

Plant Science For Global Challenges:

Integration of Nutritional Security, Food Security, and Health



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Executive Summary

Malnutrition is a major global problem resulting in massive social and economic costs. Impacts on humans include increased mortality, impaired learning, and greater susceptibility to disease and infection, with consequential economic and societal impacts. In transition countries malnutrition underlies much of the increasing incidence of obesity and associated chronic diseases including cancer, type II diabetes and cardiovascular diseases.

In July 2014 the Global Plant Council (GPC) brought together key stakeholders in Xiamen, China, to discuss and outline a strategic plan that would help to coordinate and advance global plant-based endeavors to reduce global malnutrition and improve human health.

Those present at the forum developed 10 recommendations that they believe are required for the development and deployment of high-yielding, healthy crops and foods.



Recommendations

1. Embed plant-based solutions for nutritional deficiencies into the normal process of plant research and breeding to generate locally adapted, high-yielding crop cultivars.
2. Bring other important nutritional and health factors into specific and relevant breeding programs, while recognizing that iron, zinc and vitamin A remain priority research targets.
3. Promote diversity, and develop and integrate programs on local crops, fruits, vegetables and forage, as well as research to improve major staple crops.
4. Facilitate international coordination and assessment of research and funding in this area.
5. Promote exchange of knowledge, resources, protocols and best practice via an online portal to support information flow and prevent duplication of effort.
6. Work with and establish key global networks and initiatives to enhance global coordination, capacity and training, standardization of approaches, and adoption of new technologies to facilitate research and breeding.
7. Facilitate greater collaboration between plant and agricultural scientists, food scientists, nutritionists, biomedical scientists, and clinicians.
8. Recognize that planning, implementation and delivery requires active engagement with social scientists, policy makers, community advocates and, the food industry.
9. Help to build and implement vertically integrated programs that address key nutritional needs for vulnerable communities.
10. Promote the use of all relevant technologies to develop global plant-based endeavors aimed at reducing global malnutrition and improving human health.



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Introduction

In 1996 the World Food Summit defined food security as existing “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”. Although good progress has been made towards reducing world hunger through initiatives such as the Millennium Development Goals, the number of people who are still under and malnourished today remains disturbingly high. It has been recently estimated that 868 million people (which represents 12.5% of the global population) do not have enough food to eat for their minimum dietary energy requirements, while 2 billion people suffer from one or more micronutrient deficiencies. With the increase in global population and the envisioned negative impact of climate changes on global crop yields and quality, the number of people suffering from a lack of food and key nutrients will increase. At the same time 1.4 billion people are overweight, and 500 million of these are obese. This is triggering new public health epidemics worldwide, including more people suffering from chronic conditions. Indeed, when asked to address 10 great global challenges, a panel of economic experts ranked micronutrient supplementation as number 1 (Copenhagen Consensus 2008). This ranking is perhaps not surprising considering that the term ‘vitamin’ refers to organic molecules that are essential for the human diet. Dietary deficiencies in vitamins, micronutrients, minerals, and amino acids result in increased mortality, impaired health, lower IQs, obesity, and increased susceptibility to diseases such as cancers, diabetes, and heart attacks – all of which have massive social and economic impacts. As a result of these wide-ranging implications on human health, this area of nutritional security has been gaining in importance in many spheres, as illustrated by the International Conference on Global Nutrition held in Rome in 2014, and the subsequent Rome Declaration on Nutrition.

On the 5th and 6th July 2014, 30 scientists, economists and social scientists representing 25 organizations from 11 countries from Africa, Asia, Europe, Oceania, and the Americas, gathered in Xiamen at the invitation of the

Global Plant Council (GPC). The forum provided a unique opportunity for experts from plant, crop and nutritional sciences, as well representatives from foundations and NGOs, to come together. The recommendations for stakeholders in nutritional security research, development and delivery sectors were developed after these discussions, and consideration of the following questions:

- What are the biggest nutritional challenges facing humanity?
- What projects are currently being undertaken across the globe?
- What are the major successes and impacts of these projects?
- What areas are not currently being covered?
- Are there new or more effective strategies?
- How can we best ensure that social issues are included in future projects?
- How can we better coordinate the efforts of different programs and funding agencies?

