THE ASSOCIATION OF ACADEMIES AND SOCIETIES OF SCIENCES IN Asia

iap SCIENCE RESEARCH HEALTH

the interacademy partnership

Opportunities and challenges for research on food and nutrition security and agriculture in Asia

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AASSA

AASSA – the Association of Academies and Societies of Sciences in Asia – was launched in October, 2012 with 34 member Academies and Societies of Sciences from 30 Countries in Asia and Australasia. With IAP's strong support for the merger, AASA (Association of Academies of Sciences in Asia, founded in 2000) and FASAS (Federation of Asian Scientific Academies and Societies, founded in 1984) had merged into a single Asian science organization at the inaugural General Assembly at Colombo, Sri Lanka on 17 October, 2012 with the unanimous and wholehearted endorsement from members of both AASA and FASAS.

Through the merger, AASSA is expected to gain more visibility for science and increase efficiency, particularly in relation to resources (human and financial) with reduced overlap of activities and meetings, and provide a better platform for fundraising and interaction with other science organizations.

The principal objective of AASSA is to act as an organization in Asia and Australasia which plays a major role in the development of the region through science and technology. AASSA serves as a forum for scientists and technologists to discuss and provide advice on issues related to science and technology, research and development, and the application of technology for socio-economic development of member countries.

To achieve the above-mentioned objectives, activities of AASSA include 1) facilitating exchange of scientists and promoting collaboration among Asian and Australasian countries, and with international scientific organizations; 2) contributing to sustainable development of the region, and to UN Sustainable Development Goals; 3) enhancing science literacy through good science communication with the society; 4) providing science advice to the stakeholders such as governments, business and the general public; 5) conducting workshops and other activities to enhance scientific and socio-economic capacity in the region; 6) helping initiate and conduct studies and research on STI issues related to national development agenda of member countries; 7) promoting science education at all levels; 8) carrying out any other functions to achieve the overall objectives. Recently, AASSA has put special emphasis on women and communication matters on its activities.

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Foreword by IAP Co-Chairs

The InterAcademy Partnership (IAP) global network of the world's science academies brings together established regional networks of academies, forming a new collaboration to ensure that the voice of science is heard in addressing societal priorities.

Combating malnutrition in its various forms—under-nutrition and micronutrient deficiencies as well as overweight and obesity—is a problem that is faced by all countries. The transformation of agricultural production toward sustainability is a global issue, connected with the global challenges of poverty reduction, employment and urbanisation. International academies of science have a substantial history of interest in these areas, for example as indicated by the InterAcademy Council publication in 2004 'Realizing the promise and potential of African agriculture'. Science has the potential to find sustainable solutions to challenges facing the global and national food systems relating to health, nutrition, agriculture, climate change, ecology and human behaviour. Science can also play a role in partnering to address important policy priorities such as competition with land use for other purposes, for example energy production, urbanisation and industrialisation, with environmental connections for resource use and biodiversity. The Sustainable Development Goals adopted by the United Nations in 2015 provide a critically important policy framework for understanding and meeting the challenges but require fresh engagement by science to resolve the complexities of evidence-based policies and programmes.

There is an urgent need to build critical mass in research and innovation and to mobilise that resource in advising policy-makers and other stakeholders. Academies of science worldwide are committed to engage widely to strengthen the evidence base for enhanced food and nutrition security at global, regional and national levels. In our collective academy work, we aim to facilitate learning between regions and to show how academies of science can contribute to sharing and implementing good practice in clarifying controversial issues, developing and communicating the evidence base and informing the choice of policy options. The current IAP initiative is innovative in bringing together regional perspectives, drawing on the best science. In this project, we utilise the convening, evidence-gathering, analytical and advisory functions of academies to explore the manifold ways to increase food and nutrition security and to identify promising research agendas for the science communities and investment opportunities for science policy. A core part of this work is to ascertain how research within and across multiple disciplines can contribute to resolving the issues at the science–policy interface, such as evaluating and strengthening agriculture–nutrition–health linkages. Food systems are in transition and, in our project design, we have employed an integrative food systems approach to encompass, variously, all of the steps involved, from growing through to processing, transporting, trading, purchasing, consuming and disposing or recycling food waste.

Four parallel regional academy network Working Groups were constituted: in Africa (the Network of African Science Academies, NASAC); the Americas (the Inter-American Network of Academies of Sciences, IANAS); Asia (the Association of Academies and Societies of Sciences in Asia, AASSA); and Europe (the European Academies' Science Advisory Council, EASAC). Each had an ambitious mandate to analyse current circumstances and future projections, to share evidence, to clarify controversial points and to identify knowledge gaps. Advice on options for policy and practice was proffered at the national–regional levels to make best use of the resources available. Each Working Group consisted of experts from across the region who were nominated by IAP member academies and selected to provide an appropriate balance of experience and scientific expertise. The project was novel in terms of its regionally based format and its commitment to catalyse continuing interaction between and within the regions, to share learning and to support implementation of good practice.

These four regional groups worked in parallel and proceeded from a common starting point represented by the agreed IAP template of principal themes. Among the main topics to be examined were the science opportunities associated with the following.

- Ensuring sustainable food production (land and sea), sustainable diets and sustainable communities, including issues for agricultural transformation in the face of increasing competition for land use.
- Promoting healthy food systems and increasing the focus on nutrition, with multiple implications for diet quality, vulnerable groups and informed choice.
- Identifying the means to promote resilience, including resilience in ecosystems and in international markets.
- Responding to, and preparing for, climate change and other environmental and social change.

Each regional group had the responsibility to decide the relative proportion of effort to be expended on different themes and on the various elements within the integrative food systems approach, according to local needs and experience.

All four networks are now publishing their regional outputs as part of their mechanism for engaging with policy-makers and stakeholders at the regional and national levels. In addition, these individual outputs will be used as a collective resource to inform the preparation of a fifth, worldwide analysis report by the IAP. This fifth report will advise on inter-regional matters, local–global connectivities and those issues at the science–policy interface that should be considered by inter-governmental institutions and other bodies with international roles and responsibilities. We intend that the IAP project will be distinctive and will add value to the large body of work already undertaken by many other groups. This distinctiveness will be pursued by capitalising on what has already been achieved in the regional work and by proceeding to explore the basis for differences in regional evaluations and conclusions. We will continue to gather insight from the integration of the wide spectrum of scientific disciplines and country/regional contexts.

This project was formulated to stimulate the four regional networks in diverse analysis and synthesis according to their own experience, traditions and established policy priorities, while, at the same time, conforming to shared academy standards for clear linkage to the evidence available. The project as a whole and in its regional parts was also underpinned by necessary quality assessment and control, particularly through peer-review procedures.

We anticipated that the regions might identify different solutions to common problems—we regard the generation of this heterogeneity as a strength of the novel design of the project. We have not been disappointed in this expectation of diversity. Although the regional outputs vary in approach, content and format, all four provide highly valuable assessments. They are customised according to the particular regional circumstances but with appreciation of the international contexts and are all capable of being mapped on to the initial IAP template. This latter IAP collective phase of mapping, coordination and re-analysis is now starting. According to our interim assessment, the project is making good progress towards achieving its twin objectives of (1) catalysing national–regional discussions and action and (2) informing global analysis and decision making.

We welcome feedback on all of our regional outputs and on how best to engage with others in broadening discussion and testing our recommendations. We also invite feedback to explore which priorities should now be emphasised at the global level, what points have been omitted but should not have been and how new directions could be pursued.

We take this opportunity to thank the many scientific experts, including young scientists, who have contributed their time, effort and enthusiasm in our regional Working Groups, which have done so much to help this ambitious project to fulfil its promise to be innovative and distinctive. We thank our peer-reviewers for their insight and support, and all our academies and their regional networks and our core secretariat for their sustained commitment to this IAP work. We also express our gratitude for the generous project funding provided by the Federal Ministry of Education and Research (Germany) (BMBF).

Krishan Lal
Co-chair, IAP for Science

Volker ter Meulen
Co-chair, IAP for Science
and President, IAP

October2017

Foreword by President of AASSA

The United Nations at its General Assembly in September 2015 placed 'No Poverty' and 'Zero Hunger' as its paramount goals (first and second) out of its 17 ambitious Sustainable Development Goals to be achieved by 2030. Because there are still 800 million people starving right now and because the world population will increase to more than 9 billion by 2050, getting rid of poverty and hunger, including all forms of malnutrition, is a formidable task. It requires truly multi-disciplinary and trans-disciplinary approaches engaging science, technology, social science and even the humanities. It also demands truly global scale cooperation and collaboration from all sectors of learned societies, especially from national academies and their regional associations.

Recognising this, the InterAcademy Partnership (IAP) for Science initiated an ambitious project called 'Food and Nutrition Security and Agriculture (FNSA)' in June 2015 with funding generously provided by the German Government. IAP delegated to its four regional affiliates, namely the Association of Academies and Societies of Sciences in Asia (AASSA) for Asia and the Pacific, the European Academies' Science Advisory Council (EASAC) for Europe, the Inter-American Network of Academies of Sciences (IANAS) for the Americas and the Network of African Science Academies (NASAC) for Africa, the responsibility of preparing regional reports following a 10-point template formulated after very thorough and intense discussions among the experts assembled at Halle, Germany, under the auspices of the German National Academy of Sciences Leopoldina. Each affiliate then wrote its report, taking into account commonalities and differences among the four affiliates and among the countries belonging to each.

AASSA assembled a Working Group of eight experts chosen from those nominated by member academies. The Working Group collected relevant data either through the information provided by member academies or through open sources.

After four face-to-face meetings, twice in New Delhi and twice in Seoul, and numerous communications through electronic media, the Working Group drafted the AASSA FNSA report in September 2017. The draft was then reviewed by peer-reviewers with wide experience and international stature both inside and outside the AASSA region. The final draft, which accommodated comments, corrections, additions and suggestions provided by the reviewers, was completed in early October 2017 and sent to each member academy for further comments and concurrence. As of the publication date, most member academies had enthusiastically endorsed the final draft, thus making it an official AASSA document.

At this juncture, I would like to take this opportunity to acknowledge the help that AASSA received for this project. First, I thank Professor Volker ter Meulen, senior co-chair of the IAP for Science for his vision, drive and leadership. It is he who conceived this project, secured the necessary funding and took control of the whole project. Professor Krishnan Lal, who is another co-chair of the IAP and the immediate past president of AASSA, also greatly contributed to AASSA's FNSA project. As the coordinator of this project, he directed the entire process of the AASSA's report writing. Special thanks are also due to the members of the Working Group who collected, evaluated and selected the necessary data and took on the painstaking job of writing the report.

Finally, I thank the AASSA member academies, especially the Indian National Science Academy and the Korean Academy of Science and Technology, for their help and interest in this project.

Professor Yoo Hang Kim
President, AASSA

Summary

One of the greatest challenges facing humans in the 21st century is to provide a guaranteed supply of nutritious, healthy foods that are produced in an economically, culturally, socially and environmentally sustainable manner for a rapidly growing world population. Moreover, the required increase in the net amount of food (food produced less food wasted) must occur in the face of several constraints, such as less land, water and other resources and the unpredictable outcomes of global climate change. The challenge is formidable.

The production and the supply of food follow a complex web of interacting factors and, among these, a wide range of non-technical factors is highly relevant and needs to be addressed. A systems analytical approach is needed to identify impediments and to provide workable holistic solutions. Not wishing to undermine the importance of these numerous non-technical factors, it is beyond doubt that science and technology (S&T) occupy centre stage in addressing future food and nutrition security (FNS); it is the latter S&T perspective that is the main emphasis of this report. The production of food in a sustainable manner, the processing and storage of food, the minimisation of food wastage and the development of healthy diets adapted to local conditions and populations are of paramount importance. The application of current scientific knowledge through improved education and extension practices, the development of new scientific knowledge in targeted areas and related technology developments will all be essential in terms of meeting the global food challenge.

The approach taken by the Association of Academies and Societies of Sciences in Asia (AASSA), embodied in this report, aims to broadly address aspects of future FNS in the Asia/Oceania region, particularly with respect to projected future population growth and trends in under- and over-nutrition. The report focuses on issues related to S&T and science-based education in the broadest sense. It identifies gaps in knowledge and discusses scientific approaches and a science agenda, to enable progress towards FNS for the region. A key finding is that there is an urgent need to form and fund inter-disciplinary cooperative research and education programmes, mustering the best talent and resources from across the region, to tackle targeted areas for knowledge development.

In discussing FNS, it is important that emphasis not be placed on calorie provision alone; rather, the focus should be on diverse diets supplying a balance of food types and dietary nutrients and non-nutrients that are known to influence health, and FNS should address malnutrition in all its forms, both under- and over-nutrition. Work to establish scientifically what constitutes a 'healthy diet' is urgently required. The 1996 definition of FNS by the Food and Agriculture Organization of the United Nations (FAO) was adopted for the report:

'*Food security exists 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.*' (FAO, 1996).

The approach taken in this study was to use national and regional statistics for Asia and Oceania on projected population growth, population age distributions, economic development and current estimates of under- and over-nutrition to allow a focus on key countries and geographical areas ('hot spots') that are most likely to face the harshest FNS issues. A strategy moving forward would be to use 'systems analysis' to identify key impediments to FNS in these areas and to use such analysis to prioritise extension, education and research and development (R&D). The report emphasises the need for a territorial dimension in such an analysis, recognising often profound differences between geographical areas and socio-economic groupings. The territorial approach to investigating FNS implies a shift from a sectoral (usually agricultural production), top-down, 'one-size-fits-all' approach to one that is multi-sectoral, bottom up and context specific.

The work has identified several countries within the region that are at high risk for future FNS. These areas are characterised by current high levels of under-nutrition coupled with high projected rates of population growth. Countries such as India, Bangladesh, Pakistan, Afghanistan, Nepal and Myanmar as well as the Philippines, Tajikistan, Iraq and Yemen are deemed to be particularly high risk countries for future FNS. This is not to say that all other countries in the region are free from future issues concerning FNS; rather, it gives a rational starting point as to where work may be most effective. In choosing these countries, an emphasis was placed on under-nutrition as opposed to over-nutrition because, with under-nutrition, effects are immediate and often irremediable. Once again, this is not to minimise the importance of the deleterious effects of over-nutrition. An increasing incidence of overweight or obese people is observable throughout Asia and Oceania, and any FNS strategy must account for the need to produce a greater variety of food types and to promote education about healthy eating and healthy lifestyles to prevent obesity and its associated non-communicable diseases.

Planning for future FNS in the region will require strong commitment from politicians and policy-makers, but

scientists in the region have the responsibility to provide robust peer-reviewed scientific knowledge, to allow evidence-based decision making. It is suggested that the AASSA may have a role in helping to establish a trans-national funding mechanism in the region that puts basic research connected to FNS at the forefront. A warning is given that, in considering the considerable lag time in research between investment and adoption, it is imperative that governments in the region not only maintain support for basic R&D and education related to FNS but also greatly increase, as a matter of urgency, the overall level of funding. There needs to be a considerable resurgence in agri-food R&D, extension and education, and such an emphasis needs to be more cross-disciplinary and systems oriented than in the past.

Several emerging areas of S&T are seen as ubiquitous for the region in terms of their utility of application and it is strongly exhorted that a cooperative regional approach be taken, to form well-resourced regional centres of research excellence that focus on key opportunity areas. Such virtual centres would be populated by the 'best-of-the-best' relevant scientists from throughout Asia and the Pacific and would pursue clearly conceived research plans with specific objectives. Key S&T areas, seen to have universal and prioritised application across the region, include (1) genomic-based approaches to plant and animal breeding; (2) 'big-data' capture and analysis, precision agriculture and robotics; (3) food technology innovations in harvest, processing and storage to reduce food wastage; (4) sustainable farming practices for land and water use that address wider issues such as biodiversity and climate; (5) aquaculture production and integrated farm production systems. These would be large multi-disciplinary projects reflecting public-good science and leveraging off fundamental science to build deep knowledge bases, in what are seen as critical innovation areas to secure future FNS. The Asia/Pacific food system is vast and richly endowed. It has the potential to provide more and better food, to reduce food wastage, to drive economic growth and to deliver healthier, safer diets to all, and to do this in a sustainable way. However, this potential will not be realised unless concerted efforts across the region are made to greatly strengthen both research and education. Research and education need to envelop the entire food system, to be cross-disciplinary and to aim to increase the net supply (production less wastage) of a diverse range of foods. As a predictable adequate supply of diverse healthy foods is the target outcome, an emphasis on food safety, human nutrition and well-being must be prevalent.

The AASSA Expert Working Group is confident that malnutrition in all its forms can be combated and that the future citizenry of Asia can be properly fed, as long as sufficient global investment is made in science and education. Much work remains to be done. Critical impediments that influence the region's ability to increase food production and to ensure a diversity of high-quality foods reaching consumers need to be identified. Cross-disciplinary cooperative research programmes, mustering the best resource from across the regions, need to be formed and funded to develop knowledge. That knowledge needs to be communicated clearly and to be shared freely and extensively.

1 Introduction

1.1 The global challenge

One of the greatest challenges facing humans in the 21st century is the provision of a guaranteed supply of nutritious healthy foods that are produced in a socially and environmentally sustainable manner for a rapidly growing world population. Science and technology (S&T) will need to be centre stage to meet the demands of this formidable challenge.

Globally, much more food of specified types (e.g. cereals, vegetables, fruits, nuts, dairy products, eggs, meat and fish) needs to be produced and distributed equitably to ensure a balanced diet to adequately nourish a projected population of around 9 billion persons by the year 2050. This is against a current backdrop, where around 1 billion people are undernourished and where, in many countries, there is an escalating prevalence of the metabolic syndrome and its attendant non-communicable diseases. 'Hidden hunger' is also a significant issue. In India, for example, more than 70% of the population consumes less than 50% of the recommended daily allowance of micronutrients and 50% of children under the age of 3 years are underweight (Arnold et al., 2009). This is a major challenge and will require much more robust and globally integrated strategies towards diet–food–nutrient–health security.

The increased production of food required must occur in the face of several constraints. The land area available for agriculture is unlikely to increase in the future and may well decline because of the demands of urbanisation, conservation, bio-ecology and land loss from sea-level rises caused by global warming. Limitations in the supply of other vital resources (e.g. fossil fuels, fertiliser and water) are also likely to pose a challenge. Future food increases will need to be sustainable, environmentally, economically, culturally and socially, and will occur in the face of unpredictable outcomes that are consequent upon climate change. In some cases, agricultural yields will need to be increased from what are considered currently to be high yields, and, in other cases, technology will be brought to bear to close known existing 'yield gaps'. In both cases, innovation will be necessary.

The 17 Sustainable Development Goals adopted by the United Nations in 2015 offer an important framework for addressing the challenge of the global food supply but, if these goals are to be met, evidence-based science will be a necessary prerequisite. The global science academies are committed to engaging widely to strengthen the evidence base for enhanced food and nutrition security (FNS) at global, regional and national levels. To this end, an Association of Academies and Societies of Sciences in Asia (AASSA) Expert Working Group was established (see Appendix I for its composition and meetings schedule) to prepare a report on 'Food and Nutrition Security and Agriculture in the Asia/Pacific Regions'. In this AASSA report, which is part of a worldwide InterAcademy Partnership (IAP) (a partnership of the world's academies of science, medicine and engineering) initiative, messages on how S&T can help to resolve critical issues are aimed at key Asian and Pacific government organisations and regional/national policy-makers, as well as the wider science and education community and other stakeholders.

We emphasise that the desired outcome for FNS is access for all to a healthy and affordable diet, the food production of which is environmentally sustainable and culturally appropriate. This report also aims to contribute to the broader IAP objective of facilitating learning and sharing good practice between regions and countries and science academies.

1.2 The central importance of eradicating poverty

From the outset, it was acknowledged by the AASSA Expert Working Group that the challenge of adequately feeding the world's future population in an environmentally and socially sustainable manner is complex and multi-faceted, and requires systems analysis to provide workable holistic solutions and pathways forward. It was also acknowledged that the root cause of the insufficient provision of food at an individual and family level is a lack of purchasing power, and that the eradication of poverty is pivotal to ensuring FNS. Currently, 70% of the world's extreme poor live in rural areas and are mostly farmers and net food buyers. Around 900 million people live on less than US$1.90 [2011, purchasing power parity (PPP)] per day and around 2.4 billion people live on an income of between US$2 and US$3 per day (2011, PPP). Most of the projected world population growth to 2050 (an extra 2400 million people) will occur in what are currently considered to be low-income countries (Population Reference Bureau, 2016), and almost half of the population growth will occur in Asia. The dynamics of growth in food demand are well understood. As incomes start to rise, very-low-income people spend most of the first increments to income on food. By about US$2.00 per day, most 'hunger' problems (provision of calories) can be solved and, as incomes rise from US$2.00 to US$10.00 per day, people eat more meat, dairy products, fruits, vegetables and edible oils, causing a rapid growth in the demand for agricultural commodities (Thompson, 2015). After about US$10.00 per day, people buy more processed and luxury foods and more food services, and increase their variety of foods eaten, but do not purchase more raw agricultural commodities per se. As the world's population continues to grow towards the year 2050, it is also predicted that there will be growth in the middle-class (Kharas, 2017). Combining the effects of a projected increased population growth and an increasing middle-class, world food demand is projected to grow by around two-thirds between now and 2050. About half of this increase will be due to world population growth and about half will be due to the increase from broad-based economic growth and urbanisation in low-income countries. It is considered that the number of currently low-income consumers (spending the largest fraction of their incomes on food), who escape from poverty, is the most important uncertainty concerning the future global economic demand for food. There is also an unknown but potentially large influence of the use of agricultural raw materials in the bio-based economy (and especially biofuels) on the global demand for grain and oilseeds by the year 2050 (HLPE, 2013; Baldos and Hertel, 2014).

The production and the supply of food to individuals and families follow a complex web of interacting factors and, among these, a wide range of non-technical factors such as purchasing power, barriers to trade, capital investment, infrastructure, government policies, cultural mores, demographic shifts, political and social stability, equity of access, gender equality and education are highly relevant and need to be recognised (Godfray et al., 2010; UK Government Office for Science, 2011; World Economic Forum, 2013; Pinstrup-Andersen, 2014). It is crucial that these key aspects, which can often prove to be critical impediments to food production, supply and distribution to households, be addressed by governments and relevant global organisations. Nevertheless, the production of food in a sustainable manner, the processing and the storage of food, the minimisation of food wastage and the development of healthy diets adapted to local conditions and populations are also of paramount importance and rely heavily on S&T, on education and on a sound knowledge base. It is the latter S&T perspective that is the main emphasis of this AASSA report. The application of current scientific knowledge through improved education and extension practices, the development of new scientific knowledge in targeted areas and related technology developments will be essential in terms of meeting the global food challenge, and the world's science academies have an important obligation to fulfil here in terms of science leadership.

1.3 Approach of the AASSA Expert Working Group

The AASSA Expert Working Group aimed to broadly address aspects of future FNS in the Asia/Pacific regions, with respect to future population growth and projected regional trends related to both under-nutrition and over-nutrition. The report focuses on issues related to S&T and science-based education in the broadest sense. The geographical area to which the report pertains includes Asia and the Pacific. The Pacific is defined here as Oceania (Australia, New Zealand and the Pacific Islands) and Asia is defined as bounded in the east by the Pacific Ocean, in the south by the Indian Ocean and in the north by the Arctic Ocean. It is recognised that the western boundary with Europe is based on historical and cultural constructs (Figure 1). Asia is the world's largest and most populous continent. It comprises 48 United Nations countries and six other states, and includes highly populated countries such as China, India, parts of Russia, Turkey and the Middle East as well as the countries of South-East Asia.

The analytical approach that was taken by the AASSA Expert Working Group is not exhaustive geographically; rather, several countries (Table 1) were selected (particularly where science academy representation was strong) for a detailed study to provide an overview of the region. Other countries and regions are discussed where relevant, and by exception. The region includes numerous countries that differ in gross domestic

Figure 1 Geographical area of Asia addressed in the report.

