of Nutrition
Anna Marie Ball	Sociology	IFPRI		Reaching Enduser Project Leader
Harrie Hendrickx	Marketing	CIAT		Head of Product Delivery
Joe Tohme	Genomics	CIAT		Head of Biotechnology

Nutrient(s) you are working on	Iron, Zinc, provitamin A
Crop(s) you are working on	Rice, wheat, maize, beans, pearl millet, cassava, sweet potato

Approaches you are using	Conventional breeding primarily. Five percent of our funding is devoted to transgenic approaches for iron biofortification in mega staples where conventional approaches are not technically feasible.

2.) Privacy and use of information

My answer can be printed in the annex of the report	**Y**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	**Y**
Genetic engineering for higher micronutrient content in crops	**Y**
Introduction of different crop varieties with higher micronutrient content	**See below**
Optimisation of fertiliser use for higher micronutrient content in crops	**Y**
Efforts to increase the amount or quality of *macro*nutrients in crops	**Y**
Other def.	Adaptation of different crop varieties with higher micronutrient content

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	• Cross-disciplinary collaboration (e.g. between ag. and nutrition scientists) is required. • Laboratory capacity and the availability of industry standard equipment to analyse blood samples and measure bioavailability are often lacking in target countries requiring biofortified crop samples to be shipped out of the region and potentially compromising the results of the analysis. • Local agricultural research partners must have the capacity to do the adaptive breeding and GXE work. • To be successful, biofortified crops must be breed into highly productive genotypes. Institutional barriers that do not foster integration of biofortification with on going projects for productivity traits such as drought tolerant, nitrogen use efficiency and pest and disease will hamper product adoption.
... development	Biofortification must be considered an institutional precondition for all crop improvement research and varietal release programs (just as yield, disease resistance, etc) in order to maximize its impact on public health.
... regulation	Since the current wave of conventionally bred biofortified HarvestPlus crops do not require regulatory approval this restriction does not apply. For future potential transgenic approaches, the testing will be limited to countries with well established biosafety regulations. Cost of deregulation need to be considered. Currently the cost of deregulation is quite variable and depends on the countries.
... comercialisation	• Where commercial seed industry is viable restrictions revolve around labelling and regulating seed as “biofortified” and keeping the profit margin low enough to ensure uptake by the poor and undernourished. • Where commercial entities are not available, developing private partners that will focus for the common good will prove challenging. • Commercialization of transgenic genotypes will require freedom to operate for certain technology.

... dissemination	• Risk aversion by poor farmers will minimize uptake without effective strategies for engaging innovative farmers. • When certified seed supply can not keep up with demand. • When consumption and production are predominantly subsistence and low income dictates the desire to retain own seed for successive plantings. • Working with local stakeholders (seed industry, extension agencies, Ministries of Agriculture, ...) is essential to build a sustainable and locally owned source of quality biofortified seed material. However, in many cases the local partners are weak and able to fulfil their role without external support.
... farmer adoption	• Effective, targeted and coherent communication in a country is essential. This requires that stakeholders work together for a common goal, which is not always easy to achieve. • Farmers as consumers may be resistant to visible changes in color. • Biofortified varieties must be at least as profitable, and preferably more profitable, than current popular varieties. • Farmers and consumers may be reticent to take on transgenically derived crops if the market is sensitive to their introduction.
... consumer acceptance	• From our experience invisible traits (iron and Zinc) have no consumer acceptance issues; and even coloured products may be perceived and accepted as having an additional value (nutritional) when some consumer education is provided. • Local support and local capacity are essential for sustainable changes in the agric sector. This is not always available and developing capacity not always turns out to be sustainable either. • The extent to which the target undernourished populations rely on subsistence farming, own production and own seed acquisition rather than purchasing food and seed, poses a serious challenge to broad uptake and dissemination. • Government support of cash crops leads to a neglect of attention to food security crops.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	• Agriculture, International: The potential of breeding to increase nutritional value of crops has only just been discovered – more research is needed i.e. marker assisted breeding. • Agriculture, International: Transgenic approaches to biofortification offer great promise for delivering multiple bioavailable nutrients in rich doses. • Nutrition. International. Nutrition research on inhibitors and promoters of nutrient absorption and bioavailability holds promise for improving the absorbability of nutrients from biofortified staple crops. • Public Policy. International and country. Understanding where nutrition and agriculture can most effectively leverage each others strengths to make agriculture an instrument for public health.
Applied research	• Product development, in collaboration with the private sector, is an area which still has to come to development. At this moment, potential is hard to estimate. • Gene by environment trail of varieties that have reached nutritional target levels: not enough land or other resources (including NARES commitment) to speed up the process in country.
Knowledge transfer, collaboration etc.	Advocacy is very important in producing ownership of the technology at the proper places in target countries. If biofortification is transferred as an agri-health intervention, coordination between Ministries in imperative. Higher or comparable agronomic yields are also an imperative