In this report we define nutritional security as ‘improving the nutritional value of crops and foods towards improving human health’. Biofortification describes strategies to target the levels of nutrients in the crop, distinguishing them from postharvest fortification or supplementation programs, which are not considered here. Implicit in this report is an understanding that food security is a critical challenge, and that nutritional security is intertwined with programs aimed at improving food security.



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We envisage that the application of these recommendations will take place in stages, and will require the involvement of individuals, projects, funders and non-governmental organizations (NGOs) across the globe. Therefore the first challenge to overcome, which is core to the success of outcomes from this report, is the need to secure investment to further refine the priorities and issues raised herein. The global activity outlined in this report will likely require the appointment of a coordinator to establish priorities and execute the recommendations. Such coordination serves to build scale, outcomes, and deliverables at all levels to allow for the development, implementation and delivery of solutions to meet current and future nutritional needs. A regular review of the global programs, networks and projects that are developed to meet the recommendations made in this report will be essential to ensure that the community has established better processes by which agricultural and plant science initiatives can lead to long term improvement of human health.



Recommendation 1.

Plant-based solutions for nutritional deficiencies need to be embedded into the normal process of plant research and crop breeding to generate locally adapted, high-yielding cultivars.

State of Play. Research and plant breeding for improved yield have often not considered the nutritional value of the food product under investigation. Plant breeding strategies (including biotechnology tools) for improving nutritional value need to be carried out in high-yielding cultivars that are suitable for release to the target population of environments where they will be grown, and thus be available for adoption by farmers within an appropriate timeframe. Examples of best practice in this regard are: the release of a high iron pearl millet cultivar that increases iron by 9% and grain yield by 11% (Rai et al., *Journal of SAT Agricultural Research* 11: 1–7. 2013); the development of a forage sorghum that does not accumulate compounds releasing hydrogen cyanide when subjected to drought stress (Blomstedt, *Plant Biotechnology Journal* 10: 54–66. 2012); and the vitamin A-rich orange sweet potato (Hotz et al., *Journal of Nutrition* 142: 1871–80. 2012).

The process of combining nutritional traits along with other traits such as those for edible yield, host plant resistance to pathogens and pests, and abiotic stress adaptation necessitates coordination and development of new and flexible technologies for tracking the relevant vitamin and/or micronutrient, gene variants, quantitative trait loci (QTL) and transgenes on a case-by-case basis. A particular challenge in this area will be for the continued breeding of non-visible traits such as high iron, essential amino acids, and available calcium, coupled with low levels of toxic constituents and nutrient inhibitors into new elite cultivars as they are developed by plant breeders.

Requirements and Actions. There needs to be better coordination by relevant stakeholders at pre-breeding stages of research and development (R&D) to ensure optimal germplasm is available,

and that strategies exist to deploy nutritional traits through newly developed cultivars. Ideally, as given in the examples above, new nutritional traits should be available in varieties that outperform locally grown cultivars.

Low-cost, effective technologies for maintaining nutritional traits in plant breeding programs will need to be developed. These could include genome-aided selection tools, low-cost phenotyping of the metabolic profile or micronutrient when applicable, and strategies to simultaneously monitor multiple vitamins, micronutrients, and deleterious constituents in different tissues.

The final and most important challenge is for the nutritional enhancement sector to develop partnerships with plant breeders, from both public and private sectors, to ensure traits are maintained in subsequent cultivar releases. Ideally, the value of the nutritional enhancement needs to be of such importance to farmers and consumers that it is a priority acknowledged by plant breeders. Thus, the value of the nutritional enhancement needs to be communicated to consumers, farmers, and plant breeders. This effort will require communication programs that are targeted and deployed appropriately.