Table 1 Selected countries to provide an overview of the Asia/Pacific region

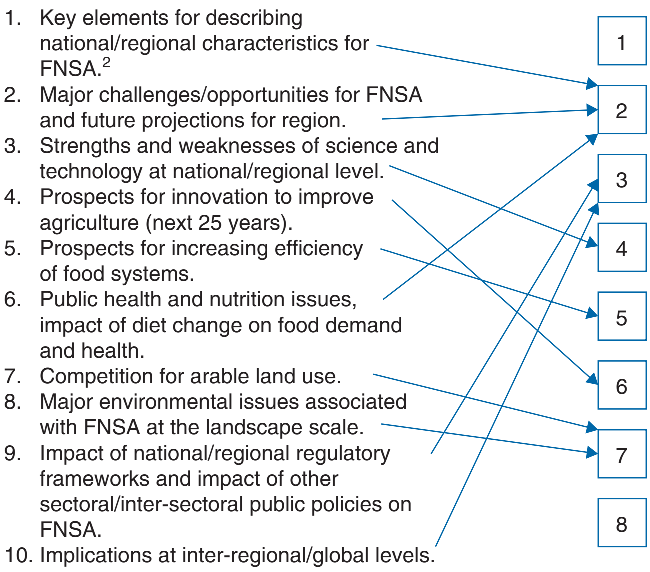
Australia
China
India
Indonesia
Israel
Japan
South Korea
Thailand

product (GDP) per capita, economic growth rate, population growth rate, natural resources, nutritional deficiencies and excesses, and political, cultural and social drivers. With reference to this diversity, the report aims mainly to identify trends and challenges that are common to countries and areas within the region, although important differences are also noted.

The approach taken by the Working Group was a 'bottom-up' analysis of FNS. Experts from science academies across the region (drawing upon the wide geographical spread of IAP constituencies) were appointed to the Working Group, and each expert was requested to provide information and insight for their country or region, which then allowed synthesis of the material by the Working Group to allow common themes to be developed, and general as well as specific conclusions to be drawn. The analysis was guided by a template of common themes for the project, developed at the IAP level (Table 2), and information was interpreted in a 'food systems' context. A strength of the inter-science academy approach was that a broad range of relevant scientific disciplines from across a wide geographical area was drawn upon, allowing the identification of scientific issues and opportunities not only at regional and global levels, but also at a national and sometimes sub-national level, reflecting diversity

Table 2 IAP template[1] for common themes in the project and how these map over to the sections of the AASSA report

IAP template theme — AASSA report section



[1]Refer to Appendix II.
[2]FNSA: Food and nutrition security and agriculture.

between and within countries. A unique feature of the approach was the regional science academies networking to allow the formation of a critical mass of accomplished scientists drawn from a wide variety of backgrounds and scientific disciplines.

1.4 IAP and AASSA

The IAP is the global network of science academies, representing more than 130 academies, aiming to harness the power, authority and credibility of its member academies and to access their combined scientific talent. Recent structural changes[1] have resulted in a new integrated organisation; what was the InterAcademy Panel was merged together with the InterAcademy Medical Panel (IAMP) and the InterAcademy Council (IAC).

Many national science academies have a tradition of responsibility in ensuring that the collective voice of science is heard in major policy debates. By engaging with its four regional academy networks (for Africa, the Americas, Asia and Europe), the IAP has the capacity to advise on the science dimensions of policy-making at the global level and across disciplines. Many member academies and the regional academy networks have previously conducted their own studies in areas relevant to FNS. In November 2014, the IAP Board and Executive Committee agreed that this was a vitally important topic with which to pioneer a new series of IAP projects.

The IAP project aims to produce four regional reports, together with a global synthesis, that highlight the similarities and differences between the regions and explore inter-regional issues, providing advice and recommendations for implementation at global, regional and national levels, customised according to local circumstances and strategic needs. Thus, this IAP activity combines twin goals of delivering strong consensus messages at the global level, with clarification of the scientific basis of current disparities in policy expectations, objectives and options in the different regions of the world. The IAP project was initiated with a meeting at the German National Academy of Sciences Leopoldina, in June 2015, bringing together experts to advise where work by the IAP and its regional academy networks might add value to the considerable volume of work already conducted by many other scientists in seeking to inform policy-makers. Collective discussion following this initial step helped to develop a common, agreed template to inform and guide all four regional Working Groups (see Appendix II and Table 2). Necessary components of this shared template are to understand regional characteristics, to delineate the significant opportunities and challenges where science can help to inform policy-making and serve as

[1] www.interacademies.net/News/PressReleases/29843.aspx.

a resource for innovation, to address the impact of the cross-cutting determinants of the various priorities and to advise on how to mobilise scientific resource.

The AASSA is an affiliated regional network of the IAP. It is a non-profit organisation with interests in S&T, the principal objective of which is to promote and preserve a society in Asia and Australasia in which S&T play a major role in regional development. The AASSA is a forum for scientists and technologists to discuss and provide advice on issues related to S&T, research and development (R&D) and the application of technology for socio-economic development. The AASSA was launched in 2012, with 34 member academies and societies of science from 30 countries.

1.5 Objectives and scope of this AASSA report

The report focuses on S&T and science-based education in relation to FNS. It contains a summary of the findings emanating from a trans-disciplinary, inter-regional, evidence-based assessment of trends in population growth and future food needs in Asia and Oceania, and defines key attributes pertaining to future FNS. The work recognises that FNS is about both food supply and food usage (demand) and it is acknowledged that the solutions to food-related problems are likely to be context, regional and culturally specific. Some of the findings and recommendations embedded in the report are specific to countries and regions whereas others are global in nature. In particular, the report identifies gaps in knowledge and discusses scientific approaches and a science agenda, to enable progress towards sustainable FNS. A 'food systems' context is pervasive, and relevant disconnects in the complex food production system are identified and discussed.

The messages and recommendations in this report are firstly aimed at regional and national governments and policy-makers in the Asia/Pacific area, as well as the science academies, scientists and educators and a wide realm of other stakeholders including interested members of the public.

The AASSA Expert Working Group is confident that malnutrition in all its forms can be combated and that the future citizenry of Asia can be properly fed, as long as sufficient global investment in science and education is made. Much work remains to be done. Critical areas influencing the region's ability to increase food production and to ensure a diversity of high-quality foods reaching consumers need to be identified. Trans-disciplinary and inter-disciplinary cooperative research programmes, mustering the best resource from across the regions, need to be formed and funded to develop knowledge. That knowledge needs to be communicated clearly and shared freely and extensively. The present AASSA report is a contribution towards this end. The report builds off and complements other published reports on what is a complex and highly diverse topic.

2 Defining the challenge

2.1 Key elements for FNS at national and regional levels

The usual approach to addressing future food security needs is to model the projected population calorie needs with the projected food supply at a national level. However, it is well established that the simple provision of calories does not necessarily ensure a healthy diet; thus, there is the need to emphasise FNS, whereby a suitable variety of food types is available to everyone, such that no macro- or micronutrients (including trace elements and vitamins) are deficient and such that other health-promoting plant and animal compounds [e.g. marine omega-3 and other key fatty acids, phytochemicals, plant non-starch polysaccharides (fibre) and specific amino acids] are present in the diet in adequate amounts. The need for a balanced diet is exemplified by several data sets. By way of example and for Indonesia, the Food and Agriculture Organization of the United Nations (FAO) reports that:

'*despite a substantial rise in the availability of dietary energy, Indonesia has made slower progress in reducing undernutrition. The most recent data suggest that the prevalence of stunting in children under five years of age was 37.2 percent in 2013, implying inadequate access to diverse foods to support good nutrition*' (FAO, IFAD and WFP, 2014).

Also, modelling the projected food supply and demand, at a national level (a 'top-down' approach), although a valid starting point, provides a somewhat blunt approach ('one-size-fits-all'). There are often large regional and sectional differences in FNS; these need to be understood using a territorial approach that is multi-sectoral, bottom up and context specific (OECD, FAO and UNCDF, 2016).

As mentioned earlier, poverty is often the underlying cause of food insecurity, and addressing poverty is essential to finding sustainable solutions. Developing business opportunities and, in many cases, promoting off-farm (for the rural poor) employment can have a positive income-related effect on FNS. However, it is also known that raising incomes is a necessary but not always sufficient solution to FNS (Warr, 2014). In addition to low incomes, other influences of food insecurity include unemployment, natural resource degradation, low health, education status, a lack of infrastructure and markets, weak institutions and governance, and a lack of coordination across multiple policies and levels of government. FNS is a multi-dimensional problem and a 'total systems' approach needs to be taken in devising solutions.

In addressing FNS, in addition to identifying problems caused by under-nutrition, it is also important to consider an increasing prevalence in populations of excess bodyweight and obesity (with their attendant higher rates of incidence of non-communicable diseases associated with the metabolic syndrome) because of an over-consumption of food calories, poorly balanced diets and lack of physical activity.

Another aspect of food security worthy of mention is food safety. A secure food supply implies food that is free of harmful microorganisms and toxins and free from adulteration and contaminants.

'*Food security exists 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.*' (FAO, 1996).

The approach to FNS analysis adopted here was to use national and regional statistics for Asia and Oceania on projected population growth, population age distributions and economic development (as depicted by changes in the middle-class as a percentage of the total population), along with current estimates of under- and over-nutrition, to allow a focus on key countries and geographical areas that are most likely to face future FNS issues. The global nature of the likely issues is identified and case studies are given of how a 'bottom-up' territorial approach is vital in defining the challenges faced by certain regions and population groupings.

Finally, in addressing FNS, it is recognised that all four components of FNS (food production and availability, access, utilisation and stability) need to be considered. With respect to over-nutrition and the 'utilisation' factor, the nutritional and health sciences have a major role to play in defining a 'healthy diet', and the human behavioural and social sciences have important roles in allowing a better understanding of motivating factors towards maintaining a balanced diet and a balanced diet/exercise regimen. The 'stability' factor speaks to regional stability in relation to stable governance, stable population movements, the absence of war and strife, and disaster management, but also infers environmentally and socially sustainable food production systems. Food production is an outcome that is dependent upon a diverse and complex array of interacting processes and two-way influencing factors; to ensure that future food production is stable and sustainable requires an understanding of agri-based ecosystems at a systems level. The stability of agri-ecosystems is further challenged by climate change and by losses in biodiversity. The sustainability of food production and its future importance is discussed in section 2.9.

Recommendation: A strategy moving forward would be to undertake systems analysis to identify key impediments to raising food yields or supplying an adequate balance of food types. The systems analysis would prioritise extension, education and R&D needs, region by region and/or group by group, and would provide guidance on means of sustainably increasing food production and diversity. There will undoubtedly be some R&D/extension/education focus areas that are of global relevance and are universally applicable.

2.2 Projected changes in population size and age distributions

Recent and projected (United Nations medium variant) population sizes for the whole of Asia, for Oceania and for selected countries (refer to Table 1) are given in Table 3. It is projected that there will be around 1 billion (about half the projected world growth) more people in Asia in 2050 compared with today. There will also be considerable growth in the populations of Oceania, albeit off a relatively small base. However, the projected population growth across Asia is not even, with some countries (notably China and Japan) having a declining population size and others (e.g. India, Indonesia and Israel) having high population growth rates. Almost half of the projected population growth for Asia is in India. Other populous countries in Asia that are expected to have large (relative to current) increases in population (2015–2050) are Afghanistan, Bangladesh, Iran, Iraq, Kazakhstan, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Saudi Arabia, Syrian Arab Republic, Tajikistan, Turkey, Uzbekistan, Vietnam and Yemen, although the current conflicts in Afghanistan, Syria and Yemen make projections difficult.

The total population of the Pacific Islands (Oceania excluding Australia and New Zealand) is set to almost double by 2050. This is worthy of emphasis; as will be discussed later, many islanders are already prone to poor nutrition and the islands are particularly vulnerable to the effects of climate change. Under ‘worst-case’ climate change scenarios, islands such as Kiribati and Tuvalu may be completely flooded, because of rises in the Pacific Ocean. The entire populations of these islands may need to be resettled. It is predicted that, over the next 50 years, there will be a large net positive migration of peoples from Melanesia to Pacific Rim countries and, in particular, to Australia and New Zealand (New Zealand Department of Labour, 2012; Bedford *et al.*, 2014; United Nations Economic and Social Commission for the Asia and Pacific, 2014).

Many of the populations in Asia and Oceania are changing not only in size but also in age distributions. Information on projected age distributions is given in Table 4.

Currently, different parts of Asia/Oceania have different age distributions in their populations. India and Indonesia have notably young populations. However, almost all of the populations are ageing quite rapidly, such that, by 2050, around 20–40% of the respective populations will be made up of people 60 years or older. Countries such as India and Indonesia will have relatively younger populations whereas, in countries such as China, Japan and South Korea, older people

Table 3 Projections of total population size (millions) based on United Nations medium variants for Asia, Oceania and selected countries

	2015	2050 (projected)
Asia	4393	5267
Oceania	39	57
Australia	24	34
China	1377	1348
India	1311	1705
Indonesia	258	322
Israel	8.1	12.6
Japan	127	107
South Korea (Republic of Korea)	50	50
Thailand	68	63

Source: United Nations Department of Economic and Social Affairs, Population Division (2015). Also refer to Lutz and Samir (2010).

Table 4 Projected percentage distribution of the population in selected age groups

	2015		2050 (projected)	
Area	0–60	60+	0–60	60+
Australia	79.60	20.40	71.70	28.30
China	84.80	15.20	63.50	36.50
India	91.10	8.90	80.60	19.40
Indonesia	91.80	8.20	80.80	19.20
Israel	84.10	15.80	78.10	21.90
Japan	66.90	33.10	57.50	42.50
South Korea (Republic of Korea)	81.50	18.50	58.50	41.50
Thailand	84.20	15.80	62.90	37.10

Source: United Nations Department of Economic and Social Affairs, Population Division (2015). Also refer to Lutz and Samir (2010).

will be more predominant. For Japan and South Korea, more than 40% of the population will be aged 60 years or older. This has important implications for the future dietary and nutritional needs of these countries, as older people may require more energy-dense diets and greater amounts of higher quality dietary proteins to attenuate the effects of body muscle loss with ageing, which is related to impaired health and physical performance in general (Wolfe, 2012; Wolfe *et al.*, 2016; Santarpia *et al.*, 2017).

2.3 Projected changes in the middle-class

It is projected that, over the next two decades, there will be a surge in the middle-class (daily income of US$10–US$100, in 2005 PPP terms) globally (refer to Figure 2 and Kharas and Gertz, 2010). Given current economic growth rates, the world is evolving from being mostly poor to being mostly middle-class. It is projected that the year 2022 will mark the first time in recent history that more people in the world will be middle-class rather than poor. It is predicted that by 2030, 5 billion people (nearly two-thirds of the global population) will be middle-class. This potential increase in the global middle-class is associated with a significant geographical re-distribution, as almost all of the new members of the global middle-class will reside in Asia (see Table 5). This projection has positive implications for FNS, as poverty underlies food insecurity at an individual and family level. It also has implications for the types of food that will need to be produced in the future, as an expanding middle-class brings an increased demand for higher value foods such as meat, dairy products, eggs, fish, nuts and fruits. On the basis of these trends in increasing income, it is predicted that global meat and milk production will need to increase considerably to the year 2050 (FAO, 2010, 2011a; Alexandratos and Bruinsma, 2012).

The production of meat, milk and fish is resource intensive. However, the efficiency and competitiveness of animal production is dependent upon competitive land use and a consideration of the protein quality of the end product (van Zanten *et al.*, 2014; Ertl *et al.*, 2015, 2016; van Zanten *et al.*, 2016); this has implications, which need to be better understood, for sustainable world food production. Such foods are of high protein quality, provide relatively high amounts of essential minerals and vitamins and may have other health benefits, which, along with their organoleptic qualities, explain why people demand such products as their income increases. Also, people may seek such foods on the basis of cultural belief systems.

2.4 Current levels of under- and over-nutrition

2.4.1 Under-nutrition

Currently, in the world, around 850 million people suffer from hunger (calorie/protein insufficiency) and about another 2 billion people suffer from 'hidden hunger' (under-nutrition where calorific and protein needs seem to be met, but where micronutrients, minerals and vitamins are undersupplied). A graphic description of 'hidden hunger' in an Indian child's meal is shown in Figure 3. As discussed previously (refer to section 2.1), calculations of insufficient calorie intake (undernourishment) alone may significantly overestimate the number of food-secure people. For this reason, indices that cast a wider net than calorie provision alone have been developed. Data for the International Food Policy Research Institute (IFPRI) Global Hunger Index (GHI) for selected countries in the Asia/Pacific region are shown in Table 6. The IFPRI GHI is a composite of: percentage of population undernourished (calories);

Table 5 A rising middle-class in the Asia/Pacific region (millions of people)

	2009	2020 (projected)	2030 (projected)
Asia/Pacific	525	1740	3228

Source: Kharas and Gertz (2010).

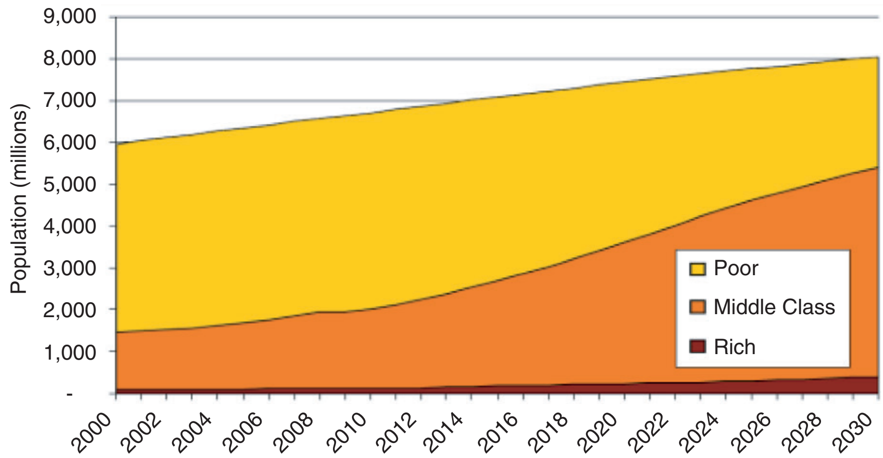


Figure 2 The projected increase in the global middle-class. Source: Kharas and Gertz (2010).

India

This example of a child's meal in India includes wheat, eggplant and potato.

What is missing?

Vitamin A: 62% of children under 5 years are deficient in vitamin A.
Iodine: Only 71% of households consume adequately iodised salt.
Iron: 70% of children under 5 years are anaemic.

*Figure 3 Snapshot of a child's meal in India. Source: The Chicago Council on Global Affairs (*2015*). Published with permission.*

Table 6 IFPRI[1] GHI[2] for selected countries in 2015

	GHI (2015)
Australia	Low
China	8.6
India	29
Indonesia	22
Israel	Low
Japan	Low
South Korea (Republic of Korea)	Low
Thailand	11.9

[1]International Food Policy Research Institute.
[2]Global Hunger Index (GHI): > 10, moderate; > 20, serious; > 35, alarming.
Source: International Food Policy Research Institute (2016).

percentage of children under 5 years suffering from wasting (low weight for height); percentage of children under 5 years suffering from stunting (low height for age); child mortality (before age 5 years). A score of 10 denotes moderate under-nutrition, a score greater than 20 denotes serious under-nutrition and a score greater than 35 denotes alarming under-nutrition. It is apparent that serious degrees of under-nutrition are currently found in parts of Asia and the Pacific, with populous countries such as India and Indonesia facing a significant challenge. Other countries in the area with evident significant under-nutrition (based on the GHI, 2015) are Afghanistan, 35; Bangladesh, 27; Cambodia, 23; Iraq, 22; Laos, 29; Malaysia, 10; Myanmar, 24; Nepal, 22; North Korea, 29; Pakistan, 34; Philippines, 20; Sri Lanka, 26; Tajikistan, 30; Turkmenistan, 13; Uzbekistan, 13; Vietnam, 15; Yemen, 34. It is clear that many of the countries facing rapid future population growth (e.g. India, Indonesia, Pakistan, Bangladesh, Afghanistan, Nepal, Myanmar, Philippines, Iraq and Yemen) are already grappling with significant FNS issues concerning under-nutrition.

Discrepancies between data for calorie provision and the GHI may not be entirely due to effects of micronutrient deficiency. Recently improved methods for describing dietary protein quality have been recommended (FAO, 2013). In a study of Indian diets, where the new improved methodologies were applied (Rutherfurd *et al.*, 2012), it was concluded that amino acid and protein deficiencies may be widespread in India, but such deficiencies are not apparent when using former approaches.

India has one of the higher incidences of childhood malnutrition in the world. Almost 30% of babies in India are born with low birthweight and are doomed to adverse consequences, including degenerative diseases in later life (Bharati *et al.*, 2011; UNICEF, 2016). A comparison of putative factors between regions (South Asia and Sub-Saharan Africa), countries within South Asia and select states within India suggests that neglect of women throughout their life is the main causative factor. A multi-disciplinary approach that is inclusive of food, nutrition, environmental and health security, with local planning and social changes to improve the health and nutrition status of women throughout their life, is required. The three 'A' strategy of awareness (among the community and the providers), access and affordability needs to be developed. A paradigm shift from child survival to child health, from literacy to education and skills for women, and from an emphasis on pregnant and lactating women to a life-cycle approach, as well as aid to empowerment through livelihood, is needed. Another country in the region deserving special mention is Timor-Leste, where a significant proportion of the population currently lives on less than US$1.90 per day, and where many people experience a 'hungry season' for up to 4 months per year (ACIAR, 2017).

2.4.2 Over-nutrition

Under-nutrition and its huge associated cost must be an emphasis of any FNS policy. However, in many countries, the development of non-communicable diseases such as cardiovascular disease, type 2 diabetes and certain forms of cancer, all associated with obesity, are becoming a significant source of human suffering and morbidity, and are contributing to early mortality. These conditions, associated with obesity, are leading to escalating medical costs worldwide (Bloom *et al.*, 2011; Withrow and Alter, 2011). Obesity is a complex condition, but fundamentally arises because of reduced physical activity and the over-consumption of food and alcohol and/or the consumption of a diet that is poorly

Table 7 Obesity[1] rates among adults in 2012, by selected countries

	% of population >15 years	
Australia	28	
China	2.9[2]	**But** large populations. Obesity (%) is on the. increase
India	2.1	
Indonesia	2.4	
Israel	16	
Japan	3.6[3]	
South Korea (Republic of Korea)	4.6	
Thailand	10.9 (2014)[4]	

[1]Defined as body mass index (BMI) > 30 kg/m^2.
[2]In some cities in China, rates of > 20% are reported.
[3]The prevalence of obesity in Japanese males doubled between 1980 and 2000.
[4]Ministry of Public Health (Thailand) (2016).
Source: OECD (2014). Also refer to Curtis (2004).

balanced for the macronutrients (protein, carbohydrate and fat). Like under-nutrition, it needs to be a focus of FNS policies moving forward. Obesity rates among adults in the year 2012 are shown in Table 7. At first sight, other than for Oceania (similar values for obesity as shown for Australia are found in New Zealand, and the Pacific Islands have some of the highest levels of obesity in the world, (World Health Organization for the Western Pacific, 2003)), the rates for the Asia area seem to be relatively low.

However, in some countries (e.g. Japan), the rate of change towards obesity is rapid and, for countries such as India and China, the relatively low proportions still translate to large numbers of obese adults.