Physical infrastructure & facilities	NARES need to develop the scientific capacity and facilities to screening farmer preferred local and newly developed varieties for nutrient concentration during the development of all lines to be released to farmers.
Institutions, legislation & politics	• Government support is key to success. From there, institutional capacity of NARS, extension and certification needs to be built. • At the target country level transgenic biofortified products present a host of legislative complications not applicable to conventionally bred biofortified crops. These barriers might be quickly overcome.
Other	Delivery: An area missing. In the past, many improved varieties of crops have been produced, but most of them never reached the farmer nor the plate of consumers. Delivery of products needs further investment including seed system development, development of viable marketing strategies, and attention to consumer acceptance. This part of the work needs to get more attention and be seen at least equal in importance to crop development.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	• The health sector and the agriculture sector need to be encouraged to join forces. Germany can serve as a catalyst to this process. • German institutions such as the University of Freiburg and the Max-Planck Institute have a lot to offer in the areas of nutritional genomics for the identification and understanding of the molecular and biochemical mechanisms of genes related to the1) increase of level of iron, zinc; 2) synthesis of provitamin A and to degradation of beta carotene. The outcomes of the work will lead to precise techniques and application of marker assisted breeding or to provide candidate genes for transgenic applications. • Metabolomics is another area of collaboration where German Institutions are world leader.
Capacity building	Food and human biological samples analysis of plant breed and human trials need to be supported in target countries.
Targeted funding	Germany has a great potential to contribute at the local level because of their physical presence and knowledge of the agric sector in many countries. That expertise could be focussed more on this issue of food quality not just quantity.
Political support	• Germany can put biofortification on the agenda for those who work in the field of fighting micronutrient deficiency as a valuable, sustainable and cost effective additional method to reach large numbers of people. Especially for those who are most vulnerable: women and children in a rural subsistence situation. • Success will depend on bringing together disciplines in the developed and developing world, UN and international organizations and members of the NGO community. Germany could be a catalyst for multi-sector approaches for ending malnutrition through improved staple crops. • Recognizing biofortification can be performed using conventional and transgenic techniques and that transgenic technology offers one of modern agricultural sciences most powerful tools, Germany can take the lead in Europe by supporting modern agricultural science to assist the poor and undernourished who are most affected by food availability and prices fluctuations and who will experience the greatest shock from the environmental challenges brought on by climate change. Germany can foster the safe and responsible development of publicly accessible transgenic crops for humanity that are particularly suited for areas with large concentrations of poverty. This will include the creation of a policy environment rooted in evidence-based decision making and not opposing imports and trade of transgenic technologies, crops and foods that would benefit low income farmers and consumers.

Markert B – keine Zugehörigkeit – COST 859

2.) Privacy and use of information

The essence of the information can be referred to as "personal communication"	**xx**

Clemens S – Universität Bayreuth – PHIME

1.) Your professional background

Your name	Stephan Clemens
Training or academic background	Professor Plant Physiology
Your affiliation	University of Bayreuth
The biofort. project you are involved in	PHIME, EU Integrated Project, www.phime.org
Your role within the project	Coordinator of project part on micronutrient content in barley
Nutrient(s) you are working on	Zn, Fe (and Cd as an “anti-nutrient”)
Crop(s) you are working on	Barley
Approaches you are using	Conventional and GM

2.) Privacy and use of information

My answer can be printed in the annex of the report	**Yes**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	**x**
Genetic engineering for higher micronutrient content in crops	**x**
Introduction of different crop varieties with higher micronutrient content	**x**
Optimisation of fertiliser use for higher micronutrient content in crops	**x**