Recommendation 2.

While recognizing that iron, zinc and provitamin A should continue to be priority research targets, it is also essential that other important nutritional and health factors, such as essential amino acids and minerals, should be brought into specific and relevant breeding programs.



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State of Play. HarvestPlus, which is included in the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH), is a leader in the global effort to end hidden hunger caused by the lack of essential vitamins and minerals in the diet. The main focus of this challenging initiative has been on iron, zinc and provitamin A carotenoids, and it has generated a number of improved micronutrient-rich cultivars of staple food crops that perform well in the field and improve nutrition. Current nutritional challenges are, however, not limited to these three micronutrients or to wheat, maize and rice, three key crops that are staples around the world, which provide less than a third of the Recommended Daily Allowance (RDA) of most vitamins. At present there are 13 vitamins and 10 essential protein amino acids, which are known to be required in the human diet because they cannot be synthesized *de novo* in humans. Low dietary content of any of these vitamins or amino acids can have a profound effect on human health including blindness, impaired learning and development, and increased mortality (Fitzpatrick et al., *Plant Cell* 24: 395–414. 2012).

It is not just a lack of vitamins and minerals that affect human health: toxic constituents present in foods also need to be detoxified and excreted. These processes often consume stoichiometric amounts of the essential amino acid cysteine, which is therefore no longer available for protein synthesis in the body. There are also many other phytonutrients that are not 'essential' but which protect against chronic diseases; these too, need to be recognized as important targets in biofortification

programs. The effects of malnutrition are having a global impact on chronic disease, which is projected to cause 388 million deaths in the next decade. It is not only the lack of food that is causing a problem: obesity is also increasingly linked to rising rates of cancer, cardiovascular disease and diabetes. As an example, 6.9% of all cancers in women are a result of being overweight. Beyond the social impact of such chronic disease, the economic impact is also enormous: it is calculated that a loss in national income caused by chronic disease in the UK is US\$ 33 billion. The millions of projected deaths from chronic disease can potentially be avoided by changes in nutrition. It is therefore essential that current research efforts are expanded to a range of important nutritional and health factors.

Requirements and Actions. The micronutrients iron and zinc, and provitamin A carotenoids, should remain research priorities, and investment into nutritional enhancement programs should be expanded to a wider range of staple crops and those countries where a need exists. In addition to this valuable work, an evaluation of the feasibility of enhancing levels of other vitamins, minerals, micronutrients, and phytonutrients should be undertaken. Strategies to secure funding, and to initiate new and expand existing projects, should be developed.

Industry and research sectors currently make investments into cereal quality, particularly seeking to improve starch quality, dietary fiber, and protein content, with a focus on essential amino acid content, and the fatty acid/oil profile,

among other traits. An evaluation should be undertaken as to whether or not this is sufficient, and whether products from such research will be available and affordable in the developing world. For example, diabetes and obesity-related diseases are rapidly becoming global problems, and the commercial drivers for some projects that impact nutrition and cereal quality in the industrialized world may not be affordable or appropriate to meet the needs of the developing world or other high-risk demographics.

Accumulating evidence indicates that (RDAs) for key micronutrients and essential amino acids are imprecise measures, with a range of factors influencing outcomes, including the food matrix, food preparation and bioavailability. The quantity and bioavailability of key nutrients in different crops, varieties and regions needs to be better documented in a manner that is available to all stakeholders. Researchers are discovering that a purified bioactive compound, such as an antioxidant, may prove more effective if delivered not as a supplement, but within the context of a meal, or ideally a food. Thus, there is a rationale for developing staples and other key vegetables with multiple optimized traits. Examples include Beneforté broccoli (Traka et al., *PLoS ONE* 3: e2568. 2008), and high anthocyanin tomato (Butelli et al., *Nature Biotechnology*, 26: 1301. 2008). This strategy of enhancing the content of key micronutrients in staple crops, and other nutrients into a select range of fruits and vegetables should be promoted, but needs to be considered in the context of Recommendation 1.