A further indication of the rapidly escalating nature of obesity is shown by the data given in Table 8. Most of the countries in the Asia/Pacific region have high proportions of children who are deemed to be overweight. This portends poorly for the future development of obesity and would suggest that particular sectors of the overall population need to be identified and considered differentially. Countries such as India, for example, will probably face dual problems in the future that are consequent upon both under-nutrition and over-nutrition. Increasing rates of incidence of excess bodyweight and obesity have implications for the composition of optimal diets in the future. As both protein and plant fibre provide low available calories per unit degree of satiety compared with fat and available carbohydrate, high protein, high fibre diets are useful for weight loss (Westerterp-Plantenga *et al.*, 2012). Moreover, high protein diets may attenuate the loss of lean body mass that often

Table 8 Overweight[1] (including obesity) among children aged 5–17 years in 2010

	% of age group
Australia	23
China	20
India	20
Indonesia	10
Israel	22
Japan	20
South Korea (Republic of Korea)	23
Thailand	20 (2015)[2]

[1]Defined as BMI > 25 kg/m^2.
[2]Ministry of Public Health (Thailand) (2016).
Source: OECD (2014).

accompanies body weight loss (Clifton, 2012; Te Morenga and Mann, 2012; Santarpia *et al.*, 2017).

2.5 Food self-sufficiency versus food security

It is interesting to look at published figures for grain production in selected countries (FAO STAT, 1970–2014). Recent (2013–2014) data indicate total annual grain productions (kilograms per capita): China, 350; India, 190; South Korea, 70; Japan, 65; Russia, 700. Some regions in the Democratic People's Republic of Korea (North Korea) have low levels of annual grain production (< 146 kilograms per capita). Grain production is particularly high in Russia, although accessibility to food is an issue in areas such as the Russian Arctic, Siberia and the Far East. Countries such as South Korea and Japan have very low levels of grain production; however, although having low 'food self-sufficiency', they achieve high 'food security' by importing food. The low food self-sufficiency of countries such as South Korea and Japan does pose risks for these nations. On the basis of in-country food calorie production and consumption, Japan was only 39% and South Korea was only 42% food sufficient in 2010. The rural populations of Japan and South Korea continue to decline, and only 2.1% and 6.4% of the populations in Japan and South Korea respectively comprise farmers. The proportion of farmers older than 65 years is 50% in Japan and 40% in South Korea. Both the Japanese and the South Korean agricultural sectors are thus not well poised for expansion and remain vulnerable to international food shortages and fuel price shocks (Barrett and Notaras, 2012). However, Japan has well-considered plans to increase its food self-sufficiency (Japan Ministry of Agriculture, Forestry and Fisheries, 2016).

2.6 A territorial approach (case studies)

As discussed above, much of the nuance in FNS can be lost when reliance is placed on overall global and national statistics. The variation in FNS can often be greater within a country than between countries (OECD, FAO and UNCDF, 2016), and a territorial-based analysis is recommended to more properly understand the state of the drivers for FNS. Differentiation may be based geographically or socially (e.g. remote rural, versus rural, versus urban). The territorial approach to investigating FNS implies a shift from a sectoral (usually agricultural production), top-down, 'one-size-fits-all' approach to an approach that is multi-sectoral, bottom up and context specific. Geographical and social divides matter, and different groups may need different policy responses to account for their unique challenges. By way of example, food security issues in remote rural areas are not the same as those in heavily urbanised metropolitan areas; neither are the problems in one rural area necessarily the same as those faced in other (even adjacent) rural areas. Aspects that are specific to a territory or group strongly influence food security and nutritional outcomes. The strength of the territorial approach to FNS analysis (OECD, FAO and UNCDF, 2016) is exemplified here by four case studies. The first is based on an analysis of FNS in Cambodia that was undertaken by an FAO, OECD, UNCDF project team (OECD, FAO and UNCDF, 2016) and the second is based upon a study of FNS in the Hindu Kush Himalayan region (Rasul *et al.*, 2017).

A data set from Iran is given, showing marked rural/urban differences in micronutrient deficiencies, along with information on daily average per capita energy and protein intakes in the Kyrgyz Republic. In the fourth case study, inter-regional differences in FNS between North Korea and South Korea are discussed.

Case study one: Cambodia

Cambodia, located in South-East Asia, has a population (2015) of 15.58 million people, the population is both growing and ageing, and the country has a GHI of 23 (von Grebmer *et al.*, 2016), implying serious issues of under-nutrition. Cambodia experienced a significant degree of economic growth between the mid-1990s and 2007; however, in spite of this, levels of poverty (reflected in the GHI) remain high. The OECD, FAO and UNCDF (2016) territorial-based study showed that FNS outcomes vary across regions and provinces of Cambodia, and that the country's ability to deal with the territorial disparities is constrained by coordination failures and disconnects between various tiers of government, as well as between the many development agencies and non-governmental organisations (NGOs) operating in Cambodia. A territorial approach to FNS in Cambodia would be instrumental in helping to ensure that policies are delivered effectively to where they are most needed and reflecting local conditions, and that policies and programmes are linked effectively, to prevent fragmentation and duplication of effort (OECD, FAO and UNCDF, 2016).

According to the Cambodian Ministry of Agriculture, Forestry and Fisheries (2015), Cambodia is food secure, at least from a food availability perspective. In fact, Cambodia is a major exporter of rice (rice surplus in 2013–2014 of around 3 million tonnes). At the sub-national level, most of Cambodia's 25 provinces achieved positive levels of rice production in 2012, 2013 and 2014. The only provinces that failed to do so were Phnom Penh, Koh Kong and Preah Sihanouk. However, the benefits of this success in agricultural production are not distributed evenly at the sub-national level, and there is much inequality, particularly in rural areas where most families are smallholder farmers. Cambodia has the capacity to produce a variety of fruits and vegetables, but its ability to do so has been constrained by, among other things, inadequate infrastructure. Consequently, Cambodia imports (70% of supply) large quantities of fruits and vegetables (CARD, 2014) and Cambodians generally consume insufficient quantities of fruits and vegetables. Cambodia's livestock sector has fared better in recent years, benefiting from technical extension services and the provision of training to farmers (OECD, FAO and UNCDF, 2016).

Per capita income in Cambodia increased from US$0.67/day in 1994 to US$3.06/day in 2015. This increase in per capita GDP has increased the average Cambodian's net purchasing power and access to food. Cambodia's economic growth is attributable, in particular, to a recovery in its construction and tourism sectors, increased agricultural exports and increased exports of clothes. Although Cambodia continues to grow economically, and poverty has been reduced, close to 3 million Cambodians live in poverty (mostly in rural areas) and a further 8 million people live just above the poverty line (World Bank, 2015). Most rural households are net food buyers and spend most of their household income on food (CDRI, 2012). Rural households are particularly vulnerable to food shortages and increases in the price of food.

The territorial dimension

Poverty rates vary greatly across regions of Cambodia. The poverty incidence rate is as low as 6.5% in some territories and as high as 51% in others (OECD, FAO and UNCDF, 2016). A food security trend analysis, on the basis of food expenditure data, suggests that overall food consumption in Cambodia has improved (the percentage of the population below the minimum daily energy requirement fell from 37% in 2004 to 33% in 2009), but there is considerable inter-territory and inter-individual variation in FNS. Undernourishment was higher (59%) in the lowest wealth quintile and, although decreasing in some regions, increased in Siem Reap, the northwest region and the south coastal region. There are marked urban/rural gaps in FNS. Childhood malnutrition is particularly marked in poorer settlements around Phnom Penh.

The OECD, FAO and UNCDF (2016) report provides detailed data that make clear a rural/urban divide in FNS, as well as very large differences between provinces. The report goes on to identify key challenges and barriers to achieving and sustaining FNS in Cambodia, which also differ territorially and by sector, and how the Cambodian Government is addressing these issues. The report concludes:

'*The adoption of a territorial approach to FNS could address many of the shortcomings that have plagued Cambodia's efforts to address issues of FNS. A territorial approach to FNS would feature the integration of local stakeholders in the development of national and sub-national level strategic plans to address FNS. This would permit the tailoring of FNS initiatives to local needs, priorities and specificities... A territorial approach would promote the implementation of a holistic and integrated approach to FNS and rural development. Such an approach would aim to diversify rural economies rather than increase their dependence on a single sector... In short, sector-based policies would be abandoned in favour of cross-cutting approaches. Territorial approaches could also help resolve co-ordination challenges that have plagued FNS efforts in Cambodia... This would facilitate the development of sustained and holistic approaches and decrease reliance on short-term,* ad hoc*, sectoral, project-based interventions*'.

Case study two: Hindu Kush Himalayan region

In the study by Rasul *et al.* (2017), the Hindu Kush Himalayan (HKH) region is, for the purpose of their work, defined as the region that extends 3500 km across the high mountain regions of eight countries: Afghanistan; Bangladesh; Bhutan; China; India; Nepal; Myanmar; Pakistan.

Malnutrition and hunger are widespread in the HKH region. It is estimated that 415 million people are undernourished in the HKH countries, accounting for more than half of the 795 million people who are considered to be undernourished globally (FAO, IFAD and WFP, 2015). The often hilly and mountainous terrain of the HKH region imposes a burden on people's health and nutritional needs. A complex interaction between socio-economic, environmental (including food production) and cultural factors is considered to be the cause of widespread malnutrition.

The mountainous areas are particularly afflicted. Over 30% of the population of the Garhwal Himalayas in Uttaranchal, India, suffer from under-nutrition (Dutta and Pant, 2003). Under-nutrition is particularly high in the mountainous areas of Nepal (National Planning Commission of Nepal, 2013) and Pakistan (Planning Commission of Pakistan, 2011), where close to 61% of the population is food insecure compared with 49% at the national level. One-third to one-half of children (aged below 5 years) suffer from stunting, with the prevalence of wasting and underweight also being very high. The prevalence of stunting and wasting in children is particularly high in some mountain areas such as the Meghalaya state in India, the western mountains and far-western hills of Nepal, Balochistan province in Pakistan, eastern Afghanistan and the Chin and Shan states in Myanmar (Rasul *et al.*, 2017). Once again, territorial differences in the prevalence of malnutrition and the underlying causes are emphasised, and an integrated multi-sectoral multi-dimensional approach is promoted to achieve future FNS in these areas. Deterioration in FNS in these areas has gone hand-in-hand with changes in food habits. Traditional mountain food systems have declined in importance, with an accompanying decline in agro-biodiversity. Factors such as poverty, food availability and access, lack of sanitation, lack of infrastructure, inadequate nutritional knowledge and environmental degradation are noted as important influences.

In the mountainous areas of the HKH region, nutritional deficiencies (protein/energy, iodine, iron and vitamin A) result from the effects of several factors, including insufficient food intake related to poverty and/or inappropriate dietary practices. Infections and parasitic burdens, linked to poor sanitation and poor health-care practices, exacerbate the effects of nutrient deficiencies. The mountain areas have a low 'carrying-capacity' for agricultural production, and cropping systems have been reliant on diverse traditional crop varieties. However, rapid socio-economic change has led to changed land use, changed crop varieties and new food consumption patterns. The planting of nutritious traditional crops, such as amaranth, buckwheat, minor millet, finger millet, proso millet, foxtail millet, sorghum, barley and sweet potato, is declining; these crops are being replaced by higher-calorie-yielding crops such as rice and wheat, leading to a decline in agro-biodiversity. The production of traditional crops is declining because of factors such as a lack of awareness of their nutritional value, a lack of local markets for the produce and an increasing demand for crops such as rice, wheat and maize. Ironically, the production of pulses (often referred to as 'the protein of the poor') has declined in the area (Government of India, 2013), leading to increased prices, such that many poor people cannot purchase adequate amounts of pulses (Rasul *et al.*, 2017). These trends are negative for FNS. Food habits and diets in the HKH region have been undergoing changes in recent years that are caused by socio-economic development (roads, schools, and access to information via radio and television). There has been a shift in foods from home-grown foods to purchased foods, from coarse-grain foods (millets, buckwheat and amaranth) to fine-grain foods (white rice and white flour) and from traditional snacks and drinks to potato chips, instant noodles and soft drinks (Rasul *et al.*, 2017). These changes are more prominent in middle and lower elevation villages, and the consumption of the traditional coarse grains is often viewed as backward in the new value system.

The trend by the urban poor away from legumes and coarse grains, and towards the consumption of oils, fats and high-sugar products, is not unique to the HKH region but is general in both China and India (Du *et al.*, 2002).

Whereas total calorie intake has increased over the years, nutritional status has deteriorated (Iyer, 2012). Food systems in the HKH region are changing, agro-biodiversity is declining and food consumption patterns are changing. Rice is subsidised, and the low price of rice has led to a lowered consumer demand for traditional crops. Well-intended interventions may lead to inadvertent negative consequences for long-term FNS, underlining once more the need to understand the total food system at a local level.

Case study three: regional data for Iran and Kyrgyzstan

A data set depicting micronutrient deficiencies in Iran, designated on a rural/urban divide, is given in Table 9. A considerable territorial effect is seen, with very high rates of deficiencies in rural populations. Marked differences in dietary energy and protein intakes are seen in data relating to different cities in Kyrgyzstan (Table 10). Both energy intake and protein intake seem to be low overall, ranging from 2183 to 2652 calories/person/day for energy and from 59.1 to 70.9 g/person/day for protein. These data highlight considerable regional variation. It should be noted that, in the Kyrgyz Republic, although the proportion of the population suffering from dietary energy deficiency has fallen post-2009, problems, particularly with micronutrient deficiencies, prevail.

Case study four: political division of Korean peninsula

The Koreans, who lived as a united people for thousands of years, are now living in two separate areas, divided into North and South, with little exchange for 70 years. South Korea and North Korea have followed very different political ideologies, and today have different characteristics (Table 11).

The daily food intake of South Koreans averages 1.3 kg, and around 20% of that amount consists of animal foods such as meat, milk, fish and eggs. The average daily food energy intake is 2000 kcal per person (65% carbohydrates, 15% protein and 20% fat). An increase in levels of obesity, particularly child obesity, has emerged as a social issue, and the metabolic syndrome and its attendant degenerative diseases, including cancer, diabetes, hypertension and heart disease, are widely prevalent. With the unlimited importation of foods, self- sufficiency in total food energy production has fallen to below 50%.

North Koreans are dependent on 500 g of daily food rations (primarily maize) and consume very little animal protein. The average daily calorie intake is estimated

Table 9 Prevalence (%) of micronutrient deficiencies (rural/urban) in Iran (2012)

	Rural	Urban	Rural and urban
Iron (anaemia) (under age 2 years)	62	21	—
Zinc (preschool)	51	15	—
Vitamin A (pregnancy)	34	6	—
Iodine (goitre)	—	—	6.5 (2007)

Source: information supplied by Professor Jalal Jamalian.

Table 10 Regional variation in dietary energy and protein intakes in Kyrgyzstan (2009)

City/Region and Population		Energy (calories) per day per capita	Protein (g) per day per capita
Total Population	5,224,260		
Batken	431, 067	2345	60.4
Jalal-Abad	993,761	2652	70.9
Issyk-Kul	434,882	2349	63.8
Naryn	271,480	2183	59.1
Osh	1,339,205	2297	59.3
Talas	219,410	2443	65.4
Chui	762,492	2485	66.0
Bishkek	823,795	2519	69.7

Source: From the Kyrgyz Republic National Statistical Committee (2009); data supplied by Dr Dilfuza Egamberdieva, Academy of Sciences of Republic of Uzbekistan.

Table 11 Comparison between North Korea and South Korea of population composition, national income and farming populations

	South Korea[1]	North Korea[2]
Population (persons)	47,990,761	24,187,000
Population growth rate (%)	0.26	0.41
Population density (persons/km^2)	485.6	196.4
Per capita income (US$)	20,562	980
Farming population (persons)	3,062,956	8,573,000 (2008)
Farming population rate (%)	6.4	36.8 (2008)

Source: Statistics Korea (KOSTAT) (2011).
[1]Statistics of Ministry of Food, Agriculture, Forestry and Fisheries, Republic of Korea (2011).
[2]WFP/FAO/UNICEF, Rapid Food Security Assessment Mission to the Democratic People's Republic of Korea (2011).

to be 1600 kilocalories per person, and people are assessed to be chronically undernourished. According to a report on the nutritional status of North Koreans, on the basis of a survey of food consumption by households (Korea Rural Economic Institute, 2004), the severely vulnerable have been identified as 70,000 malnourished children, 980,000 pregnant or breastfeeding women and 2.3 million children under 5 years of age, totalling 3.35 million.

In October 2002, UNICEF, the World Food Programme and the North Korean Government jointly conducted a survey of the nutritional status of children under 7 years of age and their mothers from 6000 randomly selected households in 10 out of 12 cities across North Korea. The nutritional status of children had improved considerably over the previous 4 years and malnutrition was significantly reduced. Among the 6000 subject children, those noticeably underweight, compared with children of the same age group, accounted for 21%, whereas children of noticeably short height, compared with children of the same age group, composed 42% of the total.

The proportion of children deemed to be severely malnourished was 2.7% in the 2002 survey, showing a considerable improvement from 16% in a 1998 survey. Nevertheless, the proportion of stunted children and children underweight for their age still amounted to more than 20%. In this regard and without access to more recent data, it is considered that the nutritional status of North Korean children remains poor.

The survey found large discrepancies in child nutrition status by region, once again suggesting the need for a territorial approach to FNS analysis. The proportion of underweight children was 15% in Nampo and Pyongyang but 25% in North and South Hamgyeong provinces and Ranggang province. The proportion of stunting in children was less than 30% in two of the 10 target cities, Nampo and Pyongyang, but was 48% in South Hamgyeong province and more than 40% in other regions. The proportion of wasting in children was only 4% in Nampo and Pyongyang, but was 12% in South Hamgyeong province. In general, children from the mountainous areas were reported to be in a much worse condition than children in urban areas.

FNS should be addressed, so that Koreans can simultaneously solve the problems of surpluses and deficiencies in South Korea and North Korea respectively.

A message that is reinforced by the above territorial case studies is that different policies and solutions for FNS will probably be required for different regions and sub-regions and that, although increasing agricultural productivity (a feature of this AASSA report) is critically important, it is only one part of a well-constructed locally informed FNS development strategy.

2.7 The four dimensions of food security

A comprehensive analysis of the influences of the four different aspects of FNS (availability, access, utilisation and stability) in different regions of the world, including parts of Asia, has been published (FAO, IFAD and WFP, 2014). Each dimension of FNS was measured according to the influence of several underlying indicators. Available data were compiled and indicators (measured on a scale from 1 to 5) for each dimension were aggregated into composite indices, using weightings derived from principal components analysis. The results of the analysis are shown in Figure 4. The analysis is valuable for further defining the root cause of current failures to achieve FNS in Asia. The results point to South Asia being particularly vulnerable with respect to food availability and food utilisation. In the Caucasus and Central Asia, access and stability are concerns. Utilisation is an important consideration in both South-East Asia and Western Asia.

The countries apparently included in the geographical regions were as follows. Caucasus and Central Asia: Armenia; Azerbaijan; Georgia; Kazakhstan; Kyrgyzstan; Tajikistan; Turkmenistan; Uzbekistan. Eastern Asia: China; Democratic People's Republic of Korea (North Korea); Mongolia; Republic of Korea (South Korea). South Asia: India; Afghanistan; Bangladesh; Iran; Maldives; Nepal; Pakistan; Sri Lanka. South-East Asia: Brunei Darussalam; Cambodia; Indonesia; Lao People's Democratic Republic; Malaysia; Myanmar; Philippines; Thailand; Timor-Leste; Vietnam. Western Asia: Iraq; Jordan; Kuwait; Lebanon; Saudi Arabia; Turkey; United

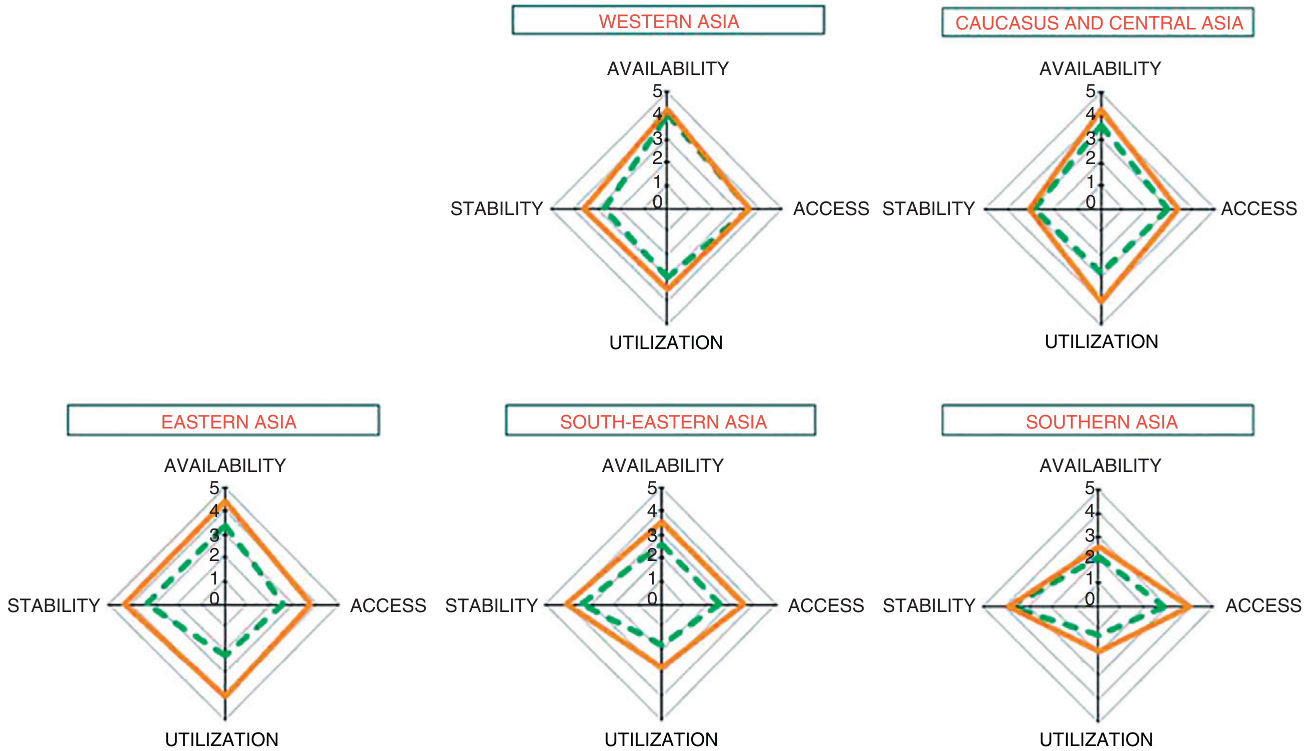


Figure 4 Evolution of food security dimensions in different parts of Asia. Reproduced from FAO, IFAD, WFP (2014) – with permission.

Arab Emirates; Yemen; Syrian Arab Republic; West Bank and Gaza Strip.

2.8 Key FNS challenge areas in Asia and the Pacific

FNS is recognised as a multi-factor problem; although all facets are important, this report focuses mainly on aspects of food availability (agricultural production and supply) and food utilisation. Our analysis identified high risk geographical areas for future FNS. These areas are characterised by current high levels of under-nutrition coupled with high projected rates of future population growth. Countries such as India, Bangladesh, Pakistan, Afghanistan, Nepal and Myanmar, as well as the Philippines, Iraq, Tajikistan and Yemen are deemed to be particular 'hot spots' for future FNS provision. The former group of countries (India, Bangladesh, Pakistan, Afghanistan, Nepal and Myanmar) may have elements in common for FNS (refer to section 2.6). Arriving at this list of 'at-risk' countries does not imply that all other countries in the region are free of future issues related to FNS; rather, it is intended to give a starting point as to where work may be most effective. In choosing these countries, an emphasis was placed on under-nutrition as opposed to over-nutrition as a primary vital factor for FNS, because, with under-nutrition, effects are immediate and often irremediable. This should not be interpreted as lessening the importance of the long-term deleterious effects of over-nutrition.