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	We still lack molecular understanding of the mechanisms controlling micronutrient content of edible plant parts.
... develop-ment	Classical breeding is hampered by lack of suitable molecular markers (see above) and reliable, inexpensive, high-throughput assays to evaluate micronutrient content. This applies in particular to bioavailable content.
... regulation	A major problem is our inability in Europe to test transgenic plants in the field. This is a very serious drawback that is currently underestimated by policy makers. In fact, I notice a complete lack of awareness.
... comer-cialisation	The market is not yet developed, products are not fully developed yet (see above)
... dissemi-nation	As indicated above we have a problem communicating any scientific aspect of agriculture because the entirely irrational debate about GM food always gets in the way.
... farmer adoption	There is very little to adopt yet since a lot of basic research needs to be done first.
... consumer acceptance	See dissemination.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	This is by far the most important area. Without understanding the mechanisms governing bioavailable micronutrient content in crops there is not much we can do except including micronutrient-rich varieties in breeding programs. However, this is extremely tedious.
Applied research	Easy and inexpensive assay systems for bioavailable micronutrient need to be developed as a prerequisite for breeding efforts.
Knowledge transfer, collaboration etc.	Such assays plus simple diagnostics for micronutrient deficiency in humans and farm animals need to be implemented, preferably embedded in international collaborations.
Institutions, legislation & politics	We have a general problem of not being able to pursue a rational dialogue on scientific issues related to food security and food quality. This is in part caused by ridiculous legislation and politics (see GM food).

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	Funding basic research on mechanisms could be by far the biggest contribution with the highest impact.
Polit. support	Put the urgent need for plant breeding aided by molecular biology on the agenda!

Beebe S – CIAT – HarvestPlus

1.) Your professional background

Your name	Stephen Beebe
Training or academic background	Plant breeding
Your affiliation	CIAT
The biofort. project you are involved in	HarvestPlus; AgroSalud
Your role within the project	Plant breeder and bean component coordinator
Nutrient(s) you are working on	Iron, Zinc
Crop(s) you are working on	Beans (*Phaseolus vulgaris* L)
Approaches you are using	Conventional breeding including both intra-specific (inter-gene pool) crosses and interspecific crosses to exploit naturally occurring genetic diversity.

2.) Privacy and use of information

My answer can be printed in the annex of the report	**Yes**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	**Yes**
Genetic engineering for higher micronutrient content in crops	**Yes**
Optimisation of fertiliser use for higher micronutrient content in crops	**Yes**
Efforts to increase the amount or quality of *macro*nutrients in crops	**Yes**

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	• Effective biofortification requires collaboration among nutritionists, plant scientists, and possibly soil scientists. However, these scientists (especially nutritionists and scientists in crop production) are normally in different institutions and respond to different administrative and funding structures. • While national research programs have the experience in adaptive research, national programs have been weakened by poor budgets and loss of personnel. This is a problem that applies to all aspects of genetic improvement, not just biofortification. • Laboratory capacity for analysis of samples is often limited in developing countries. This implies that samples must be shipped to other locations – a procedure that is sometimes limited by quarantine regulations.
... development	The biggest challenge to attaining development goals of health is to assure that biofortified crops represent a significant portion of food consumption to impact on health. This challenge needs to be met with an education component to inform consumers of the benefits of biofortification, but to date our clients seem to be extremely receptive to this message.
... regulation	• Depending on the country, a new variety might be expected to out-yield a current variety by a certain percentage. HOWEVER, to date the regulatory agencies have considered biofortified crops to be in a class of their own, and release of a new variety has not been conditioned on competition with existing varieties on the basis of yield. That is, higher nutritional value has been considered sufficient justification. • Seed regulations limit who can produce and sell “seed”, demanding that this be formally certified. This process typically has made seed too costly for small farmers. As a result farmers continue to use self-saved seed. HOWEVER, this challenge is being addressed with the private sector to package and market certified seed in small inexpensive packages of 200-500 grams, that small farmers can purchase.
... comercialisation	Our primary target is a rural population where home consumption is prevalent. However, where commercialization serves a resource-poor urban population, maintaining product identity (or avoiding mixture with non-biofortified products) will be a challenge. In this regard some specific market chains linking producers to particular groups of consumers (eg, school lunch programs) may be needed. We think that this is feasible.
... dissemination	• We originally thought that dissemination (and adoption) would be especially difficult, given that our audience is often the most remote and resource-poor. However, the demand for biofortified products has actually outstripped supply. We have found partners in all sectors (public officials at several levels; NGO’s; farmer groups) anxious to test biofortified crops. • The limitations of biofortified crops are much the same as for “standard” crops: production of seed, especially in the gap between research and large scale dissemination (ie, foundation seed). These issues are being addressed in the case of beans, by PABRA – the Pan-African Bean Research Alliance, a CIAT-administered research network that coordinates research among 24 countries in East, West and southern Africa). PABRA has facilitated communication between suppliers and demanders of seed, to assure the flow of seed to users. • In Latin America there is less experience with non-conventional institutional arrangements for seed dissemination, but great potential exists, esp. by linking the public sector to NGOs.
... farmer adoption	• Biofortified crops should equal or (preferably) out-yield current varieties to facilitate adoption by farmers. Similarly, biofortified varieties must meet culinary standards. This implies an extra challenge to breeders. HOWEVER, interest in the health effects of biofortified crops by national programs, NGO’s **and farmers** has been such that adoption seems not to be as big a barrier as we once thought.