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Recommendation 3.

As well as research to improve the major staple crops, nutritional security programs on local crops, fruits, vegetables and forage also need to be developed and integrated in order to promote diversity.

State of Play. There are over 50,000 edible plants yet just four of them provide 60% of humanity's food energy intake, and only 10 crops provide 95% of the food consumed by humans and domestic animals. Overall people are now consuming more food, and a greater proportion of the diet is comprised of energy-dense food (plant and animal sources high in fats, oils and sugars) resulting in a higher incidence of chronic disease.



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Although this greater reliance on a few staple crops has increased efficiency in the food production system, it has simultaneously made the global food supply more susceptible to widespread problems such as pests, disease, and climate change, and in some instances has exacerbated nutrition deficiencies because of the absence of sufficient levels of micronutrients, essential amino acids, antioxidants, fiber, and healthy oils in the predominant food sources. There is currently a global interest in 'new' crops, such as quinoa, which offer health benefits, but many traditional foods in many countries are being discarded due to market forces, falling demand and inadequate investment in plant breeding and agronomy.

Requirements and Actions. It is essential, for human health and for the agricultural system we rely upon, that we increase the diversity in our diets, and thus consider how this can be managed by crop diversification. Nutritional balance

can be achieved through biofortification, and by optimizing dietary intake of diverse, nutritionally rich grains, fruits and vegetables. There are opportunities to promote greater use of existing minor crops through investment in marketing and plant breeding; the examples of Beneforté broccoli and quinoa attest to this. However, to achieve this will require investment in crossbreeding, agronomy and genome-aided selection (where relevant), to ensure that crops traits such as high yield, and pathogen and abiotic stress resistance are optimized. Investment in this area should also consider ways to increase the nutritional value of a particular crop so that it can be grown in the target geographic areas, whether that is in a modern or subsistence farm setting.

An inventory of minor crops grown across the globe, together with a meta-analysis of their agronomic and nutritional values is required. The maintenance of local and indigenous crops within a geographic area necessitates knowledge of the crops, their nutritional value, and engagement with the community to ensure continued support and optimal processing. This will include defining the genetic diversity and nutritional value, and may require integration with programs such as the Diversity Seek initiative, Crop Wild Relatives project, Biodiversity for Food and Nutrition initiative, and A4NH.

The potential to fast-track plant breeding by genome-aided selection of minor crops should not be underestimated for species with large populations and geographic diversity (see Recommendation 10).

The plant science community needs to think about personalized or community nutrition in the same way that physicians view personalized medicine. There are greatly differing effects from person to person, within populations, and in different geographical areas, with respect to diet, health, and the application of meta-studies on nutrition. Engagement with nutritionists is a must to determine whether a need is global, and to tailor different solutions for specific regions or communities. Such profiling of local needs will require more information about the diet and other factors that influence a population's health.





Recommendation 4.

Facilitate international coordination and assessment of research and funding in this area.

State of Play. There are many initiatives already underway across the globe, with investment and research being funded and undertaken by governments, NGOs, research institutes and universities across all continents. A substantial proportion of these resources and activities are

focused on Africa and Asia. However, these efforts operate at different scales with varying degrees of integration and communication. Although larger organizations provide foci and a level of coordination, in some cases, research can be limited by funding opportunities

within a particular country, stochastic opportunities, and a lack of networking and coordination in the planning and execution of new programs.

Requirements and Actions. International cooperation and global coordination are needed to minimize duplication of efforts, and maximize the impact from investment. Systematic development of priorities prior to research investment, followed by multinational open calls for submissions, together with post-funding coordination of projects and progress, would help to provide optimal outcomes.