An FNS strategy must account for the need to produce a greater variety of food types and to promote education about healthy eating and healthy lifestyles to prevent obesity. Having said this, the provision of an amount of food daily, to avoid hunger and starvation, is a basic inalienable human right.

Most of the populations in countries in Asia/Oceania are ageing towards the year 2050, some considerably. Increasing levels of excess bodyweight and obesity are observable generally across Asia and Oceania, and alarmingly so in adults in countries such as New Zealand, Australia and the Pacific Islands. Obesity is prevalent and seems to be increasing in incidence in particular sectors of society in countries such as India, China, Japan and South Korea. It is clear from our analysis that, to generate knowledge and implement policies to ensure a sustained level of FNS, the complex phenomenon of FNS needs to be understood not only at regional and national levels but also at sectoral and sub-national levels. There is a dearth of quality data concerning FNS and its causes at more local levels.

Recommendation: Priority in relation to R&D and educational efforts should be given to countries and regions that have been identified as being at 'high risk' concerning current and future FNS. Particular focus should be afforded to India, Bangladesh, Pakistan, Afghanistan, Nepal, Myanmar (countries having elements in common), the Philippines, Iraq, Tajikistan and Yemen.

Recommendation: Consideration should be given to the effects of different age distributions in future populations, with respect to dietary types and nutritional needs as related to FNS.

Recommendation: Any consideration of future FNS should take into account not only the production of more food calories and nutrients (to combat potential under-nutrition), but also the production of a wider diversity of food types and strategies to prevent obesity and its associated non-communicable diseases.

Recommendation: Work should be undertaken in countries and regions at 'high risk' of future FNS, at a more localised provincial and sectoral level, to generate data to allow a better understanding of FNS and its drivers.

With reference to the first recommendation made in this report (see Appendix III), it is envisaged that a comprehensive systems analysis would be applied to the agri-food systems in at-risk countries, and in distinct geographical areas and demographic sectors within them, to identify the key impediments to raising food yields or the supply of an adequate balance of food types. Identification of the main predicted impediments would allow the formulation of a master 'blueprint' for R&D such that funding would be carefully focused around areas most likely to give the best return on investment and to allow most progress to be made in implementing solutions. The outcome of the systems analysis would be used to prioritise extension, R&D and education needs. Although not fool-proof, and relying on certain a priori assumptions, this approach does at least allow a logical and structured (rather than a 'shotgun') approach to developing an R&D, education and extension plan. If satisfactory progress is to be made, within what, in research terms, is a tight time line (2020 to 2050), an orderly well-planned approach is paramount.

2.9 Socially sustainable diets and environmentally sustainable food production systems

The delivery of FNS at a time of increasing pressures, from population growth, climate change, social and economic inequity, instability, the need to avoid further loss of ecosystem diversity and pressures on limited resources such as land, water, phosphates and harvestable energy, is a very considerable global challenge.

Diets of the future will need to account for the beliefs and preferences of society in relation to factors such as animal welfare, land use, ethics, optimal dietary patterns and risks associated with new technologies and will, therefore, need to be socially sustainable. This will impact agriculture and food production, but the definition of socially sustainable diets is likely to differ among regions, according to cultural imperatives.

There is no doubt that the global net food supply will be required to increase dramatically towards the year 2050. The required increase in the net supply may involve reducing food wastage and effects brought about by changing food consumption patterns, but will also involve producing more food from existing agricultural land. This will involve both lifting existing yield gaps (Dogliotti *et al.*, 2014) and the further intensification of food production from land that is currently considered to be yielding at a high level. Intensive agricultural production is already associated with environmental costs through features such as nutrient runoff and eutrophication of waters, greenhouse gas (GHG) emissions, soil erosion and soil degradation, as well as resource costs such as depletion of water and fertiliser reserves. Future farm production will be expected to reduce these negative environmental impacts. 'Sustainable intensification' will be required, and this will require a step-change in S&T (Pretty *et al.*, 2010; Parker *et al.*, 2014). Clearly, increased production per plant or animal, in a sustainable manner, reduces the amount of by-product (e.g. methane) production per unit (e.g. kilograms of grain or kilograms of meat).

Agriculture and food production do not exist in isolation, but are part of a widely interconnected multi-functional landscape or agri-ecosystem (Pretty, 2008; Garnett *et al.*, 2013; Godfray and Garnett, 2014; German *et al.*, 2017); for sustainability, the wider ramifications (environmental, economic, social, etc.) of changes to the systems need to be carefully assessed. These systems are not just localised; there is inter-connectedness between local, regional and global food systems, physically, biologically, economically and socio-politically, with serious implications for trade, climate change, land use and resource use and for FNS and future world political stability. Commonly, resource use in the system is improperly costed (subsidies, etc.) or resources are treated as free-of-cost (Garnett *et al.*, 2013). If the principles of natural resource economics were applied to agriculture, whereby all externalities were fully costed and the costs were internalised into the costs of production, there would undoubtedly be significant shifts in the type of food production.

There would also probably be shifts in types of food production if nutritional and health needs pervaded agricultural and health policies and governance. Such pervasiveness is urgently needed. There is much work to be done to understand fully what constitutes a healthy and sustainable diet, and how it should be produced and accessed. An integrated view is needed to tackle cross-cutting issues and to identify opportunities for a cross-disciplinary approach (including cross-disciplinary S&T) to finding solutions. The solutions for future FNS will also be context and cultural specific.

3 Science and policy context

Planning for future FNS issues requires strong commitment by politicians and policy-makers alike, but scientists must provide the robust data-driven advice from which these decisions are made. Public debate on FNS, and on the relevant government interventions, must include engagement with experts in the agricultural, nutritional and economic sciences.

As opposed to Europe, which has strong trans-national (e.g. EU) policies and regulations regarding food security, the Asia/Oceania region has no over-riding science or policy body, and policies and the involvement of scientists and scientific societies varies widely among individual nations. Table 12 briefly outlines the role of scientists in governmental and food security policy.

Relevant national and regional policies for FNS should include the following.

1. Policies that affect technological or other innovation in food systems, including, for example, those relating to the following.

    - Biotechnology in agriculture and other 'new food' technologies.
        - A common vernacular for describing the use of biotechnology in crop/strain improvement should be developed. The terms 'GMO', 'GM', 'biotech', 'genetic engineering', etc. are used interchangeably in different countries and by different agencies. As even classic breeding involves genetic modification, a precise vocabulary is called for.
    - Animal welfare.
    - Labelling of food with regard to nutrient content and nutritional value.

2. Policies that build human resources, including those relating to the following.

    - Education and training.
    - Attracting young people to work in food systems and agri-food research.

3. Policies that help to redesign the agricultural economy, particularly in regard to land use, the environment and other rural development.

    - Social policies, including access to food.
    - Policies to promote the consumption of sustainable, healthy food.
    - Policies on climate and energy use, water availability and quality, habitats and biodiversity.
    - Policies that mediate the relationship between countries within the region, and indeed with the rest of the world (e.g. trade agreements and development aid).

As food security issues often know no borders (e.g. environmental conditions, contaminations, disease, seed policies, etc.), it is essential that Asia/Oceania develops international coordination that will deal with these issues as they relate to FNS. Indeed, many general policy areas are relevant to FNS: agriculture; development; trade; immigration; consumer health; environmental protection; industry; public sector research; innovation. Further, when concrete policies are adopted, outcomes and impacts are often not properly evaluated from a social science perspective. Thus, it is necessary to mobilise scientific resources and use the evidence base to evaluate whether current policy interventions are effective; these evaluations should be publicised and discussed in neighbouring countries to enable the development of future policy.

When scientific data are used in policy decisions, it is also important to emphasise that all scientific inputs must be subject to appropriate peer review and that the policy users of research outputs must be aware of the potential influence of stakeholders. Furthermore, there is an opportunity to use the latest tools of assessment, such that new policies and innovations should be measured in terms of their regional and national impacts. An assessment that allows for navigation through multiple scales to better address communities and small farmers is needed. This will require the cooperation of biological/agricultural scientists with experts in the social and economic sciences who are versed in advanced econometric analyses and with policy-makers.

It will be instructive for the countries in the region to learn from the experience of other regions, particularly Europe, as an example of a unified approach, and Africa, where diverse countries have attempted to organise at a trans-national, regional level. Special mention needs to be made of China's influence in the Asia/Pacific region, because of its growing role as the region's export destination and its increasing infrastructure investments and initiatives such as 'the Belt and Road' (the New Silk Road) and the Asian Infrastructure Investment Bank. Also mention should be made of national and international programmes on FNS that are operational within the region (for example, the Food Security Mission, the Climate Smart Village and the Prime Minister's Crop Insurance Plan, in India). Such programmes, although undoubtedly useful, tend to be disjointed and would benefit greatly from synergistic linkages among the programmes. A 'climate smart' village must also be a 'nutrition smart' village and an 'income smart village'. S&T-related initiatives need to

Table 12 The formal role of scientists in developing and implementing government FNS-related policies

Country	Main science advisory officer	Agricultural science advisor and roles
Australia	Chief Scientist—provides high-level independent advice to the Prime Minister and other Ministers on matters relating to science, technology and innovation. Holds the office of Executive Officer of the Commonwealth Science Council.	Agricultural Chief Scientist of the Department of Agriculture and Water Resources—provides leadership and coordination to science activities in the Department. Ensures that high-quality science remains an integral part of the evidence base used in departmental decision making and leads Science Strategy 2013–2018 (DAFF, 2013).
China	Ministry of Agriculture of the People's Republic of China.	The Ministry of Agriculture (MOA) is a component of the State Council in charge of agriculture and rural economic development. It works on development strategies and long-term and mid-term development plans of agriculture and the rural economy, agricultural policies and agricultural scientific research. Specifically, the National Advisory Committee on Food and Nutrition affiliated to the MOA addresses food and nutrition issues.
South Korea	Scientists in Rural Development Administration (RDA) are responsible for FNS policy development and implementation.	Scientists in academia and research institutes are involved in the national committees for agricultural policy and other advisory activities. Korean Academy of Science and Technology and Korean Federation of Science and Technology Societies provide opinions and recommendations on FNS policy to the government.
India	Office of the Principal Scientific Advisor to Cabinet.	Director General of the Indian Council of Agricultural Research to plan and implement agricultural research programmes.
Indonesia	The Indonesian Ministry of Agriculture.	The Indonesian Ministry of Agriculture released a Strategic Plan for 2015–2019. It provides directions, targets, agricultural development programmes and control policy measures.
Israel	Office of the Chief Scientist—fosters the development of industrial R&D (including agricultural industrial research).	Chief Scientist of the Ministry of Agriculture and Rural Affairs—identifies agricultural problems in which knowledge gaps exist, determines research goals to bridge such gaps, funds such research activity (in universities and government research units) and monitors research performance, to guarantee the implementation of the outcome for the benefit of farmers, public and environment.
Thailand	National Research and Innovation Policy Council (including agriculture research). Thai National Food Committee.	The National Research and Innovation Policy Council is the single body that sets directions and policy, and produces a roadmap for research and innovation to facilitate national development. The Thai National Food Committee sets the Strategic Framework for Food Management in Thailand for FNS.

be congruent with other related initiatives at the district and national levels (for example, e-market, digital and IT initiatives, skills development and employment issues).

Within Asia/Oceania, the following trans-national bodies already exist and influence FNS policy (Table 13).

Recommendation: Scientific evidence juxtaposed with advanced assessment analyses should inform and influence policy options. To ensure and further encourage the involvement of scientists in policy decisions, at the national and regional levels, regional frameworks that encourage and facilitate interactions between government, NGO policy-makers and scientists should be initiated.

Recommendation: The IAP should convene an expert panel to determine an agreed-upon nomenclature for use in describing crops developed through biotechnology techniques. Genetic modification (GM) is a natural process, and there is confusion with current terminology.

3.1 Regulatory mechanisms regarding the use of crops or food products containing GM material

Policies regarding research and the implementation of GM crops vary widely across the region (Table 14).

Within the EU, for any GM crop to be approved, it must first undergo extensive science-based food and environmental safety evaluation by the independent European Food Safety Authority (EFSA), which is composed of 21 independent scientific experts (http://www.efsa.europa.eu/en/faqs/faqgmo.htm). If found to be safe, the EFSA then recommends to the EU that the crop be adopted; it then drafts a proposal to the section on GM Food and Feed of the Standing Committee on the Food Chain and Animal Health. If the Committee accepts the proposal, it is adopted by the European Council.

Table 13 Cooperative trans-national platforms in Asia/Oceania

Cooperative platform		Member countries	Main objective	Establishment
APEC	Asia–Pacific Economic Cooperation	Australia, Brunei, Canada, Chile, China, Hong Kong, Indonesia, Japan, South Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, Philippines, Russia, Singapore, Taipei, Thailand, USA and Vietnam	Supporting sustainable economic growth and prosperity in the Asia/Pacific region.	1989
ASEAN	Association of South-East Asian Nations	Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei Darussalam, Vietnam, Lao PDR, Myanmar and Cambodia	Promoting economic growth, social progress, cultural development and peace in the region.	1967
SAARC	South Asian Association for Regional Corporation	Afghanistan, Bangladesh, Bhutan, India, Nepal, the Maldives, Pakistan and Sri Lanka	Developing economies and collective self-reliance in the South Asian countries and stepping up the social and cultural development in South Asian countries.	1985
BIMSTEC	Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation	Bangladesh, India, Myanmar, Sri Lanka, Thailand, Bhutan and Nepal	Technological and economic cooperation, including commerce, investment, technology, tourism, human resource development, agriculture, fisheries, transport and communication, textiles, leather, etc.	
SCO	Shanghai Cooperation Organisation	China, Kazakhstan, Kyrgyzstan, Russia, Tajikistan and Uzbekistan. India and Pakistan likely to join in 2016	Primarily focused on security.	1996
MGC	Mekong–Ganga Cooperation	India, Thailand, Myanmar, Cambodia, Laos and Vietnam	Areas of cooperation: tourism, culture, education and transportation, to improve future trade and investment.	2000
SASEC	South Asia Subregional Economic Cooperation	Bangladesh, Bhutan, India, the Maldives, Nepal and Sri Lanka	Promoting regional prosperity by improving trade and strengthening regional economic cooperation.	2001
ADB	Asian Development Bank	Over 67—of which 48 are from within Asia and the Pacific and 19 are outside	Fostering economic growth and cooperation in the region of Asia and the Far East, and contributing to the acceleration of the process of economic development of the developing members in the region, collectively and individually.	1966

Source: Prins and Vojevoda (2016).

Table 14 Current status of GM technology approvals in food-based agriculture in Asia/Oceania

Country	Current status of GM technology approvals in food-based agriculture
Australia	Field trials for many GM crops have been approved by the Office of the Gene Technology Regulator (OGTR). GM cotton (insect resistance and herbicide tolerance) and GM canola (herbicide tolerance) are grown across several states, authorised by the OGTR. South Australia and Tasmania have trade-based moratoria. The labelling of food containing GM products is regulated by Food Standards Australia/New Zealand.
China	China has issued biosafety certificates for seven types of crop. It has approved the production of GM cotton and GM papaya only and prohibits commercialisation of other GM staple foods, but approves five kinds of GM crops to be imported as raw materials (soya bean, maize, cotton, rape and sugar beet). The policy of labelling takes a product-centric mandatory approach. China will strengthen the technical study and safety management of GM technology, while also raising better public awareness of the issue. GM technology research has entered a stage of independent innovation, with a series of major achievements in key functional gene discovery and the development of new cultivars.
Japan	Genetic engineering (GE) regulations in Japan are science based and transparent, and new events are generally reviewed and approved within acceptable time periods that mostly align with industry expectation. So far, over 160 events have been approved for food use. As one of the world's largest per capita importers of GE crops, improvement of the Japanese GE regulatory system has focused on long-term trends in biotechnology and will benefit all stakeholders. So far, over 120 events in eight crops have been approved for environmental release, which includes cultivation. So far, there is no commercial cultivation of GE food crops in Japan. The GE rose released by Suntory in 2009 is still the only GE crop that is cultivated commercially in Japan.
South Korea	No GM crops are allowed to be cultivated in Korea, but they are allowed to be imported for food and feed uses, when they are approved for safety by the Korean Food and Drug Administration and for the environment by the Ministry of Food and Agriculture. Field studies are allowed in a restricted area, but anti-GM groups protest against biotech research. Labelling of GM food is compulsory for soya bean, corn, canola, sugar beet, alfalfa and their processed foods. Labelling of products that do not contain modified DNA and/or proteins derived from it are exempt.
India	Academic research is encouraged. Crops other than *Bacillus thuringiensis* (Bt) cotton have not received approvals.
Indonesia	Researchers continue to develop GM crops and field studies are regulated by the Ministry of Agriculture. Indonesia has not cultivated any GM crops commercially.
Israel	Academic research is highly encouraged, and field studies are regulated by the Ministry of Agriculture and Rural Development. No GM crops are grown commercially for economic/trade reasons, as Europe is a major agricultural market. There are no policies for the labelling of food containing GM products.
Thailand	Biosafety testing of GM crops in the field requires controlled studies on effects on the environment and health in different locales, a public hearing and Cabinet approval. As a result, no GM crops have been tested in the field in Thailand. The Thai Government has banned the commercial planting of GM crops but does allow imports of GM soya beans and corn for a wide range of domestic uses, in both the feed milling and food processing industries.

Before labelling issues are considered, any food or feed containing a plant that has undergone GE must be shown through extensive risk analyses to be safe for both the consumer and the environment. Once approved as safe for the consumer, GM crops must then meet EU GM food and labelling regulations. Much controversy surrounds these regulations as they are 'trade based' and not 'science based'.

Whereas, in the USA, there is no mandatory labelling of food made from crops that have undergone GE, the threshold for a food or feed to be labelled as containing GM organisms in the EU is 0.9%. This arbitrary threshold has no safety implications (as safety was determined for 100% GM) and is used only for regulatory purposes [Regulations (EC) Nos 1829/2003 and 1830/2003]. In non-EU countries, the thresholds for labelling vary. For example, the threshold is 3% in Korea, 5% in Japan, Thailand and Indonesia and 1% in Australia.

As detailed in Chapter 6, the development of clustered regularly interspaced short palindromic repeats (CRISPR) technology in agriculture disrupts these policies, necessitating new, hopefully, regional and global policies that will enable the use of this technology worldwide for the good of global agriculture.

Several groups have undertaken foresight and horizon-scanning exercises to identify key S&T areas and dimensions for the development of policy. Some of these are discussed in Chapter 6 and are listed below in Table 15.

Table 15 S&T dimensions of policy issues: foresight and horizon scanning to identify broad themes for filling research gaps in FNS

Source	Research priority areas
Pretty *et al.*, 2010	*Natural resources*, e.g. climate, water, energy, soil, biodiversity, ecosystem services and conservation. *Agronomic practices*, e.g. crop productivity, genetic improvement, pests and diseases management, and livestock. *Agricultural development*, e.g. social, capital, gender and extension services, livelihoods, governance and economics. *Markets and consumption,* e.g. food supply chains, prices, trade, dietary patterns and health.
Parker *et al.*, 2014	*Feeding a larger and wealthier global population sustainably and equitably*, e.g. improving production and reducing waste, increasing efficiency of use of resource inputs, dietary choice and governance frameworks. *Climate change adaptation practices*, e.g. agriculture. *Multi-functional land use planning*, e.g. balancing competing demands for food, energy and environment.
Steering Committee of the EU Scientific Programme for Expo, 2015	*Improve public health through nutrition*—healthy and sustainable consumption. *Increase food safety and quality.* *Reduce losses and waste*—more efficient food chains. *Manage land for all ecosystem services*—sustainable rural development. *Increase agricultural outputs sustainably*—sustainable intensification. *Understand food markets*—in an increasingly globalised food system. *Increase equity in the food system.*
ASEAN Plan of Action on Science, Technology and Innovation (APASTI) 2016–2025)	• Food security: improvement of productivity; optimisation of resources; food safety standards; adequate nutrition. • Biodiversity for health and wealth.
The Future of Food and Farming, Foresight Programme in the UK Government Office for Science	• Improving productivity sustainably using existing knowledge. • Using new S&T (e.g. GM, cloning, nanotechnology, etc.), after rigorous multi-element appraisal, to raise the limits of sustainable production. • Reducing food wastage. • Sustainable fisheries management. • Developing sustainable intensification. • Mitigating effects of climate change.

The last report listed in Table 15 (UK Government) has an accompanying Action Plan (UK Government Office for Science, 2011). This plan is an excellent exemplar of an implementation pathway for FNS science and policy. As well as targeting its own relevant national government departments and research councils, the report actively influences international agencies such as: the United Nations High Level Task Force on Global Food Security; the Organisation for Economic Cooperation and Development (OECD); the World Bank; Oxfam; the Bill and Melinda Gates Foundation; the World Economic Forum.

3.2 S&T policy: encouraging collaboration

It is generally recognised that science, technology and innovation drive modern economies and, around the world, governments are recognising the importance of international scientific research collaboration.

Palmer (2014) noted that, in reality, science is a global enterprise and is becoming increasingly more so as it continues to assist in addressing questions of global significance. In 2011, there were over 7 million researchers worldwide, with a combined international R&D spend of over US$1 trillion. This represents a 45% increase since 2002 (The Royal Society of London, 2011). Many of the major challenges facing humans (e.g. energy supply, food and water security, climate change and population changes) are global and highly interconnected.

Solutions are likely to be multi-disciplinary based and involve cross-border knowledge generation and sharing. To maximise the chances of providing solutions in a timely manner, robust national-level and international-level policies will be required, to promote the application of evidence-based knowledge by multi-disciplinary international science collaborations.

There are examples (e.g. the Large Hadron Collider and the Human Genome Project) of successful multi-disciplinary collaborations of global significance. Such sizeable well-resourced collaborations in FNS should be encouraged. Advances in information and communications technology (ICT) as well as easier, cheaper travel have greatly assisted the logistics of international research collaboration.

Researchers can and do develop international science collaborations through developing their own personal networks, but there is much opportunity for accelerated collaboration through targeted research collaborations, and national and regional policies should allow for and incentivise this. The European Cooperation in Science and Technology, COST programme, is a shining example of such a programme within Europe. Traditionally, global innovation networks have been dominated by the USA and Europe, but there is a new dawn ('the Asian Century'—see Australian Government, 2012), especially with the ascendancy of science in China and India, and a great opportunity exists for establishing more formally S&T networks and collaborations in the Asia/Oceania region.

Recommendation: Policies at both national and regional levels within Asia/Oceania should be developed, to form multi-disciplinary S&T collaborations to target specific outcomes.

3.3 S&T policy: barriers to trade

The Asia/Oceania region can benefit greatly from 'gains from trade', and a more open, transparent market place for foods has the potential to greatly assist the region in achieving FNS in the future. To promote trade requires government policies to remove or reduce tariff and non-tariff barriers to trade, as well as to form cooperative free-trade agreements. The necessary economic and political incentives need to be in place, to encourage increased food production and export in those countries that have a natural comparative advantage for particular types of food production. Supply chain transparency and suitable consistent regulatory integration are also necessary.

Regional strategies, policies and regulatory activities need to be cohesive and supportive of international trade in food and agriculture.

4 Strengths and weaknesses of S&T at national/regional levels

4.1 S&T as the engine of long-term change in FNS

Long-term improvements in FNS are directly linked to scientific and technological advances and thus to R&D. The huge gains in FNS in Asia, in particular, and indeed globally over the past half century are due to the adoption of advanced technologies in seed and crop development, irrigation, mechanisation and data analysis, which themselves are direct outcomes of years of basic and applied research.

To keep our terminology clear, we use here the OECD definitions.

'**Basic research**' is defined as *experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.*

'**Applied research**' is defined as *original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.*

Although these gains are clearly recognised, as seen in Figure 5, the benefits of investments in S&T research are realised only years, if not decades, following the initial research investment. This lag in return is detrimental to political desires for fast improvements that fit a voting cycle.