... consumer acceptance	• To date we have two experiences of testing biofortified beans with consumer panels. While these studies dealt with intermediate products with levels of iron that were still below the goal levels, consumers found the biofortified beans to be totally acceptable compared to the local check. • In our own tests among bean research staff of a high iron bean with iron at goal levels, we found the bean to cook quickly, and to be especially delicious. • We thus have seen no evidence whatsoever that high iron beans have problems with consumer acceptance.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	• We still do not have an understanding of iron and zinc nutrition within the PLANT of high mineral genotypes, and ways that this could be manipulated. Nor do we understand related issues of GxE [genotype vs. environment] and the way the plant responds to the environment. (Our work to date has been totally empirical.) Support in plant nutrition would be welcome. • In the area of human nutrition, some effort on uptake promoters (substances that facilitate uptake of minerals in the gut) could also be useful. For example, in Africa bean leaves are often consumed as spinach, and elements in the leaves may affect uptake.
Applied research	Again, more studies of GxE in the field in coordination with more basic research on plant nutrition.
Knowledge transfer, collaboration & coordination	Latin America can play a particular role, considering that it has: 1) well developed research structures in both nutrition and agriculture. The nutrition community has a public health outlook that is often lacking in Europe and the USA; 2) potential to explore processing of biofortified crops with the private sector; and 3) both under-nutrition and over-nutrition. Latin America can serve to develop an integrated model on a national level for a coherent relationship of human nutrition and agriculture.
Physical infrastructure & facilities	Some national programs need improved analytical facilities, but these would best be developed as regional facilities, given the need for specialized training of personnel, and delicate conditions for operations and upkeep (e.g., stable electrical current).
Institutions, legislation & politics	At least 4 countries in Latin America have national nutrition policies that recognize biofortification as a viable component of a micronutrient strategy. More information needs to be shared with national policy makers to increase the number of countries that incorporate biofortification into their official agenda.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	• German institutions could give support in genomics and metabolomics of nutritional components. • German institutions also have world level expertise in plant nutrition, and this could be focused on biofortification, defining factors of mineral uptake, GxE, and mineral remobilization to and storage within the grain.
Capacity building	• National programs have almost no capacity in plant nutrition. Degree training would be useful if done at a practical level, and less at a molecular level since infrastructure for molecular work is often limiting upon return the national program. • There are also far too few human nutritionists in Africa. HOWEVER, training should be in the context of public health, and not in clinical nutrition as often is the approach in developed countries.
Targeted funding	• Support to a Latin American regional network would facilitate exploiting the potential cited above.

	• Support to PhD students in the fields cited above. Universities may or may not be in developed countries • Several key countries such as Burundi, Ethiopia and Haiti have had limited participation to date, and should be brought on board. Future support to countries with documented nutritional problems (e.g., Bolivia, Guatemala, Honduras, Kenya, Malawi, Nicaragua) needs to be raised to bring to fruition current work. • Some diagnostic work to target future interventions may also be useful, for example, in areas of West Africa where bean is the preferred grain legume and relatively little is known about its consumption patterns.
Political support	• As noted above, several countries already have incorporated biofortification into national nutrition policies. This should be promoted. • In Latin America and East Africa, local and regional functionaries of the World Food Program have accepted and/or promoted biofortification as part of a micronutrient strategy. This could be carried to a higher level.