For such an approach to be successful it is essential that the administration and management of such programs are minimized, and mechanisms for cross-border funding are identified and employed. Ideally a body that manages and distributes contributed funds would be sought, but in reality, identifying an organization that does not have a perceived or real conflict of interest could prove difficult. An alternative would be for an existing organization that sees merit in such a scheme to adjust its objectives to ameliorate any perceived conflict of interest. A number of exemplar NGO and government schemes already exist under which projects have been funded by multiple sources across different regions of the globe; for example the EU-driven ERA-NET for Coordinating Action in Plant Sciences (ERA-CAPS), and the US National Science Foundation NSF - Bill and Melinda Gates Foundation Basic Research to Enable Agricultural Development (BREAD) grants.

Improved intergovernmental communication and interaction with a focus on research is essential, as is the provision of appropriate and adequate funding for coordination across projects and borders. We recommend greater engagement across governments, CGIAR, the EU, UN and NGOs to develop proposals for better coordination that are in the interest of the global community. To achieve this we propose a follow-up meeting to the GPC forum to include key funders from both the private and public sectors.

We also recommend an increase in the funding of public plant breeding programs by governments, especially those that meet the needs of specific geographic, national and regional areas.



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Recommendation 5.

Promote exchange of knowledge, resources, protocols, and best practice via an online portal to support information flow and prevent duplication of effort.

State of Play. Development of new, cost-effective protocols, resources and best practice for new projects have substantial resource implications, and should be coordinated, communicated and not unnecessarily duplicated. Expertise in understanding the requirements for, *inter alia*, best practice management of data, germplasm development, regulatory release or efficacy trials related to the release of transgenic crops is scarce, and can lead to high costs and the delayed release of new cultivars. It is therefore essential that this information is generated, documented and made available online. Facilitated exchange of resources will also help to address some of the concerns expressed in the preceding recommendations.

Requirements and Actions.

We recommend the development of a single portal for the distribution of knowledge, resources, protocols and best practice on a voluntary basis. An independent yet accountable

organization, such as the GPC, should be identified to develop and obtain funding for such a portal. A mixed model of core funding and subscription services should be considered to ensure long-term sustainability and maintenance. Specific high-end functions, such as project management and data tracking software, would require external funding, whereas the provision of protocols and guidelines for best practice R4D might be provided by engaging with the community. Open source protocols will help to offset a lack of coordination. Promoting the exchange of germplasm, and nutritional composition data and trials, will help to advance projects and address a number of aspects outlined in Recommendations 1 and 2, and provide a home for the inventory described in Recommendation 3. The portal could also serve to catalog current projects, and engage with social media tools to help build and promote interdisciplinary and global networks (see Recommendations 6 and 7).



Recommendation 6.

Work with and establish key global networks and initiatives to enhance global coordination, capacity and training, standardization of approaches, and adoption of new technologies to facilitate research and breeding.



State of Play. Globalization of research is an imperative, however funding of research and development generally occurs at the national level. As a result, expertise and best practice can end up being siloed in specific geographical areas or domains of expertise. There are, of course, examples of bilateral agreements, continental schemes such as the those in the EU, and even broader global initiatives such as the International Wheat Yield Partnership (<http://iwyp.org>) that are funded by national funding bodies, government departments, NGOs and consortia. However, the establishment of such schemes has been the exception, not the rule, and the focus and criteria of national funding schemes do not always facilitate this recommendation.

Requirements and Actions. Improved coordination of projects across funding bodies, governments, NGOs and consortia will maximize return per dollar invested. For example, the criteria used by IWYP to fund projects via a competitive tender that includes key stakeholders and a requirement to coordinate field trials, populations and planning across borders has great merit. It is no coincidence that IWYP arose from G20-level discussions, and has taken years of planning to come to fruition. An analysis of the implementation and outcomes of this scheme might inform the design of other schemes. We recommend that similar initiatives be undertaken within the area of plant nutrient improvement, commencing with landscaping and scoping studies to identify

areas of impact and need. We strongly recommend that such initiatives are not limited to “immediate goals”, but that they include the development of technology platforms, protocol standardization, and skills in research, plant breeding and community engagement in developed and developing countries that will have long standing benefits and outcomes. Similarly, linking current projects across the globe – either virtually, via the portal outlined in Recommendation 5, via newsgroups and social media, or physically – to exchange knowledge and expertise in formal events such as meetings and workshops, would help the exchange of best practice, facilitate training and capacity building, and promote standardization and data sharing.