Clear examples of such investment are illustrated in Figure 6 (Beddow, 2012), which shows, over the past century, the rate of adoption of new technologies in the USA from discovery to acceptance. As these data come from the USA, these graphs represent rates of adoption of novel, initially unproven, technologies, developed within the same country, within a mature market. Yet these trends are important for understanding future trajectories in different parts of Asia.

It took over a quarter of a century before hybrid maize became the dominant technology in the corn industry because of its outstanding yields. Similarly, the adoptions of herbicide use and advanced fertilisers took three decades to permeate the market. Interestingly, this R&D lag has shrunk, especially in the adoption of GM technology, where, for some crops, the lag has been 15 years or less. In contrast, the lag for the adoption of GM technology for most food crops has so far been endless because of regulatory issues.

For most of Asia, over the past 50 years, the extensive gains in FNS have been due to the adoption of technologies based largely on discoveries made in laboratories primarily based in North America and Western Europe. A glaring exception to this, and an exemplar of what is possible, is the development of drip irrigation technology in Israel in 1959. The first commercial producer of drip irrigation equipment, Netafim, was founded in 1964. Today, Netafim is the global market leader in drip irrigation. The industry's second largest producer is Indian NaanDanJain Irrigation Ltd, which was formed between the merger of the Israeli NaanDan company and the Indian Jain Irrigation Systems Ltd company. Because of drip irrigation, crops are now growing in desert and marginal climates, which would not have been feasible previously. Water conservation efforts in some regions of the world that are susceptible to drought have incorporated drip irrigation as the primary method of watering crops. Crop yields in virtually all environments have increased significantly while utilising less water because of drip irrigation technology. For example, in the Philippines, the installation of a sub-surface drip system on a sugar cane farm resulted in a 90% increase in yield compared with conventional irrigation methods, and a 70% reduction in water use– resulting in a dramatic increase in water productivity and a 5% increase in sucrose content as an added benefit. The most dramatic gains have occurred in China and India, the world's top two irrigators, where the area under micro-irrigation expanded 88-fold and 111-fold respectively over the last two decades. India now leads the world, with nearly 2 million hectares under micro-irrigation methods. Significantly, it must be pointed out that the development of drip irrigation was first a result of private initiative followed by industrial R&D and not a long-term benefit of a national science agenda.

Other examples, of Asia/Oceania centric technology developments, are: grazing systems and pasture seed varieties developed in New Zealand; soil conservation methods developed in Australia; plant/aquaculture systems developed in China; cassava breeding programmes in Thailand giving rise to the high yielding cassava Kasetsart 50 or KU_{50}. KU_{50} is the world's most widely cultivated cassava variety and accounts for 1 million hectares of land in Thailand and Vietnam, as well as large areas in Cambodia, Indonesia, Laos and the Philippines (Schmidt, 2016). Considerable lifts in agricultural productivity have been accomplished in Myanmar with the development and planting of insect-resistant Bt cotton (Ngwe Chi 6; James, 2015). The Philippines is highly active in plant-based biotech research and commercialisation, with several GM varieties being developed and approved for use. With proper investment, future gains in Asia/Oceania will come from additional technologies developed locally, and this will be particularly important in the context of localised problems and opportunities.

Current knowledge and new understandings emanating from research programmes can be used in conjunction with 'real-time data capture' within agri-production systems, to derive a dynamic approach to optimising inputs (e.g. water, fertiliser and pesticides).

4.2 S&T within the Asia/Oceania region at the national level

Investment in S&T across the region varies widely (Table 16 and Figure 7), but can be divided roughly into four classes.

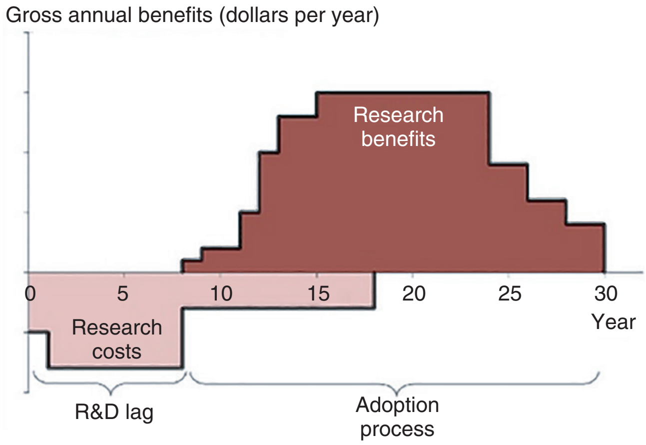


Figure 5 Research lag between investments and benefits. From Alston et al. *(2008).*

4.2.1 *Mature S&T countries*

Australia, New Zealand, Israel, South Korea and Japan have mature S&T cultures that are on a par with those in North America and Western Europe. National funding agencies in these countries have, for the past two decades, encouraged basic research, with translation and application often funded through the private sector. However, with the clear exception of South Korea, the steep increases in research funding at the beginning of the 21st century have levelled off and even decreased. This worrisome trend is also being seen in other developed regions of the world. Considering the research lag from investment to benefit, this drop-off in research investment from countries with a proven history of agricultural research and technology could have far-reaching negative effects in the latter half of the 21st century, in missed opportunities for innovation and agricultural gains.

4.2.2 *Advanced developing S&T countries*

India and China are the prime examples of countries where the national governments over the past two decades have made major commitments to academic and industrial research infrastructures, and to recruiting leading scientific authorities to lead these laboratories, often recruiting them from high profile positions in western countries. Whereas initially applied in nature, a growing investment in basic research is spearheading rapid S&T development. Integration between public and private sectors is often difficult and still needs to be further developed. China, in particular, has increased R&D funding 350% over the past two decades, having surpassed the research funding of the EU, and soon to surpass that of the USA. Although India is ranked sixth in the world in total R&D expenditure, as a percentage of GDP, it still lags leading investors.

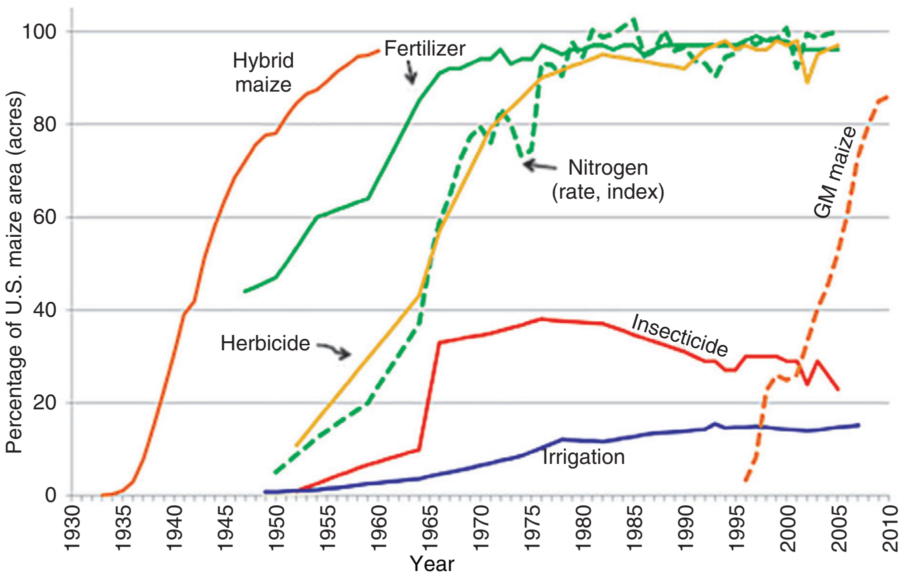


Figure 6 Rate of adoption of new technologies underpinning maize production on the USA (1935–2010). From Beddow (2012).

Table 16 R&D investment in selected countries of Asia/Australasia

Country	R&D investment as % of GDP (PPP)	Total investment in R&D (billions of US$, PPP)	Change in GDP since 1996 (%)
Australia	2.12	23	137
China	2.10	409	360
India	0.85	66.5	130
Indonesia	0.08	2.0	125
Israel	4.30	12.7	158
Japan	3.60	179	129
South Korea	4.30	91	192
Thailand	0.39	12.7	400

Data taken from Australia, Australian Bureau of Statistics (2015); China, National Bureau of Statistics of the People's Republic of China (2016); India, R&D Magazine (2016); Israel, OECD (2017); Indonesia, Japan, South Korea and Thailand, World Bank (2017).

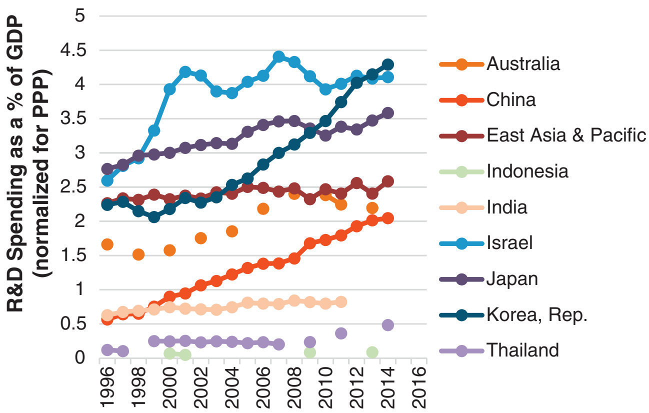


Figure 7 Trends in R&D expenditures (% of normalised GDP). Data taken from the World Bank (2017) and data within.

4.2.3 Developing S&T countries

Thailand exemplifies countries where the government has recently placed an increasing emphasis on national R&D. Thailand has increased R&D expenditures over 400% in the past 20 years, and now has some excellent international centres of S&T, which can influence regional FNS. Much of the research connected to FNS is goal based, and the leading scientists are still largely trained abroad. However, R&D spending as a percentage of GDP is still low. If Thailand continues the trends of recent years, R&D spending could reach 1.5% of GDP within a decade, with significant scientific and economic returns expected.

4.2.4 Countries with limited S&T capacity

Many of the countries in the Asia/Oceania region, particularly in South-Eastern, Central and Western Asia, are currently lacking in significant investment in S&T. For example, Indonesia invests less than 0.1% on R&D. As these countries struggle to reach millennium goals, the long-term political will for investment in basic science infrastructures is tested.

In ASEAN (Association of South-East Asian Nations), only 0.2–0.4% of GDP is spent on R&D in agriculture, except for Malaysia and Singapore, where expenditure is higher, and, in Thailand, where investment is increasing. The limited investment in research and technology undoubtedly affects the development of the agricultural sector. ASEAN countries are also still not taking full advantage of new technologies such as genomics, GE and 'big-data' digital analysis (National Science and Technology and Innovation Policy Office, 2012). This seems to be due to limitations of technology readiness, a lack of IT literacy and inadequate infrastructure and policies for adopting new technologies. For instance, in Thailand, biosafety testing of GM crops in the field requires control methods and studies on the effects on the environment and health in different locales, a public hearing and Cabinet approval. As a result, no GM crops have been tested in the field in Thailand (National Science Technology and Innovation Policy Office, 2012). The ASEAN has 18,000 researchers in agriculture, whereas China has up to 43,000 researchers in this field (Flaherty et al., 2013). The problem inherent in the relatively low number of researchers in agricultural science is likely to be exacerbated in the future, as agriculture is not a popular discipline with high school graduates. This is a major problem for the region to address if it hopes to enhance agriculture productivity through the use of S&T.

4.2.5 Public/private partnerships for S&T

The important role played by the private sector in FNS-related research and agri-innovation should be acknowledged. There is a great opportunity for expanding public/private partnerships aimed at FNS research, education and extension, leveraging off corporate social responsibilities.

4.3 S&T within Asia/Oceania region at the trans-national level

Although other regions in the world, and particularly Europe and Africa, have various frameworks that attempt to organise trans-national cooperation and collaboration in S&T, such infrastructures are lacking within the Asia/Pacific region. There is no organisation that is comparable with the European Science Foundation or Biosciences Africa that is specifically for the Asia/Oceania area.

This lack of coordination is somewhat filled by international research organisations such as those funded or established by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR has 15 centres working on global food security and makes contributions to public spending in agricultural R&D in developing countries. The research in these centres involves cutting-edge approaches that largely concentrate on clear and pressing agricultural needs. Whereas the questions being asked often have basic science components and outputs, the centres largely encourage applied research that eventually leads to area-specific extension.

However, CGIAR expenditure represented only 2% of total national investment in the Asia region in 2008. Historically, the funding of CGIAR centres comes primarily from western countries and Japan. Many of the countries that directly benefit from the research have, over the past decade, become much more economically developed (e.g. 'advanced and developing S&T countries' in sections 4.2.2 and 4.2.3). An acceleration in CGIAR investment by these countries would assist in supporting country-led strategies to achieving FNS in Asia.

The activities of international research organisations have been particularly important in Central Asia and the Caucasus. Central Asia and the Caucasus (CAC; Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan in Central Asia; Armenia, Azerbaijan, and Georgia in the Caucasus) is home to more than 78 million people, covering an area of 416 million hectares, of which about 70% is classified as agricultural land. With only 15% of arable land, wheat, cotton and livestock are the important agricultural commodities. The R&D programmes in Central Asia have been augmented by the activities of the CGIAR centres in a significant manner. The International Food Policy Research Institute (IFPRI) provides evidence-based solutions for promoting agricultural development and advancing food security in the region. It collaborates with several economic, nutrition and agricultural policy research institutions in Central Asia and Russia to conduct applied research, to strengthen local policy research capacities and to engage governments in policy dialogue. They focus on economy-wide modelling to evaluate: alternative growth and investment options, trade and regional integration policies; climate change and its potential impact on agriculture and food security in the region; agriculture–nutrition linkages and value chains from food safety and health perspectives; emerging issues related to agriculture and food security, including migration and remittances, market integration and price transmission across food and commodity markets, agricultural productivity and the role of agriculture and the rural economy in structural transformation in the region. The International Centre for Agricultural Research in Dry Areas (ICARDA), operating from Kazakhstan, focuses on productivity of agricultural systems, natural resources conservation and management, genetic resources and socio-economic and public policy research. Annually, about 5000 germplasm entries from 80 different nurseries (cereals, legumes and forage crops) are tested in the region. In all the eight CAC countries, new promising varieties have been identified, which are being used to improve local germplasm, or for direct multiplication and release to farmers.

In general, investment in food and agriculture R&D gives a high return. It is estimated in India, for example, that the return on R&D is 13 rupees per rupee invested (Fan, 2013). Doubling investment in R&D could lead to 261 million people moving out of poverty globally in 2025, compared with 124 million under historical rates of investment.

In lieu of broader frameworks, several bilateral funding mechanisms exist along with various research agreements between National Science Foundations or universities in different countries. These arrangements are critical for fostering the integration of research agendas across the region, and for ensuring that basic research continues to be promoted.

Recommendation: Common impediments to increasing FNS at national, regional and local levels should be identified and evaluated, along with generic over-arching technologies, to form a blueprint for future Asia/Pacific FNS R&D.

Recommendation: The AASSA should work with its constituent societies to develop a trans-national funding mechanism that puts *basic research* connected to FNS at the forefront. Such a framework, if properly funded, can have far-reaching consequences for both S&T and FNS in the Asia/Pacific region, similar to the effect of the European Research Council (ERC) integration grants on science in Europe.

Recommendation: The AASSA should work with its constituent societies to further develop binational research cooperation in FNS.

Recommendation: Considering the R&D lag between investment and adoption/return on investment for agricultural and food research, national governments should not only maintain support for basic R&D, but also increase overall levels of funding (as a % of GDP) for FNS.

5 Opportunities for innovation in food, nutrition and health

5.1 Nutrients, foods and diets

Traditionally, the study of human nutrition has relied upon a reductionist approach, whereby a diet is seen as a combination of meals, meals are seen as a combination of foods, foods themselves are seen as a combination of nutrients and nutrients (amino acids, glucose, fatty acids, etc.) are viewed as the fundamental unit of nutrition. This paradigm has been queried (see Jacobs and Tapsell, 2007; Kongerslev Thorning et al., 2017), and it has been suggested that a food, not a nutrient, should be viewed as the fundamental unit of nutrition. The latter view is promulgated for two reasons.

Firstly, foods have complex physical and chemical structures that are released and alter during gastrointestinal digestion and interact with each other and with other structures from other foods eaten as part of a meal, thereby influencing the physicochemical environment in the gut lumen and influencing both the extent and the rate of nutrient digestion. There are many examples of this. Casein (often referred to as a 'slow' protein) molecules, for example, coagulate in the stomach and are digested and absorbed slowly relative to whey protein or hydrolysed casein (often referred to as 'fast' proteins), which do not coagulate and are rapidly digested and absorbed. The rate of amino acid uptake influences plasma amino acids and post-prandial metabolism (Boirie et al., 1997; Dangin et al., 2001; Deglaire et al., 2009). Similarly, Barbé et al. (2014) found very different plasma leucine (a key amino acid and metabolite) profiles in subjects given either acid gel milk or rennet gel milk. Clearly, differences in the structure of the same raw material alter digestion and absorption patterns. Berry et al. (2008) found very different plasma triacylglycerol (TAG) profiles, reflecting large differences in the rate and extent of digestion, in subjects given either whole almond seed macro-particles or almond oil mixed with almond flour. Almonds in their raw state significantly lowered the area under the TAG plasma curve, 8 hours after feeding. It has been known for many years that the low absorption of fatty acids from a saturated fat (e.g. tripalmitin) given on its own is dramatically increased if given along with a small amount of an unsaturated fatty acid such as oleic acid (Kidder and Manners, 1978). A synergistic interaction between the two types of fatty acid occurs such that the digestibility values determined for the fatty acids on their own are no longer additive. As the effect is probably mediated through the process of micelle structure formation in the gut, fatty acid uptake is dependent upon the types and compositions of fats and oils present in a food or meal. A further example is that, on the basis of its sodium and saturated fat contents, full-fat cheese would be seen as an 'unhealthy' food but, to the contrary, has been demonstrated to have important health effects for the prevention of type 2 diabetes and cardiovascular disease (Kongerslev Thorning et al., 2017). A complex interaction between beneficial bacteria, minerals, bioactive peptides, bioactive proteins, other bioactive constituents and complex structures present in cheese is thought to mediate these positive effects.

Secondly, foods contain many compounds that are not classically viewed as nutrients (e.g. phytochemicals, bioactive proteins and peptides, and fibre), but may have important effects upon human health. Examples, among many, are immunoglobulins in milk, probiotics in yoghurt and other fermented foods, catechins in tea, bioactive peptides released from many proteins, flavonoids in cocoa, and tannins and anthocyanins in fruits and berries.

In the future, more attention in nutrition studies needs to be given to the holistic nature and properties of individual foods. For example, there are multiple differences, other than the nutrients provided, between a food such as milk and a food such as nuts. Both will provide nutrients but each will also provide its own influence on gastrointestinal digestion consequent upon unique and very different physical and chemical structures. Both foods will supply important chemical compounds, in addition to the classic nutrients, but the types of these compound and their target tissues can be expected to differ greatly.

Armed with better information on the holistic values of foods, nutritionists will be able to develop and validate diets and dietary patterns for their long-term healthfulness. Having accurate information on the amounts of dietary nutrients required to support body processes (dietary requirements) is important but not sufficient. In the future, knowledge of the holistic properties of foods themselves and how these interact with the properties of other foods will be important for understanding and defining healthy diets.

The role of diets in influencing gene expression in humans (nutrigenomics) and how genetic makeup influences dietary effects on physiology, metabolism and health (nutrigenetics) offer great potential for a better understanding of nutrition and its influence on health, and pave the way for personalised nutrition (Fenech, 2008).

5.2 Functional foods and food fortification

Some foods have, naturally or because of fortification, particularly high levels of certain bioactive compounds, such that the food has particular importance, not only in relation to the provision of nutrients but also because of the physiological effects consequent upon its ingestion. Such foods are called 'functional' foods (Diplock et al., 1999; Foster and Lunn, 2006; Thompson and Moughan, 2008). Examples of such natural foods are oily fish supplying the marine omega-3 fatty acids [docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA)], oat bran containing soluble fibre that may attenuate fatty acid and cholesterol uptake, and lycopene and lutein (antioxidants) in tomatoes influencing oxidative reactions in the body. An example of a functional food based on fortification is margarine enriched with plant sterols and stanols, formulated to help to maintain low blood low density lipoprotein (LDL) cholesterol levels. A starch source processed to be resistant to digestion (resistant starch), leading to lower blood glucose levels, would also be considered to be a functional food or functional food ingredient.

Functional foods are likely to be recognised as important constituents of a 'healthy' diet. Whereas 'functional foods' is a relatively new concept in the West, such foods have long held a high status in Asia. An example of this is the well-developed FOSHU (foods for specified health uses) movement in Japan. For many centuries, Asia has emphasised the importance of combinations of foods and an overall balance of food types in diets. This knowledge needs to be captured and promoted for future FNS, and traditional foods need to be promoted, where appropriate, for their healthfulness over and above being merely a source of nutrients.

5.3 Defining a healthy diet

It is important, in terms of monitoring and planning for FNS, to be able to define what is meant by a 'healthy diet'. However, changing views on healthy and unhealthy dietary components, over the years, disclose that the definition of a 'healthy diet' is a moving target. By way of example, not so long ago, dietary cholesterol and, in particular, eggs were seen as unhealthy, but this view has changed (Shin et al., 2013; US Department of Health and Human Services and US Department of Agriculture, 2015). More recently, strong views concerning the influence of saturated fats on the development of cardiovascular disease have been expressed; however, although the effects of saturated and trans fatty acids remain controversial, these views have also been called into question (de Souza et al., 2015; Hamley, 2017). Currently, unprocessed red meat has been implicated in the development of bowel cancer, but there is conflicting information (Lin et al., 2004; Alexander and Cushing, 2011). National food pyramids, at least in some jurisdictions, have altered over the years, recently de-emphasising highly available carbohydrates including sugars.

It can be expected that, as knowledge concerning the nutritional and other effects of specific foods and food types accumulates, it will be easier to define 'healthy diets', and refined versions of diets, such as the 'Mediterranean-type' diet, will be developed. It is interesting to note that the Mediterranean diet is rather rich in functional foods (see section 5.2, e.g. tomatoes, olives, green-leaved vegetables, capsicums, legumes, artichokes, fish and red wine—all contain bioactive components). Healthy diets are likely to be diets that are diverse in a wide range of food types, including fruits, non-starchy vegetables, nuts, legumes, whole-grain cereals and animal products (Rajaram, 2003; Esposito et al., 2010; Bertoia et al., 2015; The Chicago Council on Global Affairs, 2015; Bagheri et al., 2016), and, in terms of FNS planning, provision should be made for a wide variety of culturally acceptable food types to be made available to local populations. A diet that is deemed to be healthy and socially and culturally acceptable is likely to vary widely with region, and such diets should be defined locally.

There is much evidence that often poor nutritional choices are made at the point at which foods are selected for consumption, and better education at all levels on the impact of food and nutrition on health is critical.

There would seem to be much scope for encouraging farming programmes among smallholder farmers that aim to diversify diets and improve nutrition. Such programmes (Girard et al., 2012) aim to increase household production of perishable nutrient-rich foods (e.g. fruits, eggs, meat, fish and milk). The production of such foods on the farm makes them accessible and less vulnerable to storage and transport losses. Such an approach has been shown to diversify the diet of often nutritionally vulnerable smallholders (Iannotti et al., 2009).

It is recognised that a healthy diversified diet providing complete nutrition is particularly important for the first 1000 days of life and for the mother during pregnancy. The first 1000 days of life are profoundly important for proper growth and for proper physical and mental development. Nutritional deficiencies in this period of the life span can be irreversible and the consequences last a lifetime. Breastfeeding (with adequate maternal nutrition during both pregnancy and lactation) should be encouraged, and nutrient-rich foods need to be provided during and after weaning. The first 1000 days should be a special focus for an FNS strategy.

Recommendation: There should be research effort to understand the holistic nutritional and health properties of individual foods and mixed diets, so as to better define the characteristics of a healthy diet.