Dubock A – Syngenta (ehemalig) – Golden Rice

1.) Your professional background

Your name	Adrian Dubock
Training or academic background	BSc, PhD. (Vertebrate Zoology), 2 years Ministry of Agriculture (UK) experience as scientist, 30 years industrial experience for ICI/Zeneca/Syngenta in business development and business strategy and operational roles. Specialist in IP licensing, Mergers and Acquisitions, biotechnology collaboration structuring & negotiation, product development, marketing, product portfolio management, general management. Has worked in excess of 85 countries.
Your affiliation	Since end 2007 retirement from Syngenta, independent consultant, (adrian@dubock.eu) contracted to University of Freiburg. Founder & Member of Humanitarian Board for Golden Rice. Steering Group Member for Protein, Vitamin and Mineral rice Consortium (PVMRC) Project.
The biofort. project you are involved in	Golden Rice Project & PVMRC Project
Your role within the project	I am Project manager for both of the above projects
Nutrient(s) you are working on	Pro-vitamin A, high protein, iron, zinc and Vitamin E (to stabilise pro-vitamin A)
Crop(s) you are working on	Rice, with involvement also with banana, sorghum, cassava
Approaches you are using	GM + conventional breeding + marketing research + communications development + seed system development and enabling environment creation all for positive product adoption to combat VAD and other micronutrient and macronutrient deficiencies.
Additional info	For research to be effective, products must be introduced! For a nutritional traits product, normal farmer introduction methods for economically-advantageous-to-the-grower products will be insufficient, and for visible traits behaviour change at both the grower and consumer levels are essential. The skills to accomplish this are not conventionally included in technical training nor both private sector or public sector research establishments. They are however available from the private sector, although technically trained people from the

private or the public sector usually have trouble recognising what they don’t know and therefore selecting appropriate assistance.

2.) Privacy and use of information

My answer can be printed in the annex of the report **Yes**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	√
Genetic engineering for higher micronutrient content in crops	√
Introduction of different crop varieties with higher micronutrient content	√
Efforts to increase the amount or quality of *macro*nutrients in crops	√

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	Traits which are novel in the wild type of a crop may only be introduced (if possible at all) by genetic modification. Funding for GMO crop research is extremely difficult to obtain. Practically impossible in Europe, FOR SOLELY POLITICAL REASONS. Golden Rice is a good example.
... development	1. Scientists reward structures are too inflexible. Use of publication as a measure of success ensures that only novel work is funded, as only that is published in peer reviewed journals. What value to society is only novelty, unless some of the novelty is developed for use by society as products? Some scientists need to be also rewarded for the patient research which is necessary for product delivery. Some of this is not novel, and may be very time consuming (as a result of politics) This is hugely valuable, and essential for an economic return on investment, and ways need to be found to recognise the worth or those involved, and ensure their funding and advancement does not suffer. 2. The development processes for GMOs are more complex and time consuming and costly than scientifically necessary, due the regulatory and political dimensions of GMO crops. 3. For GMO crops development is scalable and easily accommodated within existing developing country capabilities. Product development in developing countries should be embraced by collaboration. (GMO research should also be encouraged in developing countries, and experience shows with a little investment in capacity and infrastructure can be successful. But the basic research capability is harder to attain than the development capability.) 4. Politicians often overlook the long lasting, cheap, positive political & cultural influence which can be obtained by funding, for example a studentship programme for individuals from developing countries in developed countries, especially as part of an ongoing programme which also involves them in worthwhile projects on their return to their country of origin. Such students are always friends of the funding countries in the future, and build & maintain understanding between cultures.
... regulation	Regulation process for GMOs is in most countries adversely affected by politics. Independent scientific institutions globally, including the EU, have adjudged that there is NO EVIDENCE of any harm to man or the environment from GMO crops. (Ref Dubock 2009, Nutritional Reviews)
... comercialisation	Lack of recognition by funding agencies of the need to fund this activity, and lack of skills in the public sector additionally hamper progress
... dissemination	Lack of recognition by funding agencies of the need to fund this activity, and lack of skills in the public sector additionally hamper progress
... farmer adoption	Lack of recognition by funding agencies of the need to fund this activity, (different from consumer and agronomic traits) and lack of skills in the public sector additionally hamper progress