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Recommendation 7.

Facilitate greater collaboration between plant and agricultural scientists, food scientists, nutritionists, biomedical scientists, and clinicians.



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State of Play. An awareness of the need to link researchers across disciplines is a key strength of the nutritional security field. Exemplar programs on a large scale include the vitamin A-rich, orange-fleshed sweet potato project from Harvest Plus. On a smaller scale, it is common for plant research articles to include bioavailability and bio-absorption data, or to be tested on model animals and systems such as artificial intestines. Regrettably, this level of integration is not widespread, and rarely does it extend to clinicians and nutritionists, especially in the planning stages of a research project. This reflects multiple challenges, including, but not limited to: a lack of dialog and collaboration between plant scientists, food scientists, nutritionists, biomedical scientists and clinicians; a reluctance of scientists to move fields and take risks; insufficient funding for combined research programs; and an awareness of colleagues with similar interests across these diverse disciplines. For example, the common bean is an important source of nutrients for more than 300 million people in parts of Eastern Africa and Latin America, and a

major source of micronutrients including iron, zinc, thiamin and folic acid. Plant breeding programs, including that of Harvest Plus, have developed and released new *Phaseolus vulgaris* bean varieties with iron concentrations above 94 µg/g (<http://bit.ly/1Yw5zBH>). However, uptake of this increased iron is often limited because of a lack of bioavailability as result of iron absorption inhibitors found in common bean. Further investment, and multidisciplinary approaches are therefore needed to research and enhance the bioavailability of vitamins, minerals and phytonutrients.

Furthermore, there is a long complex pathway between basic research, which may merit an excellent publication, and the development of a food product that could be used in dietary studies. The latter requires significant investment; collaboration with the agri-food industry; understanding of the different needs, time frames and philosophies of academic and industry partners; and does not usually result in high profile articles on which academic careers are built.

Requirements and Actions. Enhanced networking tools must be established to promote awareness and foster linkages between scientists in different disciplines. These tools can be achieved at different levels with low-to-moderate cost, including social media, calls for joint submissions in funding schemes, multidisciplinary conferences that facilitate networking, and workshops such as the GPC meeting in Xiamen that brought together such a grouping. We also view a role for advocates in the various professional societies to promote an awareness of opportunities and the concepts herein to their members. To this end, establishing an *ad hoc* small group of representatives from the different disciplines to develop and implement strategies has merit. Full engagement will require funding schemes calling for such projects, with the funders and employers rewarding those who engage in such schemes that may not lead to the traditional measure of scientific output.

Recommendation 8.

Recognize that planning, implementation and delivery of nutritionally enhanced crops and food requires active engagement with social scientists, policy-makers, community advocates, and the food industry.

State of Play. With a few notable exceptions research programs are planned and undertaken in isolation, without appropriate and early engagement with social scientists, policy-makers, community advocates or the food industry. Across community and stakeholder groups the level of trust in scientists, their research and data varies greatly. Negative perceptions can arise from a complex mixture of targeted advocacy by sectors of the community that are against science-driven issues such as global climate change and transgenic-derived foods; mistrust of large multinational organizations; misinformation; inadequate engagement with the community; and valid concerns.

Requirements and Actions. All major research programs in nutritional enhancement should have appropriate involvement with the aforementioned stakeholders, from planning through to research, development and delivery. Investment of time and money to develop solutions to nutritional and health challenges need to be made in conjunction with investment in programs that engage effectively and productively with the stakeholders. Expertise should be heeded to maximize a program's likelihood of success, and to build community awareness and acceptance of the program's goals and strategies. In terms of achieving said goals, many of the strategies covered for Recommendation 7 apply.