Recommendation: Ultimately food types and diets that are both healthy and socially and culturally acceptable should be defined at a local level, taking into account a wide diversity of views and beliefs.

Recommendation: The food S&T, nutrition and plant/animal breeding disciplines should work together to develop functional foods containing high natural levels (or following fortification) of health-enhancing bioactives as well as minerals and vitamins. Such functional foods should be targeted constituents of healthy diets.

Recommendation: There should be better education concerning the role of food and nutrition in health, and such education should occur at all levels of the education system and should be generic. There should be specialised training for health professionals, including doctors and other primary influencers. The role of dieticians in communities should be expanded.

5.4 Food safety and food wastage—the role of food technology

There is considerable wastage of foods along all steps of the food supply chain, including wastage during harvesting, transport, processing, storage and distribution to retailers, and wastage at the point of consumption. Minimisation of such wastage provides a considerable opportunity to increase food availability. The provision of infrastructure, where appropriate, to allow for in-field cooling, refrigeration and refrigerated transport should be a priority, as should the development, where needed, of appropriate food processing technologies (such as heating, freezing, canning, aseptic packaging, drying, salting and fermentation). All these processes rely on what are already well-developed technologies and have the potential to greatly decrease the loss of food material and the loss of food nutrient bioavailability as well as to enhance food safety. Food processing also allows for the fortification of staple foods with key vitamins, minerals and bioactives. There is also considerable potential to introduce less common but often highly effective novel food technologies such as HTST (high temperature, short time) processing, high pressure processing, pulsed electric field

processing, ultrasonic processing and irradiation technologies (Fryer and Versteeg, 2008); new improved storage and processing technologies should remain a priority objective for food technology R&D. There is potential to enhance the shelf life of food products and to provide more accurate data on 'use-by' dates, which may enhance food utilisation. The introduction of a new processing technology does not necessarily imply a more heavily processed food in the sense of a more degraded food. Many innovative technologies (e.g. high pressure processing) are designed to retain the natural characteristics of the food. Technologies that minimise the degree of refinement and degradation of a food and allow the retention of natural food characteristics (e.g. whole foods, whole-grain foods and minimally processed foods) but give the food a prolonged shelf life and superior palatability should be a focus. Packaging technologies also have much to offer, but the use of non-biodegradable materials (e.g. plastics) can present a disconnect with environmental objectives; therefore, research needs to be directed towards the production and use of smart biodegradable materials to allow minimal food packaging but packaging that will prolong food shelf life and safety, and thus lead to lower food wastage.

Foods must be free of harmful microorganisms and toxins, and food allergens need to be accounted for, which, for efficient food production and distribution, implies a need for proper food processing. The traceability and the integrity (freedom from contamination and adulteration) of the food supply chains are also important issues.

It is likely that, in the future, with increased urbanisation, the extent of food processed in some way to allow the storage and distribution of perishable and seasonal foods at a later date will only increase (Lillford, 2008). Whereas conventional food processing has sometimes been blamed for leading to a loss of nutrients during refining steps, and for the destruction of natural (often health-enhancing) food structures inherent in the food matrix, a better understanding of the relationship between food structures, nutrition and health can lead to new food processing approaches to ensure the retention of nutrients and structures, and even the development of new health-related food structuring (Dickinson, 2014; Donato-Capel et al., 2014; Singh and Gallier, 2014). Such a research direction, for the retention and indeed the creation of 'healthy' food matrices during food processing and storage, would be worthwhile. The food processing industry is highly adaptable, and can rapidly and relatively easily introduce ubiquitous healthy manufactured foods into the food chain. It seems likely that highly processed, highly refined (often reconstituted) foods have contributed to the upsurge in obesity. These foods often lack essential vitamins and minerals, dietary fibre and phytochemicals, and are often high in sucrose, rapidly digested starches and fats, and salt. They are engineered to be tasty and convenient; as they are often affordably priced, they appeal to consumers. There may need to be incentives for manufactured foods that offer the same taste convenience and price appeal, but that minimise the inclusion of unhealthy food ingredients (e.g. trans fatty acids, highly available sugars and starches) and are produced to have healthy attributes. The food industry can be used to advantage. There is also an economic opportunity to add value to minimally processed commodities. By way of example, ASEAN's cassava exports are largely in the form of cassava chips, which have the potential to be processed into higher value colourless, gluten-free products, thereby raising returns to famers.

Recommendation: Reliable data on food wastage and how it varies with the food production system and with socio-economic sectors of a population need to be generated, and strategies to minimise food wastage need to be devised.

5.5 Sustainable diets

Diets need to be not only healthy but also sustainable, economically, socially, culturally and environmentally. The environmental sustainability of food production is likely to be influenced by climate change. The FAO (2012) has given a consensus definition for 'sustainable diets':

'*those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources*'.

This is a fulsome definition and covers the key interacting determinants of a sustainable diet. However, the actual description of the farming systems and types of diet likely to be sustainable in the future is more difficult. Johnston et al. (2014) caution:

'*Today, it is challenging to define what a sustainable or unsustainable diet translates to in practice. There does not yet exist an agreed on approach or tool to determine the level of sustainability of a diet or the tradeoffs associated with any attempts or recommendations to increase the sustainability of a diet. If those working to advance sustainable diets are able to devise means to measure diets and build measurement mechanisms that are easy to use (for both policymakers and consumers), many stakeholders will be better positioned to realize the potential benefits of sustainable diets and mitigate the risks associated with growing unsustainable agricultural and consumption practices*'.

So far, narratives around required changes to farming systems (e.g. less animal/more plant production) have been overly simplistic and one dimensional; it is important that all interactive elements of food systems are assessed simultaneously, that investigations are evidence based, and that evidence is applied in the correct context. In deriving conclusions about the future of animal production, for example, in addition to GHG emissions and biological efficiencies of production, considerations such as type of animal (and competitiveness of food source with humans directly), comparative nutrient/health characteristics of animal-based foods, other products from animals (e.g. hair, wool, leather, draught power, manure and transport), cultural aspects, employment and organoleptic qualities of foods all need to be taken into account. Alternative land use arguments are also very important (Mottet et al., 2017). The Global Dairy Platform points out that the area of grazing land in the world (suitable for pasture but not for cropping) is double that of cropping land. Some of that pasture land will be suitable for intensive grass-fed dairy production, but much will be best suited to less intensive grazing species of animals (cattle, sheep and goats). All of these factors, and their complex interactions, need to be fully understood in devising sustainable food production systems for the future (Global Dairy Platform, 2014).

Sustainable diets are the outcome of sustainable food systems and will vary from country to country. A sustainable Mediterranean-type diet in Turkey or Israel is likely to be quite different from a sustainable diet in Central or East Asia. Each country/region should define for itself, through close cooperation with nutrition/health experts, sociologists, ecologists and agricultural experts, its own sustainable food system and diet.

Recommendation: Valid metrics and measurement mechanisms and approaches to enable practical descriptions of sustainable farming systems and sustainable diets should be developed, to allow a complete evidence-based assessment of sustainable diets.

6 Opportunities for innovation in agriculture, aquaculture and marine resources

Long-term improvements in FNS are directly linked to scientific discovery and technology advances. The huge gains in FNS in Asia in particular, and indeed globally, over the past half century have been due to the adoption of advanced technologies of the ‘green revolution’, which included innovations in seed and crop development, irrigation and mechanisation.

A ‘3rd green revolution’ is needed if we are to meet the demands of producing more food, on less land and in the face of an ever-changing environment. These external pressures present an opportunity for new research directions, which, in addition to contributing to the global research output, will lead to new technological innovations and business opportunities. The goals of this research should be to eventually develop ‘climate smart agriculture’ that provides more food energy and protein with fewer inputs. Several in-depth reviews that prioritise areas of FNS worthy of enhanced research and that are relevant to the Asia/Oceania region have been undertaken (Pretty et al., 2010; Tonini and Cabrera, 2011; Parker et al., 2014; European Union, 2015). Highlight areas for research are discussed below.

6.1 Advances in plant-based agriculture

Over the past 10,000 years, advances in agriculture have been driven first and foremost by improvements in seeds, i.e. the development of crops with ever better characteristics such as yield and taste. Long-term gains in FNS will come from the development of better seeds, and yield gains will come through the adoption of superior genotypes in agriculture. The potential to lift current crop yields is great. For example, the gaps in yield between those of ASEAN countries and the world’s highest yields are around 69, 15, 66 and 150% respectively for rice, sugar cane, cassava and maize (Office of Agricultural Economics, Thailand, 2015).

Hybrid rice accounts for less than 6% of India’s 44 million hectares under rice cultivation, but its use has been gathering momentum since 2005 (Spielman et al., 2013). In contrast, hybrid rice accounts for more than 50% of all Chinese land under rice cultivation, yielding up to 30% more than other cultivated varieties (Ma and Yuan, 2015). Thai researchers have employed marker-assisted selection and standard breeding methods to develop a flash-flood-tolerant rice variety that could recover after being submerged under water for as long as 2–3 weeks (Toojinda et al., 2003). During 2008–2016, 836 hectares of flash-flood-tolerant rice was cultivated. It is expected to create an economic impact of at least US$29.2 million. Currently, the same strategy has been applied to develop rice varieties that are more resilient to biotic and abiotic stress conditions. Plant breeding techniques are being used in Asia for biofortification, similar to the production of golden rice. In India, conventional plant breeding is being used to develop β-carotene-rich sweet potato and iron- and zinc- biofortified millets.

6.1.1 Utilisation of landraces and the wild gene pool

Asia/Oceania was a hotspot of plant and animal domestication that allowed for the development of civilisation. Rice, barley, wheat, alfalfa, sugar cane, soya beans, apples, oranges, almonds and others all have their domesticated beginnings in Asia or Oceania. Because of this, the wild relatives of most of these crops still grow as ‘weeds’ in natural environments, where they retain traits of natural resistances to biotic and abiotic stresses. In many cases, the offspring (F_1 generation) of crosses between modern cultivated species and their wild relatives retain fertility, facilitating breeding programmes.

In addition, numerous landraces of these domesticated crops are still used by villagers across the area. Landraces are genetically distinct from their wild relatives and, less so, from each other, and have been domesticated locally over centuries (Camacho-Villa et al., 2005). As cultivated species, landraces contain the key traits that allowed domestication (e.g. a shatter-proof spikelet in wheat), although overall yields of these local species often fall well short of those of modern industrial breeds.

With the development of the modern, standardised, high yielding breeds used in post-green-revolution agriculture, the use of landraces has been discouraged because of their relatively poor yields. However, landraces taken together contain a large amount of genetic diversity that is not found in commercial strains. Although many landraces have been lost, efforts to conserve landraces and wild species to preserve genetic diversity have gained momentum in the past decades (Maxted et al., 2013).

A case in point is the use of wild emmer wheat and other wheat relatives in the fight against stem rust. Stem rust in wheat (*Triticum aestivum* L.) is caused by *Puccinia graminis* Pers. f.sp. *tritici* Erikss. & Henn. An especially virulent form of stem rust, popularly termed UG99b, was discovered in Uganda in 1998 (Singh et al., 2011). Because fungal spores are carried by the wind, UG99 crossed into Asia, was first detected in Yemen in 2006, and had reached the wheat fields of Iran by 2008, further threatening the large wheat expanses of India and Central Asian countries. Ug99 defeats virtually every race-specific resistance gene used in commercial varieties grown throughout the world; over 90% of the world's commercial wheat varieties are susceptible to UG99, including almost all of the wheat on the predicted path between East Africa and South Asia. In early 2008, the Bill & Melinda Gates Foundation awarded a grant addressing 'durable rust resistance in wheat' to a consortium of institutions led by Cornell University; the consortium included researchers and institutions in Australia, India, Israel, Syria and Turkey. Although the consortium has adopted several approaches, one approach that has proved to be successful is the introgression of a UG99 resistance gene from a wild relative of wheat into a cultivated strain (Millet et al., 2014).

Recommendation: Efforts to collect, phenotype, catalogue and preserve diverse wild relatives and landraces of cultivated crops should be extended. In particular, efforts must go into advanced high throughput phenotyping and genotyping technologies.

6.1.2 Molecular breeding and CRISPR technology

Classic plant breeding techniques are based on crossing wild species or landraces with commercial species; then, through a series of backcrosses to the cultivated strain, desired characteristics such as resistance or higher yield are selected for, whereas deleterious traits from the sub-par strains are selected out. This process takes many generations of growth over several years and, because of linkage issues, it is often impossible to completely separate desired genes from deleterious genes.

New breeding techniques (NBTs), including molecular breeding and CRISPR/Cas9, give scientists the ability to modify DNA more precisely by turning genes on or off, or to exact edit DNA for a desired new modification. Molecular breeding employs the techniques of crossing and segregation while using molecular markers based on high throughput DNA sequencing to select progeny with the correct segregating alleles. In a recent report (Klümper and Qaim, 2014), a meta-analysis of 147 published studies showed that crop yields have increased 22% and that pesticide use has been reduced by 39% on the basis of using GM seeds. Such potential yield increases are likely to be central to meeting future FNS needs.

CRISPR/Cas9 differs substantially from traditional transgenic approaches, which rely on the insertion of genetic material, as gene editing and other NBTs allow scientists to avoid crossing the so-called 'species barrier', a concern promoted by those not in favour of GE in agriculture. Plants and animals bred with these techniques may face lower regulatory hurdles than traditional transgenic products.

Researchers are working on CRISPR/Cas9-edited versions of commodity crops, such as corn, soya beans, canola, rice and wheat, with new traits such as drought resistance and higher yields, both critical features for farmers trying to deal with a changing climate. The technique can also be used to remove allergens in peanuts or to make food more nutritious, all while using genes that occur naturally in the plant. Anti-molecular technology proponents refer to CRISPR and other gene-editing techniques as 'extreme engineering', and are attempting to have them regulated as transgenic breeding. It will be important that decisions are made and that consequent regulations are 'evidence based', as such techniques are considerably powerful for lifting crop yields and in building plant resilience. It is the view of this Working Group that biotechnology and GM, applied to both plants and animals, will be central to securing future FNS. Scientists need to better articulate the benefits and risks associated with biotechnology-based crops. Better communication and a more developed public understanding are required. The National Sciences Academies of Asia/Pacific have an important role to play here, in providing thought leadership on this critical issue.

Recommendation: Research efforts, including new target identification studies, to further develop CRISPR/Cas9 and similar NBTs for use in crops should be enhanced. Regulations should be evidence based and, where supported, NBTs should be classified as non-GM (see recommendation 7, regarding nomenclature, in Appendix III).

6.2 Advances in animal-based agriculture

Pork and poultry dominate global meat production and are very important in Asia/Oceania. Although gains in increasing the efficiency of the conversion of feed to meat have been made in the past, there is still considerable opportunity to increase productive efficiency. In particular, the efficiency of conversion of animal feed protein to meat protein is low, and scientific investigation at a mechanistic level is needed to allow increases in the efficiency of the utilisation of protein. Research into alternative feed sources is needed, particularly those not in direct competition with human foods (e.g. synthetic amino-acid-based diets for pigs, poultry and fish). Meat production from ruminants is less efficient technically than that from simple-stomached animals and makes a significant contribution to GHG emissions. However, much of the world's land is suitable for grazing rather than cropping, and, on a competitive land-use basis, ruminant meat and milk production make a valuable contribution to the world food protein supply (Mottet et al., 2017). Introducing superior technologies in pasture-based feeding systems offers much promise.

GHG mitigation research should remain an important target. Traditional animal breeding technologies, genomic-based selection, transgenics and new reproduction technologies all hold considerable promise for increasing the efficiency of animal production (Suttie et al., 2011), and such technologies need to be widely disseminated and supported within the region. Gene banking, to preserve genetic material of wild and rare domesticated species, is important, as discussed in section 6.1.1 for crops. Sustainable intensification will probably be important where possible for future animal production, with higher meat and milk yields per animal and with consequent lower amounts of mineral waste and GHG per kilogram of meat or litre of milk (The Royal Society of London, 2009; Bajželj et al., 2014; Pardey et al., 2014).

There is an opportunity in the future to develop combinatorial (e.g. meat, dairy, algae, cereal, fungi and synthetic amino acids and peptides) proteins that are better suited to meeting human nutritional requirements and that lead to a higher overall efficiency of use of dietary proteins. A good example of this type of research is that of the USA Nutrition Council and the University of California, Davis, which has created a meat–mushroom amalgam that greatly extends the use of beef protein (Jacewicz, 2016). Compared with meat, mushrooms have fewer calories, less sodium and no saturated fat, and mushrooms require less water to grow than beef, use less space, reach maturity quickly and use carbon-rich agricultural by-products.

Recommendation: Research into developing new feedstuffs (lower down the food value chain) for simple-stomached animals (e.g. pigs, poultry and fish), and into the underlying mechanisms of productive efficiency, is urgently needed. Research into pasture-based systems for ruminant production and the mitigation of GHGs should be a priority. NBTs and new reproductive technologies need to be properly assessed on the basis of scientific evidence and, where found to be acceptable, should be pursued vigorously.

6.3 Precision agriculture/robotics

Precision agriculture, or precision farming, is an emerging farming concept that utilises geographical information to determine field variability, to ensure optimal use of inputs and to maximise the output from a farm (ESRI, 2008). Precision agriculture was born with the introduction of global-positioning-system (GPS) guidance for tractors in the early 1990s; the adoption of this technology is now so widespread globally that it is probably the most commonly used example of precision agriculture today. The technology reduces steering errors by drivers and therefore any overlap passes on the field. In turn, this results in less wasted seed, fertiliser, fuel and time.

Next-generation precision agriculture systems are part of the data-science movement. By collecting real-time data on weather, soil parameters (e.g. pH, levels of moisture, nitrogen, minerals such as phosphorus magnesium or potassium, and other organic compounds such as pesticides and herbicides) and air quality, together with crop parameters such as size, photosynthetic output, colour and temperature, predictive analytics can be used and coupled with data on yield to make better farming decisions. The farmer's and/or researcher's ability to locate their precise position in a field allows for the creation of maps of the spatial variability of as many variables as can be measured.

With precision agriculture, remote control centres collect and process large complex data sets in real time to help farmers make the best decisions with regard to planting, fertilising, irrigating and harvesting crops. The data come either from sensors placed throughout the fields or through remote sensing using satellite imagery and robotic drones. These data are used for making local decisions regarding fertigation, pest management and harvest, thus reducing inputs. Predictive models from this 'big-data' approach are able to build simulations that can predict future conditions and can help farmers to make proactive decisions, thus minimising crop loss.

Particularly in the developing world, the use of precision agriculture and new age robotics has the potential for greatly assisting small scale farmers. If the data are collected and analysed remotely, the resulting instructions (e.g. time to harvest) can be delivered through pervasive smart phone technology in a graphical manner.

ASEAN countries have started to employ precision technologies for agriculture. For instance, the International Rice Research Institute (IRRI) in the Philippines calculates appropriate amounts of fertilisers for rice by analysing nutrients in rice leaves. In Thailand, the National Electronics and Computer Technology Center (NECTEC) has developed a phone application to detect leaf colour, with accompanying NPK (nitrogen/phosphorus/potassium) fertiliser advice. Farmers have found that this application helps to reduce the cost of chemical fertilisers (Intaravanne and Sumriddetchkajorn, 2012).

Recommendation: Inter-disciplinary research among engineers, geographic scientists, biologists and data scientists to develop better-integrated sensing and reporting systems and to promote precision agriculture and robotics should be encouraged.

Recommendation: Impact analyses to identify and overcome impediments to adopting precision agriculture systems among small scale farmers should be encouraged.

6.4 Alternative food sources

Alternative food sources are needed to provide protein for farm animals, in place of proteins that can be consumed by humans directly. New proteins sources are also required for human nutrition. Insects and algae provide several advantages over classic plant-based sources of protein (e.g. grains and legumes), especially in terms of yield per unit area and environmental footprint when considering GHG emissions, etc. It is also possible to rear animals such as pigs and poultry on diets comprising synthetic amino acids and simple carbohydrates (e.g. sucrose and purified starch), and these feeding systems should be further explored.

In many societies across the world, particularly in East Asia, people traditionally eat a wide variety of insects, both cooked and raw, on a regular basis. According to van Huis (2013), approximately 1900 insect species are eaten worldwide, mainly in developing countries. They constitute quality food and feed, and their production is typified by high feed conversion ratios and low emissions of GHG. Some insect species can be grown on organic side streams, reducing environmental contamination and transforming waste into high protein feed that can replace increasingly more expensive compound feed ingredients. This requires the development of cost-effective, automated mass-rearing facilities that provide a reliable, stable and safe product. Furthermore, research and innovation in food technologies are needed to yield an appealing food product for human consumption. Although research in this direction should be encouraged, close attention should also be paid to the overall efficiency of the food-producing system. In relation to housefly larvae meal, van Zanten et al. (2015) reported a trade-off between decreased land use on the one hand and increased energy use and the potential for increased global warming potential on the other hand.

Biomass generated from cultivated algae also has potential as a protein source. Algae contain high levels of protein, relatively well-balanced amino acid profiles and rich contents of minerals and vitamins (Lum et al., 2013). Microalgae can also provide bioactives such as omega-3 (*n*-3) polyunsaturated fatty acids including DHA and EPA. Thus algae can be used in new generation animal feeds.

Recommendation: New scalable insect and algal species for use in the food industry and alternative animal feeding systems should be identified. Studies into algal chemistry pre- and post-extraction and the identification of novel chemistries should be encouraged.

6.5 Aquaculture and marine resources

Aquaculture is regarded worldwide as one of the fastest growing food-producing sub-sectors, particularly in several developing countries (Figure 8). China is clearly the world leader in aquaculture production, with Indonesia and India having rapidly developing aquaculture industries. The development and wider adoption of aquaculture can be seen as a significant basis for improving household food security and other needed welfare. Constituting a supply of food and a commodity for trade, aquaculture has the potential

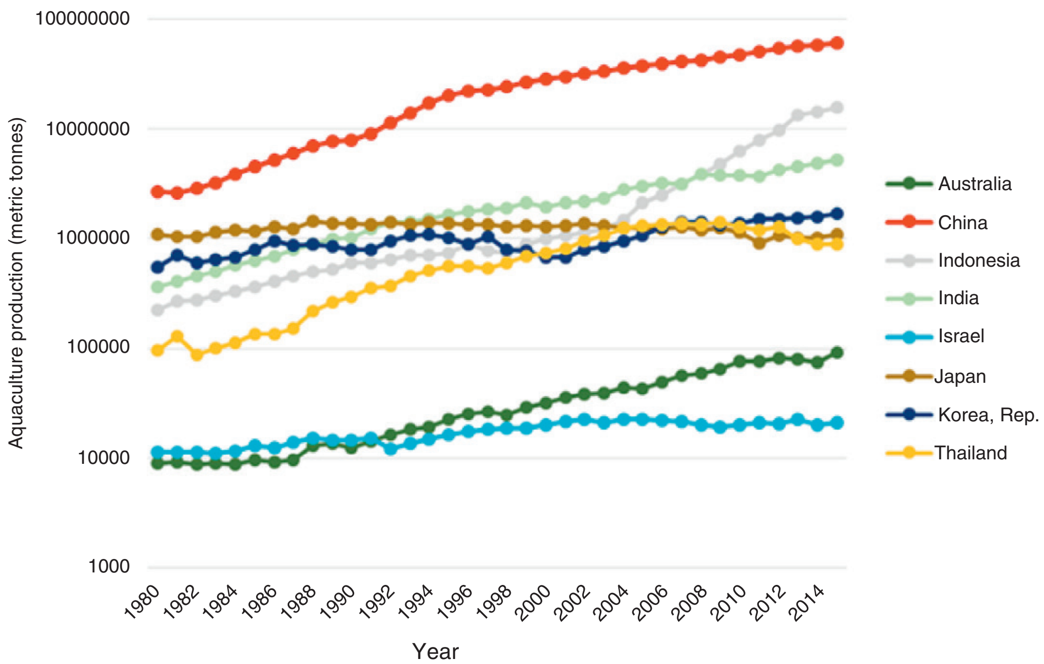


Figure 8 The growth of aquaculture production over time. Data taken from the World Bank (2017) and data within.

to contribute to the food and nutritional status of numerous people and is an especially valuable source of protein (Ahmed and Lorica, 2002). The dramatic growth in Asia shrimp production as an example of one sector of aquaculture has been reviewed by Tanticharoen et al. (2008), and underlines the importance of S&T innovation and education. The usefulness of 'cluster groups' in identifying research priorities and disseminating research results is discussed. The Asia/Oceania region has a vast ocean fisheries resource that needs to be carefully managed for a future sustainable fish supply and that constitutes a valuable resource for aquaculture development.