... consumer acceptance	Lack of recognition by funding agencies of the need to fund this activity, and lack of skills in the public sector additionally hamper progress
Other	Politics!!! Especially European!!! Particularly Germany. These negative GMO attitudes deny poor people sustainable low cost life saving solutions not available by other means. The negative attitudes have become so engrained as “received wisdom” which has not earlier been politically counteracted that a positive and sustained campaign is now necessary to reverse the incorrect perceptions.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	GMO funding, in country and international
Applied research	GMO funding, in country and international
Knowledge transfer, collaboration etc.	Establish studentship programme for PhD’s in Germany, within a programme which continues for a while on return, probably with prior agreement with the developing country to match funds on return and take on full funding for a period. Eg a sustainable programmatic funding.
Physical infrastructure & facilities	For as long a regulatory demands necessitate, developing countries will need screen houses for practical seed breeding involving GMO crops. Very small funds will assist. (Developing countries networks and infrastructure for conventional seed breeding are generally adequate.)
Institutions, legislation & politics	Have Germany follow the advice of the EU Scientific panel that there is no scientific reason to mitigate against GMO crops. The technique is another tool in the toolbox and should be embraced where useful. Politicians should promote all agricultural technologies available to increase food quality and quantity. In particular politicians should through specific directed funding to GMO crop projects try to undo the damage their attitudes over the past decade has done to research, research institutions and research scientists in Germany, and to poor people. Undoubtedly, GMO crop technology is here to stay in the world. Undoubtedly Europe will also be forced to accept the technology. GMO technology is already widely accepted in pharmaceutical applications. The faster this adoption in Europe occurs the less damaging it will be to future competitiveness. European attitudes thus far have impacted mostly developing countries. But the attitudes have already impacted European agricultural and scientific competitiveness, with a technology where Europe was, and especially Germany in the case of biofortification is, a global leader.
Other	There is scope for, and need for, political leadership to LEAD Europe out of a situation largely created by over belief in advocacy NGO’s ideological arguments. The EU must stop funding such lobbying by advocacy NGOs with taxpayers' money.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	Funding research at University of Freiburg (PI Prof Peter Beyer, co-inventor of Golden Rice) and collaborator institutions in USA and Asia especially, as well as Africa, for additional biofortification efforts especially in rice, including stabilisation of carotenoids, increasing uptake of iron, (increasing mental capacity of children during development and stacking with folate traits to reduce neural tube defects at birth.
Capacity building	Continuing to provide world class leading support of Prof Beyer’s team to global biofortification projects of all types.
Targeted funding	Funding the introduction of the Golden Rice Humanitarian Board to guide the strategy for product introduction of the product in the next 5 years, and contribute to reducing 6000 deaths a day from Vitamin A Deficiency, and three of the Millennium Development Goals.

Political support	1. Providing political leadership to acceptance of all technologies for food production, including GMO technology, in line with very broad scientific establishment consensus internationally & globally. 2. Dismantling the erroneous over regulation of GMOs, and insisting on this internationally. 3. As soon as practical cease, differentiating between GMO and other techniques used in crop breeding and production – it is the product which is important and its properties, not the method of production. 4. Supporting the new Codex Alimentarius process whereby each country accepts the reasonable regulatory clearances of another for GMO crops which may (in any amount, or at least) with respect to small amounts, enter the food chain, to enable international trade. 5. Funding jobs, including but not limited to academic jobs, in plant biotechnology in Germany so that students interested in studying the related subjects have career opportunities and Germany, and Europe, loses no further competitive advantage in one of the most useful and cheap technologies of the past 50 years.

Cahoon EB – University of Nebraska-Lincoln – BioCassava Plus

1.) Your professional background

Your name	Edgar B. Cahoon
Training or academic background	Ph.D., Plant Biochemistry and Molecular Biology, Michigan State University
Your affiliation	Associate Professor, University of Nebraska-Lincoln
The biofort. project you are involved in	Provitamin A biofortification of cassava in support of the BioCassava Plus program funded by the Gates Foundation
Your role within the project	Project leader
Nutrient(s) you are working on	Provitamin A or beta-carotene
Crop(s) you are working on	Cassava
Approaches you are using	GM
Additional info	We have had success with engineering the trait in the lab and are now conducting field trials in Puerto Rico.

2.) Privacy and use of information

My answer can be printed in the annex of the report	**Yes**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	X
Genetic engineering for higher micronutrient content in crops	X
Efforts to increase the amount or quality of *macro*nutrients in crops	X

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... development	Often there is little public sector money to translate potential breakthroughs in model plants such as Arabidopsis into crop plants.

... regulation	The regulatory process in the U.S. for GM products is extremely expensive and limits the number of traits that will ever be commercialized. The costs also limit who can apply for regulatory approval. Large corporations can file for regulatory approval of new traits, but small companies and universities are largely not able to pursue regulatory approval of new GM traits. In some developing countries, regulatory agencies may not exist or do not have policy developed for approval of GM crops.
... comercialisation	It is not always clear that consumers are willing to pay the extra costs (higher prices) associated with the commercialization of a nutrient-enhanced GM product.
... farmer adoption	Engineering of biofortification traits needs to be done in farmer preferred varieties and cannot impact yield. Yield is the most important thing to a farmer.
<u>Other</u>	Intellectual property restrictions on the use of certain technologies have the potential to block the development of traits that would benefit small farmers in developing countries.