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State of Play. The emphasis of this recommendation is vulnerable communities. What are their key nutritional needs and what are the impediments to improving their health? NGOs, charitable trusts and government agencies have been tasked with supporting these communities and targeting the consequences of poverty and poor nutrition on both a local and global scale. The challenge is how to prioritize requirements to address the needs of these communities in an effective manner.

Requirements and Actions. Research and development projects cannot be developed in isolation. The needs of the communities for whom crop or food is being developed must be considered alongside the science. Plant scientists and other groups need to partner and/or liaise with NGOs, aid organizations and representatives of vulnerable communities to ensure the end product will meet the needs of the community, and that there are effective delivery mechanisms and community engagement programs for the product. A specific objective of vertically integrated programs will be advice in priority setting, and guidance on the development of outputs to maximise the likelihood of success from project conception through to product delivery.

Recommendation 9.

Help to build and implement vertically integrated programs that address key nutritional needs for vulnerable communities.



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Recommendation 10.

Promote the use of all relevant technologies to develop global plant-based endeavors to reduce global malnutrition and improve human health.



Advocacy: While recommending that all relevant technologies be available and supported by the community, we are not recommending any specific technology, or that all technologies be used in each and every instance. There are strong reasons for supporting deployment of diverse strategies. All the technological ‘tools in the box’ should be available, ranging from traditional breeding, genome selection through to transgenic technologies. For a given crop and given nutrient(s) the feasibility, time and cost of the different strategies needs to be considered, including: research, development, incorporation of the trait(s) in elite varieties, regulatory approval, outreach, education, and marketing. We recommend better support for educational and community outreach initiatives that promote knowledge of the different technologies and strategies, and recognize that there are many different models for achieving this. We would recommend that any future large programs in the area of nutritional security should include a strong outreach and education program. Accessible and easily understandable resources must be generated and made available online via the GPC and other organizations. Currently available resources need to be promoted and shared, including examples of community engagement by specific projects, for example goldenrice.org, and examples of activities undertaken by research organizations across the globe.

State of Play. A broad spectrum of approaches and strategies are available for developing new crops and varieties with improved nutritional value. Some, such as better technologies for assaying vitamin levels, are not contentious, while others, such as transgenic-derived foods, can be. The regulatory environment surrounding the development of crops and foods varies across countries and continents and is continually shifting as the result of new technologies such as gene editing, and social, political, and economic pressures. Therefore, programs aiming to reduce global malnutrition and improve human health must consider all available scientific approaches and select the most appropriate for their needs based on current evidence, while balancing this with the feasibility and cost of obtaining regulatory approval for the end product of the program, and public acceptability.

the return of funders because data sets are less likely to be compromised by a simple oversight, findings can be better integrated, and progress can thereby be accelerated. Solutions required include a series of practical, solvable challenges, such as a supply of chemical standards, development of robust, low cost technologies, or – when not available, cost-effective sharing of services through platforms; this includes x-ray fluorescence and near infrared spectroscopy, genotype and data storage. Reliable, reproducible, low-cost bioavailability assays are needed, including some that might work in the field, and industry engagement may enhance progress in this area. We need to go one step beyond what we are currently doing to achieve step changes. Layering a new technology onto current efforts might be one way to achieve this, as well as the translation of these technologies to emerging crops. A further and likely achievable challenge is the application of genome-aided selection to crossbreeding. Examples of new areas are: to link metagenomics research (interaction of foods and bacterial genome in the gut) to plant science, and agricultural breeding programs.

Requirements and Actions.

Technology: Investment in new technologies that are low cost and can be deployed globally, together with standardization of analytical methods, and training in design and experimental analysis are needed. This will maximize



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Annexe 1 - Organizers and Contributors

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