6.5.1 Two case studies of basic aquaculture research leading to enhanced performance

We present case studies of R&D in which basic research, often beginning in universities, has led to significant improvements in FNS. These stand as examples of what can be achieved from greater investment in agri-food R&D.

Tilapia lake virus

Tilapia are farmed globally and are the second most important aquaculture species in terms of volumes produced, providing a key source of affordable animal protein, income to fish farmers and fishers and domestic and export earnings. Five of the top six tilapia producers for 2015 were in Asia: China (1.8 million tonnes); Indonesia (1.1 million tonnes); Bangladesh (324 thousand tonnes); Vietnam (283 thousand tonnes); the Philippines (261,000 tonnes). Considering a value of approximately US$1,500/tonne, tilapia play a major role in local economies.

Tilapia lake virus (TiLV), a novel virus identified only in 2014, poses a great threat to the tilapia sector (Eyngor et al., 2014). Initial outbreaks of the TiLV symptoms, which led to great reductions in yield, were first seen in 2009 in both farmed and natural populations of tilapia. Subsequently, similar disease descriptions were reported in numerous countries worldwide.

To understand the causal pathogen for this contagious disease, a team of scientists in Israel first isolated the virus and then, together with a team in the USA, sequenced the viral genome (Eyngor et al., 2014; Bacharach et al., 2016). From a basic science perspective, the scientists identified a novel orthomyxo-like virus and confirmed that it poses a global threat to tilapia aquaculture. From a practical point of view, the study and identification of this virus is the necessary first step in developing a vaccine that can be employed in tilapia farming worldwide. In the short term, the DNA sequence enabled the development of a polymerase chain reaction (PCR)-based diagnostic kit (Dong et al., 2017; Kembou Tsofack et al., 2017).

Molecular control of sex in shrimp using RNAi

Monosex culture, common in animal husbandry, enables gender-specific management. For commercial prawn farms, all-male populations are highly desirable as males are considerably larger than females. Furthermore, an absence of females prevents energy from being used in reproductive efforts, causing the males to grow faster and to reach a greater overall size. Thus the prawn industry would greatly benefit from a technology that would yield only males. This is an example of how basic research can lead to discoveries that can lead to innovation in agriculture.

Male sexual differentiation in crustaceans is regulated by the androgenic gland that overrides a default programme of female differentiation, allowing male features to develop. If the gland is surgically removed from a male, it results in a feminised prawn that is genetically male. Thus, all of its offspring are male. However, surgically removing the androgenic gland is not a feasible option for large farms.

Israeli scientists have developed a novel molecular method for generating single-sex populations of prawns. The scientists found that prawn androgenic glands produce specific molecules known as insulin-like androgenic peptides (IAGs) (Rosen et al., 2013; Sharabi et al., 2016*).* Working on giant freshwater prawns (*Macrobrachium rosenbergii*), they used RNA interference (RNAi) to generate populations of feminised males (Sharabi et al., 2016). The prawns were injected with a sequence designed to silence an IAG-encoding gene. This caused the males to undergo complete sexual reversal until they were indistinguishable from normal females, with the key difference, however, that these feminised males produced solely male offspring.

This technology has now been commercialised, with the juvenile feminised prawns produced in Israel. The small juveniles are then exported to other countries in the Far East where they are grown for commercial production. These prawns could also be used 'as sustainable biocontrol agents' against freshwater snails that carry diseases (including schistosomiasis) or damage rice paddy fields. As these prawns cannot form reproductive populations, there would be no risk of them becoming invasive species themselves. This is a good example of modern molecular biology increasing aquaculture efficiency, and of regional cooperation.

Recommendation: Further adoption of aquaculture technologies through research into intensified growth conditions and the identification of new species should be promoted.

Recommendation: Specific food security research calls in aquaculture, which will attract scientists in other fields (e.g. virologists and engineers) to pursue relevant research, should be encouraged.

6.6 Potentially disruptive technologies

Discoveries, often arising from fundamental science, have the capacity to lead to step-changes in agricultural productivity. Examples of emerging disruptive technologies are three-dimensional printing from the ICT sector, driver-less vehicles and bio-based manufacturing to produce fuels, chemicals and materials through advanced, efficient and environmentally friendly approaches. Synthetic approaches to producing animal-free meat and milk have garnered much media attention and venture capital investment, particularly in and around the Silicon Valley. Such products may have advantages in cost of production, ethical acceptance and sustainability, but consumer acceptance is yet to be tested.

Synthetic biology approaches are also leading to developments that can improve soil health. For example, an extension of the artificial leaf technology, developed by Daniel Nocera and colleagues at Harvard University, uses a bacterium that is engineered to express a nitrogenase enzyme. The bacteria combine hydrogen and carbon dioxide, in the presence of sunlight, to make a solid biofuel that they can store internally. Once the bacteria are added to soil, they can use the stored energy to drive the fixation of nitrogen in the air to ammonia, to fertilise plants. The system is reported to have been applied to radishes, with the fertilised crop being 150% heavier than controls (see O'Driscoll, 2017).

6.7 Concluding remarks

Meeting the FNS needs of the Asia/Oceania region over the next few decades will be a formidable challenge and will need the input of the brightest minds and the best research, both fundamental and applied. Two over-arching recommendations are made.

> **Recommendation:** Investment in inter-disciplinary R&D relevant to FNS in Asia/Oceania needs to be increased significantly. Consideration should be given to forming cross-nation, cross-disciplinary consortia (centres of research excellence), to focus on defined pressing issues related to FNS.

> **Recommendation:** Regional cross-nation initiatives should be implemented to greatly increase the quantum of education and training of the next generations of scientists, technologists, extension officers and leaders in agriculture, nutrition and food. Training should have a trans-disciplinary basis.

Agricultural and rural development were priorities for foreign aid and international development banks before the mid-1980s, but investment in this area has declined in subsequent years. Agriculture and food have been off the global development agenda and this must be reversed.

7 Key issues for managing competition for land use and other resources: sustainable development and the wider ecosystem

7.1 Understanding resource competition

The demand for land is increasingly facing competition among different sectors of the global economy. Land competition occurs when there are several high demands for goods or services that are produced on limited land areas (Haberl, 2015). This competition places pressure on human lives because land is a natural resource that is needed to sustain lives by growing food items for human consumption (NRMED, 2017).

In addition, the competition for water resources is growing throughout the world (FAO, 2011b). Around 1 billion people in Asia could face water scarcity issues within the next 35 years (Kramer, 2016). The United Nations currently considers water availability to be a major issue for the 21st century (United Nations, 2017). This issue is alarming because water is an essential resource for agriculture and thus for food security.

These competition trends are becoming more concerning day by day because of increasing growth in the human population, which is projected to continue to increase to the year 2050 (Dimick, 2014). As humans rely on both land and water resources for sustenance, these competition trends can produce undesirable societal and human effects.

7.1.1 Categorising resource competition in Asia/Oceania

Many issues contribute to land and water competition in Asia/Oceania. These issues are related to the wider ecosystem and can be grouped into three categories, namely social (i.e. issues that affect lifestyle), environmental (i.e. issues that interfere with the environment) and economic (i.e. issues that deal with the consideration of financial data in decision-making processes) (BBC, 2014).

This section highlights and explains these issues concerning land and water resource use as related to the topics listed in Table 17.

Categorising resource competition in Asia/Oceania—social issues

Fast fashion: 'Fast fashion', a new term in the fashion industry, refers to adopting a model of operation that centres on the quick sourcing and production of fashion products (Ethical Fashion Forum, 2016). Fast fashion trends are the result of increased demand for fashion items. About 80 billion new clothes are bought globally each year, representing a 400% increase in the amount of clothing items bought over two to three decades ago (CNN Money, 2015).

The fast fashion business is global in nature, with widespread activities in China, India and Thailand. Although top fashion firms in the world such as Zara and Marks and Spencer are based in western countries, their production processes have shifted to the aforementioned countries in Asia for financial reasons.

Land and water are crucial resources that underpin fast fashion. For example, cotton, which is the most used raw material in the fast fashion industry, is increasingly being grown on lands that were previously used to grow food items, thereby competing with land for food in China, India and Thailand. Also, cotton is produced using large amounts of water. Specifically, 2.6% of global water use relates to cotton production (Sense & Sustainability, 2016). The excessive use of water to grow cotton in Asia and Australia is putting a strain on water resources in general, and on the food-producing agriculture industry specifically.

Population and urbanisation: Urbanisation is the process whereby rural communities advance to form cities. China and India are increasingly being urbanised. China now has more than 600 cities, many of which were small towns just a few decades ago. China, India and Nigeria are projected to account for 37% of the projected growth of the world's urban population; between 2014 and 2050, India is projected to add 404 million urban dwellers and China is projected to add 292 million urban dwellers.

Population growth in India and China will continue to at least 2031, with India projected to be the most populated country on the globe by 2028, with approximately 1.45 billion people (United Nations, 2015).

There are growing demands for land and water resources in these countries because of the need to sustain their increasing population and urbanisation activities.

Food security and urbanisation: Food security concerns have been heightened in China and India because of the growth of the human population (European Commission, 2015). The demand for agricultural lands is increasing because the demand for food is exceeding supply. Urbanisation is also growing in these countries and land that was previously used for food is being used to build social infrastructures such

Table 17 Causes of land and water competition in Asia/Oceania

Social issues	Economic issues	Environmental issues
Fast fashion	GM foods	Climate change
Population and urbanisation	Cheap labour and production costs	Industrial activities and waste
Food security		Biofuels
		Pesticides pollution

as libraries, parks and leisure centres to sustain urban populations.

Economic issues

GM and industrialisation: GM technology is increasingly being adopted in China and India, particularly in the use of Bt cotton. Indeed, as of 2015, these two countries were the two largest producers of Bt cotton globally (ISAAA, 2015a, 2015b). There are concerns that the land that is meant to be used for growing food crops is being used to grow highly profitable Bt cotton for export to western countries either as a raw material or as finished products.

Cheap labour and production costs: Manufacturing costs in developing countries such as China, Thailand, Indonesia and India are low because of the existence of weak labour unions and legislation, making labour costs very low (Ethical Fashion Forum, 2016). As a result, manufacturing companies around the world are moving most of their production processes to these countries to cut production costs. Land and water resources are being used to build and operate manufacturing plants, limiting the amount of land and water resources available for domestic use.

Environmental issues

Climate change: Water scarcity and land degradation are some effects of climate change. The earth's temperature is rising and water is evaporating from water bodies at a much faster rate (Grace Communications Foundation, 2017). In addition, China has some of the most serious land degradation issues in the world (Geocases, 2017). Around 35% of the total land area in China is suffering from degradation, with only 7% of its land area being suitable for growing food crops.

Countries in Southern Asia such as China and India will experience significant climate change impacts. However, these countries continue to emit more GHGs to the detriment of their natural resources and well-being (Friedrich et al., 2017). China, India, Thailand, South Korea, Japan and Indonesia are among the top 10 emitters of GHGs worldwide.

Industrial activities and waste: The activities of industries across the world have increased since the industrial revolution (York University, 2016). Potentially harmful chemicals such as mercury, lead and sulphur are being used in manufacturing companies in China, India, South Korea and Japan, where business environmental management laws are not well enforced. As a result, toxic industrial waste is increasingly being sent to landfill and spread by the wind to land and water resources, thereby contaminating them.

Biofuels: Industrialisation and urbanisation are growing in China and India and are very dependent on energy (Biofuel.org.uk, 2010). For example, the number of vehicles on the road in China has grown from 75 million in 2005 to nearly 250 million in 2012. The number of road vehicles is projected to increase to over 700 million by 2035.

There are growing concerns about energy security to sustain industrialisation and urbanisation in China and India. These countries are shifting to biofuels to meet their increasing energy needs.

China has implemented financial incentive programmes to increase and make the production of biofuels more attractive, and thus is currently the world's fourth largest producer of biofuels.

China, India and Indonesia are Asia's top three producers of biofuels. Despite the populations in China and particularly India increasing and the arable land area decreasing, these countries continue to pursue programmes to increase the production of biofuel, heightening concerns that lands that were previously used to grow food crops are being used to grow biofuels. Furthermore, biofuel production relies on the supply of water (Grid Arendal, 2017). The southwest of China is seen as the most suitable location for biofuel production because of the presence of two of the world's largest rivers, the Yangtze and the Mekong. However, there are growing concerns that the production of biofuels in South-West China is reducing water quality levels and draining water reserves.

Pesticides and fertilisers: Pesticides can be harmful chemicals that contain chlorine, oxygen, sulphur, phosphorus, nitrogen and bromine as well as heavy metals such as arsenic, copper sulphates, lead and mercury (NSW EPA, 2016; US National Library of Medicine, 2017). When pesticides are applied indiscriminately on land used to grow crops, they are often carried away from the areas on which they were initially applied by heavy wind or rainfall, contaminating air, water and land resources nearby or far away.

In addition, fertilisers are used to provide nutrients to crops, improving crop growth (Patton, 2015). As Asia has adopted modern agronomic practices of the green revolution over the past half century, there has been a dramatic increase in the use of fertilisers in many countries, particularly China, India and Thailand.

China consumes around one-third of global fertilisers (Patton, 2014). According to the World Bank, 647.6 kg of fertiliser per hectare of arable land was used in China in 2012, compared with 131 kg in the USA and 124.3 kg in Spain. Only 30% of fertilisers used in China are taken up by crops. The remainder is wasted and causes land and water pollution (Meng, 2012).

This excessive use of chemical fertilisers and pesticides in China has created polluted waters (Patton, 2014). Soils have been contaminated with heavy metals, making water and land resources unsuitable for human and domestic use. Although China is presented here as an extreme example, similar scenarios are being followed all through Southern and South-Eastern Asia.

7.2 Environmental impacts of land competition and use of resources in Asia

The social, economic and environmental causes of land competition in Asia/Oceania listed in section 7.1 reflect human and industrial activities concerning land and water resources. This section addresses the environmental impacts with each identified cause of land and water competition (known as environmental aspects) listed in section 7.1.

An impact is a change in the environment that results from an aspect of a process or activity. From a sustainability point of view, impacts can be analysed under three forms: resource consumption (changes to the environment as a result of the use of materials, energy, water, fuels or land), health and well-being (changes to the health and well-being of either humans or ecosystems) and pollution (i.e. emissions to the land and atmosphere).

In addition, the environmental impacts associated with each environmental aspect listed in section 7.1 can be both positive and negative. The negative impacts are known as 'risks' whereas the positive impacts are known as 'opportunities'.

7.2.1 Environmental aspects, opportunities and risks associated with land competition and use of resources in Asia/Oceania

Fast fashion

Environmental aspects: The use of excess water to grow cotton for fast fashion products in China, India, Thailand and Indonesia and the increasing use of lands for cotton production that were previously used to grow food.

Environmental opportunities: The processing of fast fashion items in China, India, Thailand and Indonesia has provided employment opportunities for many people in these countries. Over 10 million of the population in China work in the garment industry (Kane, 2015). The industry is responsible for 47% of the country's GDP and contributes around US$164 billion from the export of garments.

Environmental risks: Seven of the world's top ten cotton-growing nations are in the AASSA region, including China, India and Australia (http://www.worldatlas.com /articles/top-cotton-producing-countries-in-the-world.html). The water requirements for the increasing production of cotton in these countries could exacerbate the aforementioned environmental impact if an alternative feedstock or an improved measure is not developed on a commercial scale (Sense & Sustainability, 2016). There are growing concerns that the cultivation of cotton for fast fashion competes for land meant for food production. Furthermore, the World Wildlife Fund highlights that '*cotton . . . accounts for 24% and 11% of the global sales of insecticides and pesticides respectively*' (WWF, 2017). Pesticides used in cotton farming can sometimes find their way into water bodies and these contribute to open and ground water pollution.

Urbanisation and population

Environmental aspects: The growing rate of urbanisation in China and India relies on the use of land and water resources, denying these to agriculture.

Environmental opportunities: China is seen as an attractive country in which industries can invest, as it is competitive because of the presence of urban cities (Dumon, 2017). In the early 2000s, China overtook the USA as the world's largest recipient of foreign capital. The foreign direct investment in the country is over US$100 billion per annum.

In addition, the large population of China presents good opportunities for diverse skills that are sought by western industries. The growing population of countries in East and South Asia, in general, is seen as a potential for the market growth of any product because of the population's increasing demand for commodities.

Environmental risks: The growing urbanisation rate in China and India is accompanied by increasing demands for commodities such as food and water (European Commission, 2015). This is due to the observation that urbanisation increases human exposure to and demands for goods and services. Many commodities in today's world are made directly or indirectly from natural resources, leading to water and land scarcity in these countries. In addition, the air quality in cities is increasingly being eroded because of growing urbanisation activities, leading to health and safety concerns.

Food security and urbanisation

Environmental aspects: Lands that were previously used to grow food crops are being used to urbanise Asian countries such as China, Thailand and India.

Environmental opportunities: There has been a rapid movement of rural dwellers to urban areas, earning them employment (Woke, 2017). For example, about 15 million to 20 million people are added to city populations in China for every 1–1.5% increase in urban developments. Across Asia, urbanisation exposes citizens to a potentially more civilised and healthy lifestyle, with access to social amenities such as libraries and hospitals.

Environmental risks: The number of undernourished people in urban areas is increasing in China (Satterthwaite et al., 2010) as well as in India, Indonesia and Bangladesh (Rudert, 2014). The ratio of urban farmers to urban dwellers is also decreasing. Urban development activities are polluting land and water resources, making them unsuitable for agricultural purposes. In addition, some urban people are not consuming balanced diets because of food shortages and/or changes in habits, leading to increases in illnesses. Furthermore, the rapid movement of rural dwellers to urban areas is causing congestion and pressures on basic infrastructure, heightening health and safety concerns. Pressure on land use, partly because of increased urbanisation, can impact on losses of natural landscape, with critical losses in biodiversity.

GM crops and industrialisation

Environmental aspects: The use of GM technology is increasingly being adopted in China and India, particularly in the use of Bt cotton.

Environmental opportunities: Cotton farmers in China were in the past seriously affected by insects and pests, in terms of yield, farmer health and poisoning of ground water (Huang et al., 2002). In China, in 2000, 29% of farmers who did not use Bt cotton suffered from pesticide poisoning, whereas only 7% of those who did use transgenic cotton reported effects of poisoning. As an added bonus, the yield of Bt cotton is up to 50% per hectare higher than that of non-Bt cotton crops, and revenue is higher by 400% per hectare. In India, Bt cotton has brought about a 24% increase in cotton yield per hectare through reduced pest damage and a 50% gain in cotton profit among smallholders (Kathage and Qaim, 2012). By 2013, the adoption of Bt cotton led to a reduction of 497 million kilograms of pesticides worldwide, and a reduction of CO_2 emissions of 26.7 billion kilograms per year. Studies have shown that the lower levels of pesticide being sprayed on cotton crops promoted biodiversity by allowing non-target species such as ladybirds and spiders to become more abundant (Lu et al., 2012).

Environmental risks: The increased yields and profits of Bt cotton and other crops has led to an expanded cultivation, often at the expense of natural systems. Also, the use of GM crops no doubt leads to mono-cropping and reduces biodiversity around the world. The adoption of glyphosate-resistant (RoundUp Ready) crops has no doubt led to an increase in the use of this herbicide. Despite much debate, a recent EU assessment did not identify a carcinogenicity hazard for glyphosate. Two complementary exposure assessments, human biomonitoring and food residues monitoring, suggest that actual exposure levels are below reference values and do not represent a public concern (Tarazona et al., 2017).

Cheap labour and production costs

Environmental aspects: Many companies and groups in China and India are increasing their agricultural production, leading to greater utilisation of land and water resources.

Environmental opportunities: Apart from the fact that companies such as Nestlé and BSR (Business for Social Responsibility) provide employment to many people in China, there have been opportunities for personal development through skills acquisition provided by many companies from developed nations. BSR has a popular programme known as 'women in factories China program', empowering women with work skills, to improve communities (BSR, 2017). Many western companies have corporate social responsibility programmes that require them to invest in both the workforce and local communities wherever they operate.

Environmental risks: The presence of manufacturing companies in China and India is because labour is cheap in these countries and legislations are fragile. The manufacturing process does not require high-level skills, and workers accept low wages (Turker and Altuntas, 2014). Women and young children also make up a significant part of the workforce in developing countries such as China, India, Indonesia and Thailand. Thus, there are challenges concerning child labour within the workforce in these countries. There are numerous cases of forced labour with no pay, or unreasonably long work days. For example, it was reported recently by the Clean Clothes Campaign that garment workers in China work for 13–14 hours non-stop per day (Ethical Fashion Forum, 2016). Long working hours have been associated with feelings of depression, dejection and loss of confidence. These feelings can interfere with other aspects of a worker's life and can create other social problems such as relationship breakdowns and crime.

Climate change

Environmental aspects: Both human and industrial activities in Asia/Oceania are utilising land and water resources and changing the environment. In parts of Southern Asia such as China and India, water scarcity and land degradation are partly the result of the effects of climate change (Blum, 2013; Feng et al., 2015).

Environmental opportunities: The climate change issue is bringing about increasing developments in climate policies and this is good for governance. China, India, South Korea and Japan are continually launching innovations and infrastructures such as wind turbines and photovoltaic systems to adapt and mitigate the effects of climate change. These innovations are good not only for the environment but also for the general population. In addition, global warming has opened up and will open up new areas in northern latitudes to agriculture, and may provide opportunities for agriculture in certain regions with an expansion of the growing season with milder and shorter winters. This could increase productivity and allow the use of new and potentially more profitable crops (Agriculture and Agri-Food Canada, 2014).

Environmental risks: China is the world's largest emitter of GHGs (Meyer, 2015) and the growing urbanisation in both China and India relies on fossil fuels. Floods, water scarcity, land degradation, storms, hurricanes, wildfires and diseases are all impacts of climate change. Extreme weather events are known to cause significant yield reductions in some years, despite technological improvements that increase corn yields (Figure 9, USGCRP, 2009). Although increased CO_2 can stimulate plant growth, it also reduces the nutritional value of most food crops. Rising levels of atmospheric CO_2 reduce the concentrations of protein and essential minerals in most plant species, including wheat, soya beans and rice. This direct effect of rising CO_2 levels on the nutritional value of crops represents a potential threat to human health. Human health is

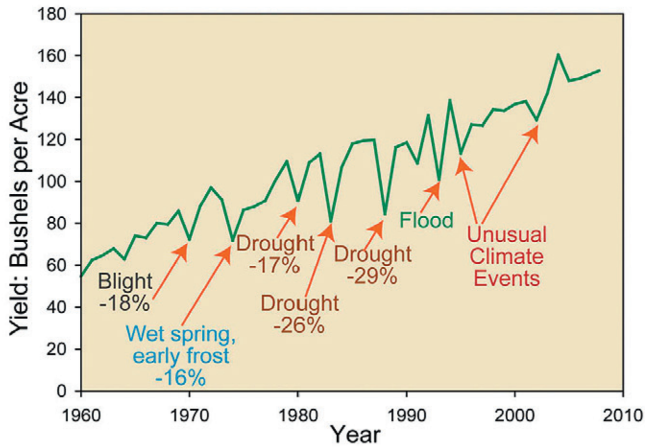


Figure 9 Corn yield in the USA over time and in relation to climate events. Source: USGCRP (2009).

also threatened by increased pesticide use because of increased pest pressures and reductions in the efficacy of pesticides (USGCRP, 2016).