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Applied research	More funding for translation of findings from model plants to crop plants would speed up the development of biofortification traits.
Institutions, legislation & politics	The government needs to maintain high standards for ensuring that new traits do not negatively impact the safety and health of consumers. Yet, at the same time, regulatory requirements need to be rational and based on good science.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

International collaborations	It is always best to build partnerships with the leading biotechnologists in developing countries. It is best to let the people of developing countries take ownership for new traits for their markets.
Capacity building	Educational exchanges are good. Students and young scientists from developing countries can come to Germany, and student and young scientists can visit and train in developing countries.
Political support	Stop anti-GM rhetoric within the government. Educate the citizenry and farmers about the benefits of biotechnology.
<u>Other</u>	If Europe shows such hesitancy to adopt GM technology for their own market place, what message does this send to developing countries? If Europe really wants to help the developing world through the use of biotechnology, then they need to fully accept its value for European consumers. Otherwise this talk is all hypocritical.

Rai KN – ICRISAT – HarvestPlus

1.) Your professional background

Your name	Kedar Nath Rai
Training or academic background	Ph.D. in Genetics from the University of California, Davis, USA; and 32 years of research experience in pearl millet improvement at ICRISAT, especially hybrid parents development
Your affiliation	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India
The biofort. project you are involved in	HarvestPlus Biofortification research program of pearl millet for the last five years; and now the additional responsibility since October 2009 of Director, HarvestPlus-India Biofortification Program

Your role within the project	Lead the pearl millet project, including partnership building, to develop pearl millet hybrid parents with high iron and zinc content; and as Director, coordinate HP and Department of Biotechnology (Government of India) biofortification projects in India on several crops. ssva.
Nutrient(s) you are working on	Iron and Zinc
Crop(s) you are working on	As a breeder, pearl millet; as a director, coordination of research on several crops.
Approaches you are using	Mostly conventional, and very little of marker-assisted breeding.
Additional info	The entire pearl millet research done in partnership with the NARS and private seed companies through a consortium approach

2.) Privacy and use of information

My answer can be printed in the annex of the report	X

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	X
Genetic engineering for higher micronutrient content in crops	X

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	(i) Limited availability of a rapid screening technology for evaluation of breeding lines, and (ii) greater dependence on NARS and the private seed companies to provide test locations for the field evaluation of breeding lines and intermediate products developed for high iron content.
... development	None in India as the seed production and marketing for pearl millet hybrids is well developed.
... regulation	Varieties with high iron content are yet to be incorporated as an important trait in variety release policy.
... comercialisation	Pearl millet flour has a short (7-10 days) shelf life, though laboratory technologies for enhancing the shelf life up to a month have been developed, but not adopted on commercial scale.
... dissemination	The value of pearl millet as a highly nutritious cereal has not been well publicized.
... farmer adoption	Farmer should be paid premium price for the biofortified grains to compensate for any lower yield of biofortified cultivars as breeding for one additional nutrient trait leads to natural genetic slippage (as for any other additional trait(s)
... consumer acceptance	High iron grains will be no different in taste and appearance than those with low iron

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Basic research	Priority 2: development of more cost effective analytical tools for rapid mineral analysis.
Applied research	Priority 1: Applied breeding research at an international center, with focus on a country with largest crop area.
Infrastructure & facilities	Priority 2: Strengthening the existing facilities (and developing new facilities as the case may be) for rapid and cost-effective analysis of grain samples.

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

Capacity building	Priority 2: Capacity building in pearl millet breeding and laboratory mineral analysis for Western Africa
Targeted funding	Priority 1: Applied pearl millet breeding at ICRISAT, targeted both to the Asia region (with India as the largest l millet producer in the world, and considerable malnutrition), and Africa (Niger and Nigeria having the largest area in Africa)

Barry G – International Rice Research Institute – Golden Rice

2.) Privacy and use of information

The essence of the information can be referred to as "personal communication"	x

Broadley M – University of Nottingham – verschiedene Projekte

1.) Your professional background

Your name	Martin Broadley
Training or academic background	PhD (1997)
Your affiliation	University of Nottingham, UK
The biofort. project you are involved in	1. Selenium biofortification of UK wheat (2005-2009). Funder: Department of Environment, Food, and Rural Affairs, UK (plus industry contribution from across food chain) 2. Biofortifying Brassica with calcium and magnesium (2009-2013). Biotechnology and Biological Sciences Research Council, UK (plus industry contribution) 3. Biofortifying Malawi maize with selenium (2008-2011). Yara GmbH and University of Nottingham. 4. Various PhD studentships (3)
Your role within the project	Lead PI/supervisor
Nutrient(s) you are working on	Se, Ca, Mg, (and Zn to lesser extent)
Crop(s) you are working on	Wheat, maize, Brassica
Approaches you are using	1. Attempting marker-assisted breeding in wheat and Brassica 2. Agronomic biofortification using fertilisers

2.) Privacy and use of information

My answer can be printed in the annex of the report	**YES**
The essence of the information can be referred to as "personal communication"	**YES**

3.) Definition of "biofortification"

Conventional breeding for higher micronutrient content in crops	**YES**
Genetic engineering for higher micronutrient content in crops	**YES**
Introduction of different crop varieties with higher micronutrient content	**YES**
Optimisation of fertiliser use for higher micronutrient content in crops	**YES**
Efforts to increase the amount or quality of macronutrients in crops	**YES**

4.) In your work, where do you see specific restrictions that hamper biofortification efforts? For instance, what are barriers and restrictions in...

... research	General lack of funding for ‘applied’ R&D. Interdisciplinary research can be challenging to manage/deliver. Long-term ‘public-good’ breeding R&D is difficult with short-term grants
... development	(1) challenging to monitor health impacts of biofortification , (2) lack of clear commercial exploitation routes for industry
... regulation	Some essential elements (Zn, Se) can be toxic at high levels
... commercialisation	Lack of clear commercial exploitation routes
... farmer adoption	Requiring more expensive fertilisers (?)
... consumer acceptance	GM issues, fear of “mass medication”, mixed messages of health benefits in the press

5.) In which fields do you see the biggest potential for providing support to biofortification efforts or for facilitating its implementation? What kind of support?

Other	All of above. Support for biofortification should come within a general umbrella of food security R&D requirements ("nutritional security"), as described in Royal Society report. This requires capacity and infrastructure at all levels (http://royalsociety.org/Reapingthebenefits/).

6.) Where do you see the biggest potential contribution of Germany (and Europe)?

Other	The potential contributions of the UK/European biological sciences community to food security is summarised clearly as 12 recommendations in recent Royal Society report. Specific details on biofortification are in Section 3.3.6 of this report (http://royalsociety.org/Reapingthebenefits/).

Welch RM – Cornell University & USDA/ARS – HarvestPlus

2.) Privacy and use of information

The essence of the information can be referred to as "personal communication"	x

Strategien zur Behebung von Mikronährstoffdefiziten:

Wie gut sind neue Ansätze der Pflanzenzüchtung im Vergleich und was sind die Hürden für eine erfolgreiche Umsetzung?

Neben direktem Hunger stellt der Mangel lebenswichtiger Vitamine und Mineralstoffe weltweit das größte Gesundheitsrisiko dar, das zu menschlichem Leiden bei den Betroffenen, wie auch zu erheblichen gesamtwirtschaftlichen Wohlfahrtsverlusten führt.

Da sich das Ideal einer ausreichenden und ausgewogenen Ernährung aller selbst mittelfristig kaum erreichen lassen dürfte, werden bisher Maßnahmen wie die Verteilung pharmazeutischer Ergänzungspräparate, die industrielle Anreicherung von Lebensmitteln oder Ernährungsaufklärung mit dem Ziel einer Verhaltensänderung durchgeführt.

Ein neuer Ansatz, die "biologische Anreicherung", ergänzt dieses Instrumentarium in sinnvoller Weise und verspricht zudem, eine äußerst kostengünstige Maßnahme darzustellen. Unter biologischer Anreicherung wird vor allem die Züchtung von Pflanzen mit hohem Mikronährstoffgehalt verstanden.

Aufbauend auf eine umfassende Literaturübersicht und die Auswertung einer Expertenbefragung werden in diesem Gutachten die noch offenen Forschungsfragen sowie die für eine erfolgreiche Einführung biologisch angereicherter Pflanzen (BAP) aus dem Weg zu räumenden Hindernisse identifiziert. Selbst wenn dies nur einen Teil der BAP betrifft, so wird ebenfalls die Wichtigkeit einer rationalen Auseinandersetzung mit dem Einsatz der Gentechnik auch in der Landwirtschaft hervorgehoben. Das Gutachten schließt mit kurzen, allgemeinen Handlungsempfehlungen.

Alexander J. Stein
Matin Qaim

Dezember 2009

Gutachten für das
Büro für Technikfolgen-Abschätzung,
Berlin

TA-Projekt »Welchen Beitrag kann die Forschung zur Lösung des Welternährungsproblems leisten?«