Industrial activities and waste

Environmental aspects: Potentially harmful chemicals such as mercury, lead and sulphur are increasingly being used by manufacturing companies in China, India, South Korea and Japan, where business environmental management laws are not uniformly enforced.

Environmental opportunities: The use of chemicals in industrial activities in China produces waste, which is contaminating water and land resources. As a result, there are opportunities for R&D in the chemical industry in China. There are ongoing research initiatives on how to develop sustainable chemicals with lower environmental impacts (IBIS World, 2016). Organic chemicals such as ethylene, propylene, pure terephthalic acid (PTA), benzene, toluene, xylene and styrene are being produced in China and sold to the rest of the world. The organic chemical industry in China constitutes a major industry.

Environmental risks: The use of chemicals in industry produces harmful industrial wastes. Such wastes are occasionally carried to water bodies, killing aquatic life such as fish, thereby endangering biodiversity. In addition, harmful waste comes into contact with land resources, altering soil pH levels and rendering the land infertile for food production (Singh et al., 2016).

Biofuels

Environmental aspects: China and India are pursuing programmes to increase the production of biofuel, heightening concerns that lands that were previously used to grow food crops will be used to grow biofuels.

Environmental opportunities: China is experiencing rapid economic and population growth. The country relies on the availability of energy to fuel these economic developments. Biofuel is now being used to meet part of China's energy demand, improving the country's energy security and independence. The production of bioethanol in China has been increasing and bioethanol-blended petrol accounted for 20% of the total petrol consumption in China in 2005 (Wang et al., 2009). China currently has a mid- and long-term development plan for renewable energy, which aims to increase the consumption of biodiesel to about 2 million tonnes by 2020; if met, it will impact positively on environmental concerns.

Environmental risks: The use of land resources to grow biofuels in China, India and other countries requires considerable water and land resources (Grid Arendal, 2017). Land and water resources that were previously used to grow food items in China are no longer available, leading to hunger issues and disease.

Pesticides

Environmental aspects: China, India and other parts of Asia are experiencing population growth and an increasing demand for food items. There has been an increase in the use of fertilisers in these countries. The excessive use of fertilisers and pesticides in China, for example, has created polluted waters (Patton, 2015). Soils have sometimes been contaminated with heavy metals, making water and land resources unsuitable for human and domestic use.

Environmental opportunities: The use of pesticides in China and India has improved food crop yields (Aktar et al., 2009) and has reduced the effects of pests and insects on agricultural lands. For example, food grain production in India reached its highest level in 2013–2014, with 265.57 million tonnes (of grain production) (Mohan, 2015). The top 100 agrochemical companies in China made around US$17 million from the sales of pesticides in 2014 (Agronews, 2015). The agrochemical industry in China continues to make year-on-year increases in the sales of pesticides. In addition, the revenue generated from the sales of pesticides is generating employment opportunities in China.

Environmental risks: Pesticide pollution and pesticide poisoning are harmful to human health (Alton, 2016). They can cause diseases when people come into contact with land or water resources that have been polluted by pesticides. Some of the diseases that are implicated by pesticide pollution are Parkinson's disease and brain and lung damage. Also, pesticide poisoning can slow down the growth of babies and cause severe harm. Pesticides can cause fertility problems in people exposed to them.

Recommendation: The implications of the use of land for non-food crop production (including for clothing and biofuels), urbanisation and industrial expansion for FNS and the preservation of biodiversity need to be better understood and reflected in policies and planning.

Recommendation: The rapid change in the world's climate introduces considerable uncertainty and risk for future world food production. The recommendations of the main international climate agreements, including Paris 215, the Sendai Framework for Disaster Risk Reduction 2015–2030 and the United Nations Sustainable Development Goals 2015, need to be addressed. Means to mitigate these risks in the Asia/Pacific region should be a priority.

Recommendation: Water and soil use management (and the contamination of water, soil and food with fertilisers, herbicides and pesticides) needs to be an integral part of any strategy to increase food production. Sustainability of production must be to the fore.

8 Conclusions and recommendations

This report focuses on FNS in the Asia/Oceania region but, given the size and importance of the region and the considerable inter-connectedness of matters influencing food production, food consumption, nutrition and human well-being, many of the observations and recommendations made are global in nature. These will be further addressed under the IAP's global scoping report.

The target outcome of our deliberations is future FNS, i.e. access for everybody to a diverse healthy diet that is underpinned by a production/distribution/consumption system that is sustainable, environmentally, socially and culturally. It is recognised that there are many facets to FNS, and a systems approach to analysis is recommended, where the complex interactions between scientific and technical (physicochemical, biological and environmental), economic, political, social and cultural dimensions are considered together. Having said this, in preparing this report, the Working Group, and reflecting its expertise and mandate, has chosen to focus on the crucial role to be played by S&T (both R&D and education) in securing future FNS. Increasing pressures from population growth, urbanisation, land availability, resource and water availability, pollution, global climate change and biodiversity loss conspire to make FNS a formidable near-term challenge. S&T offers solutions, but plans need to be made now, and enacted boldly and decisively if catastrophe and great suffering are to be avoided. There needs to be a considerable resurgence in agri-food R&D, extension and education, and such a focus needs to be more multi-disciplinary and systems oriented than in the past.

Our analysis for the Asia/Pacific region finds that impediments to food availability, access and utilisation are often specific to countries, regions within countries and groups within regions, and that a territorial approach rather than a 'one-size-fits-all' approach is required for defining targets where there will be a maximum return on investment. In many cases, existing knowledge can be brought to bear to make very significant gains and, in these cases, both extension and education need to be to the fore. Major investment in the region is required, to gain a better understanding of impediments to FNS for the most at-risk areas and population groups. On the basis of such an analysis, a blueprint for education, extension and national/international S&T programmes should be put in place. Much can be achieved, if the problem of present and future FNS is seen as transcending the usual geographical and national boundaries, and the region's nations work cooperatively to achieving solutions, with a common end goal. In this respect, several emerging areas of S&T are seen as ubiquitous for the region in terms of their utility of application and it is strongly exhorted that a cooperative regional approach be taken, to form well-resourced regional centres of research excellence focusing on key opportunity areas. Such virtual centres would be populated by the 'best-of-the-best' relevant scientists from throughout Asia and the Pacific and would pursue clearly conceived research plans with specific objectives. Key S&T areas, seen to have universal and prioritised application across the region, include (1) genomics-based approaches to plant and animal breeding; (2) 'big-data' capture and analysis, precision agriculture and robotics; (3) food technology innovations in harvest, processing and storage to reduce food wastage; (4) sustainable farming practices for land and water use that address wider issues such as biodiversity and climate; (5) aquaculture production and integrated farm production systems. These would be large multi-disciplinary projects that reflect public-good science and leverage off fundamental science to build deep knowledge bases, in what are seen to be critical innovation areas to secure future FNS.

Our analysis encourages each country and the region overall to prepare and implement a detailed FNS and agriculture action plan with defined targets, outcomes and implementation pathways. FNS, being of a systems oriented, multi-disciplinary and multi-lateral nature, should operate in a national collaborative mission mode, converging relevant ministries and departments and with well-defined responsibilities, expected outcomes and accountabilities.

The report makes several specific recommendations, which are presented together in Appendix III. All of these recommendations are important but the over-arching significant high-level recommendations are as follows.

1. Priority in relation to R&D and educational efforts should be given to countries and regions that have been identified as being at 'high risk' concerning current and future FNS. Particular focus should be afforded to India, Bangladesh, Pakistan, Afghanistan, Nepal, Myanmar (countries having elements in common) and the Philippines, Iraq, Tajikistan and Yemen.

2. A strategy moving forward would be to undertake systems analysis to identify key impediments to raising food yields or supplying an adequate balance of food types. The systems analysis would prioritise extension, education and R&D needs, region by region and/or group by group, and would provide guidance on means of sustainably increasing food production and diversity. There will undoubtedly be some R&D/extension/education focus areas that are of global relevance and universally applicable (see above).

3. The AASSA should work with its constituent societies to develop a trans-national funding mechanism that puts *basic research* connected to FNS at the forefront. Such a framework, if properly funded, can have far-reaching consequences for both S&T and FNS in the Asia/Pacific region, similar to the effect of the European Research Council (ERC) integration grants on science in Europe.

4. Investment in inter-disciplinary R&D relevant to FNS in Asia/Oceania needs to be increased significantly. Consideration should be given to forming cross-nation, cross-disciplinary consortia (centres of research excellence), to focus on defined pressing issues related to FNS.

5. Regional cross-nation initiatives should be implemented to greatly increase the quantum of education and training of the next generations of scientists, technologists, extension officers and leaders in agriculture, nutrition and food. Training should have a trans-disciplinary basis.

The Asia/Pacific food system is vast and is richly endowed. It has the potential to provide more and better food, reduce food wastage, drive economic growth and deliver healthier, safer diets to all, and to do this in a sustainable way. However, this potential will not be realised unless concerted efforts are made across the region to greatly strengthen both research and education.

Research needs to envelop the entire food system, be inter-disciplinary and have as its aim to increase the net supply (production less wastage) of a diverse range of foods. As diverse healthy diets must be the target outcome, an emphasis on food safety, human nutrition and well-being must be prevalent. The region already has numerous universities and training facilities that have strong backgrounds and reputations in agricultural science, food science and nutrition, and this considerable intellectual asset base should be fully leveraged to train the next generation of agriculture, food and nutrition leaders. Just as for research, education needs to cross-disciplinary boundaries, to produce rounded graduates who can appreciate the complexity and inter-connectedness of food systems, and who are able to engage with problems and opportunities that cannot be adequately viewed in isolation.

There is overwhelming evidence that urgent action to address the global food system and, as has been the focus of this report, the Asia/Oceania food system is required. In the coming years, the needs of a growing population will have to be satisfied as resources such as water, energy and land become more and more scarce, and all this in an area of the world that already witnesses widespread malnutrition. Simply increasing food production will not suffice, and addressing equally alarming issues such as food quality, global climate change, the loss of biodiversity and environmental pollution will be paramount. Piecemeal approaches will not work; holistic solutions are needed.

The economist Dr Robert L Thompson, Professor Emeritus of Agricultural Policy, the University of Illinois at Urbana-Champaign, USA, has defined the long-run prospects, and we quote:

'*The world's farmers need to double agricultural production in the next forty years using less water and little more land than today. Malthus has been wrong for more than two centuries, and there is no more reason for him to be right in the 21st century than in the 19th and 20th. However, he will continue to be wrong only if investments in agricultural research and education increase global agricultural productivity faster than demand grows. Whether world market prices trend upwards, downwards or sideways in the 21st century will depend on whether agricultural research increases land and water productivity faster, slower or at the same speed as world demand for food grows. The drop in public sector investments in agricultural development (and agricultural research in particular) must be reversed if there is to be any chance of avoiding an upward trend in prices, which would be devastating to low-income consumers who spend a large fraction of their incomes on food*'.

From an address by Dr Robert L Thompson, March 2017

As stated at the end of Chapter 1 of this report, the AASSA Expert Working Group is confident that malnutrition in all its forms can be combated and that the future citizenry of Asia can be properly fed, as long as sufficient global investment in science and education is made. Much work remains to be done. Critical areas influencing the region's ability to increase food production and to ensure a diversity of high-quality foods reaching consumers need to be identified. Trans-disciplinary and inter-disciplinary cooperative research programmes, mustering the best resource from across the regions, need to be formed and funded to develop knowledge. That knowledge needs to be communicated clearly and shared freely and extensively.

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Appendix I

Meeting composition and meeting schedule

The report was prepared by consultation with a Working Group of experts selected among the nominees from the member academies of the AASSA.

Working Group

Professor Paul Moughan (New Zealand)
Professor Daniel A Chamovitz (Israel)
Writers of report

Professor Xiangzheng Deng (China)
Professor Tan Swee Lian (Malaysia)
Professor Morakot Tanticharoen (Thailand)
Professor S Ayyappan (India)
Professor Jalal Jamalian (IR Iran)
Professor Cherl-Ho Lee (South Korea)

Project coordination

The AASSA's IAP food and nutrition security and agriculture (FNSA) project was coordinated by Professor Krishan Lal (Co-chair of the IAP and former President of the AASSA) and his assistants at the Indian National Science Academy, i.e. Dr Umesh Srivastava, Mr Sandeep Kumar Chauhan, Dr Ila Mukul Tiwari and Mr Pradeep Kumar.

Administrative support

Administrative support and financial management were provided by the AASSA Secretariat led by Professor Yoo Hang Kim (President of the AASSA) and Professor Mooha Lee (Executive Director of the AASSA) and its staff Mr Sang-cheol Kim and Ms Lyunhae Kim. Typing and layout of the draft report was expertly undertaken by Mrs Terri Palmer of the Riddet Institute, New Zealand.

Meeting schedule

First meeting (hosted by the Indian National Science Academy): 25–27 April 2016 (New Delhi)

Second meeting (hosted by the Korean Academy of Science and Technology): 18–19 July 2016 (Seoul)

External guests: Professor Volker ter Meulen (Co-chair of the IAP)
Professor Robin Fears (UK)
Dr Claudia Canales (Norway)

Third meeting (hosted by the Indian National Science Academy): 6–9 February 2017 (New Delhi)

A special feature was participation of the following young scientists recommended by GYA:
Dr. Dilfuza Egarberdieva (Uzbekistan temporarily in Germany)
Dr. A. Arunachalam (India)
Dr. Monir Uddin Ahmed (Bangladesh)
Dr. Zhihui (Zofia) Li (China)

Fourth meeting (hosted by the Korean Academy of Science and Technology): 14–15 September 2017 (Seoul)

Dr. Robin Fears (EASAC) participated as a special invitee.

Peer-review referees

Professor R B Singh (Chancellor, Central Agricultural University; Former Assistant Director-General and FAO Regional Representative for Asia and the Pacific Immediate Past President, National Academy of Agricultural Science in India)

Professor Bruce Tolentino (Deputy Director-General and Secretary, IRRI Board of Trustees)

Professor Kazim Sahin (Turkish Academy of Sciences)

Professor Dr Adel El Beltagy (Former Chairman, Global Forum for Agricultural Research, FAO, Rome)

Professor Mei Fang Quan (Chinese Academy of Sciences; Member, FAO Committee on Food Security)

Appendix II

IAP Template for Common Themes in the Project

1 What are key elements to cover in describing national/regional characteristics for FNSA?

- Definitions and conceptual framework for FNSA, including: how measured; links with health; covering demand-side issues as well as supply-side issues to assess overall current 'fitness for purpose' and to clarify boundaries for framing the themes.
- Including status and standards for population groups (variation within a region, demographic, vulnerable).
- Covering excess consumption as well as under-nutrition.

2 What are major challenges/opportunities for FNSA and future projections for the region?

- Climate change (impact of climate change on FNSA and contribution by agriculture to climate change).
- Population growth, urbanisation, migration.
- Supply instabilities and others (e.g. political, economic, financial).
- Ensuring sustainability (environmental, economic, social) and building resilience to extreme events (e.g. to address increasing systemic risk from interruption of increasingly homogeneous food supplies).
- Agriculture and food in the bio-economy.
- Scenario building.

3 What are strengths and weaknesses of S&T at the national/regional level?

- Relevant cutting-edge capabilities: including social sciences, inter- and trans-disciplinary research, modelling.
- Opportunities and challenges for research systems in the context of tackling major vulnerabilities in FNSA; relative contributions from public and private sectors.
- Handling and using 'big data' in food and nutrition science/open data opportunities.
- Issues for mobilising science and deploying outputs from research advances, addressing innovation gaps and ensuring the next generation of researchers, farmers, etc.
- Science–policy interfaces. Sharing science within the region.
- External (indirect) effects—impact of research and innovation in the region on outside the region.

4 What are the prospects for innovation to improve agriculture (e.g. next 25 years) – at the farm scale?

- Issues for societal acceptability.
- Plants (e.g. plant breeding, ensuring genetic diversity).
- Animals (e.g. advent of genome editing).
- Tackling pests and diseases.
- Food safety issues.
- Agronomic practices (e.g. precision agriculture).
- Not just terrestrial—also use of aquaculture/marine resources, developing market potential while avoiding over-exploitation and depletion of genetic diversity.

5 What are the prospects for increasing efficiency of food systems?

- Understanding the agricultural/food value chain and institutional frameworks so as to characterise issues for the integrative food system.
- Issues for food utilisation and minimising waste (including during harvesting, processing, consumption stages).
- Tackling governance/market/trade issues to ensure affordable food and to minimise market instability.
- Food science issues. Food retail issues.

6 What are the public health and nutrition issues, particularly with regard to impact of dietary change on food demand and health?

- Characterising current trends in health related to issues for FNSA.
- Issues for expected changes in consumption patterns (and implications for food importation); understanding and incentivising behavioural change, emerging personalised nutrition.

- Innovative foods and new food sources.
- Food safety issues.
- Promoting nutrition-sensitive agriculture to provide healthy and sustainable diets with connected issues for resource use and food prices.

7 What is the competition for arable land use?

- Impacts of urbanisation (including issues for agricultural labour force and new opportunities in urban agriculture as well as issues for available arable land).
- Bioenergy and other bio-economy products.
- Multi-functional land use – goals for biodiversity and ecosystem services.
- Potential for expanding arable land availability (e.g. from marginal land).
- Implications of forestry trends.
- Also competition for resources with regard to marine sustainability.

8 What are other major environmental issues associated with FNSA—at the landscape scale?

- Contribution of agriculture to climate change.
- Intersections with other natural resource inputs (water, energy, soil health) and fertilisers/other chemicals. Irrigation issues in multi-use water systems. Waste water.
- Balancing goals for sustainable development and FNSA.

9 What may be the impact of national/regional regulatory frameworks and other sectoral/inter-sectoral public policies on FNSA?

- Policies that foster technological innovation.
- Policies that build human resources (e.g. education, gender, equity).
- Policies that redesign whole agricultural ecology (land use, bio-economy, etc.).
- Policies to promote consumption of healthy food.
- Issues for policy coherence.

10 What are some of the implications for inter-regional/global levels?

- Link with global objectives, e.g. 2015 United Nations Sustainable Development Goals and Climate Change Conference (COP21)—issues for their scientific underpinning and resolution of conflicting goals.
- Wider impact of national/regional policy instruments, e.g. trade, development policies.
- International collaboration in FNSA research and research spillovers.
- International FNSA science governance infrastructure and science advisory mechanisms.

Appendix III

Recommendations

1 A strategy moving forward would be to undertake systems analysis to identify key impediments to raising food yields or supplying an adequate balance of food types. The systems analysis would prioritise extension, education and R&D needs, region by region and/or group by group, and would provide guidance on means of sustainably increasing food production and diversity. There will undoubtedly be some R&D/extension/education focus areas that are of global relevance and are universally applicable.

2 Priority in relation to R&D and educational efforts should be given to countries and regions that have been identified as at 'high risk' concerning current and future FNS. Particular focus should be afforded to India, Bangladesh, Pakistan, Afghanistan, Nepal, Myanmar (countries having elements in common), the Philippines, Iraq, Tajikistan and Yemen.

3 Consideration should be given to the effects of different age distributions in future populations, with respect to dietary types and nutritional needs as related to FNS.

4 Any consideration of future FNS should take into account not only the production of more food calories and nutrients (to combat potential under-nutrition), but also the production of a wider diversity of food types and strategies to prevent obesity and its associated non-communicable diseases.

5 Work should be undertaken in countries and regions at 'high risk' of future FNS, at a more localised provincial and sectoral level, to generate data to allow a better understanding of FNS and its drivers.

6 Scientific evidence juxtaposed with advanced assessment analyses should inform and influence policy options. To ensure and further encourage the involvement of scientists in policy decisions, at the national and regional levels, regional frameworks that encourage and facilitate interactions between government, NGO policy-makers and scientists should be initiated.

7 The IAP should convene an expert panel to determine an agreed-upon nomenclature for use in describing crops developed through biotechnology techniques. GM is a natural process, and there is confusion with the current terminology.

8 Policies at both national and regional levels within Asia/Oceania should be developed, to form multi-disciplinary S&T collaborations to target specific outcomes.

9 Common impediments to increasing FNS at national, regional and local levels should be identified and evaluated, along with generic over-arching technologies, to form a blueprint for future Asia/Pacific FNS R&D.

10 The AASSA should work with its constituent societies to develop a trans-national funding mechanism that puts *basic research* connected to FNS at the forefront. Such a framework, if properly funded, can have far-reaching consequences for both S&T and FNS in the Asia/Pacific region, similar to the effect of the European Research Council (ERC) integration grants on science in Europe.

11 The AASSA should work with its constituent societies to further develop binational research cooperation in FNS.

12 Considering the R&D lag between investment and adoption/return on investment for agricultural and food research, national governments should not only maintain support for basic R&D, but also increase overall levels of funding (as a % of GDP) for FNS.

13 There should be research effort to understand the holistic nutritional and health properties of individual foods and mixed diets, so as to better define the characteristics of a healthy diet.

14 Ultimately food types and diets that are both healthy and socially and culturally acceptable should be defined at a local level, taking into account a wide diversity of views and beliefs.

15 The food S&T, nutrition and plant/animal breeding disciplines should work together to develop functional foods containing high natural levels (or following fortification) of health-enhancing bioactives as well as minerals and vitamins. Such functional foods should be targeted constituents of healthy diets.

16 There should be better education concerning the role of food and nutrition in health, and such education should occur at all levels of the education system and should be generic. There should be specialised training for health professionals, including doctors and other primary influencers. The role of dieticians in communities should be expanded.

17 Reliable data on food wastage and how it varies with the food production system and with socio-economic sectors of a population need to be generated, and strategies to minimise food wastage need to be devised.

18 Valid metrics and measurement mechanisms and approaches to enable practical descriptions of sustainable farming systems and sustainable diets should be developed, to allow a complete evidence-based assessment of sustainable diets.

19 Efforts to collect, phenotype, catalogue and preserve diverse wild relatives and landraces of cultivated crops should be extended. In particular, efforts must go into advanced high throughput phenotyping and genotyping technologies.

20 Research efforts, including new target identification studies, to further develop CRISPR/Cas9 and similar NBTs for use in crops should be enhanced. Regulations should be evidence based and, where supported, NBTs should be classified as non-GM.

21 Research into developing new feedstuffs (lower down the food value chain) for simple-stomached animals (e.g. pigs, poultry and fish), and into the underlying mechanisms of productive efficiency, is urgently needed. Research into pasture-based systems for ruminant production and the mitigation of GHGs should be a priority. NBTs and new reproductive technologies need to be properly assessed on the basis of scientific evidence and, where found to be acceptable, should be pursued vigorously.

22 Inter-disciplinary research among engineers, geographic scientists, biologists and data scientists to develop better-integrated sensing and reporting systems and to promote precision agriculture and robotics should be encouraged.

23 Impact analyses to identify and overcome impediments to adopting precision agriculture systems among small scale farmers should be encouraged.

24 New scalable insect and algal species for use in the food industry and alternative animal feeding systems should be identified. Studies into algal chemistry pre- and post-extraction and the identification of novel chemistries should be encouraged.

25 Further adoption of aquaculture technologies through research into intensified growth conditions and the identification of new species should be promoted.

26 Specific food security research calls in aquaculture, which will attract scientists in other fields (e.g. virologists and engineers) to pursue relevant research, should be encouraged.

27 Investment in inter-disciplinary R&D relevant to FNS in Asia/Oceania needs to be increased significantly. Consideration should be given to forming cross-nation, cross-disciplinary consortia (centres of research excellence), to focus on defined pressing issues related to FNS.

28 Regional cross-nation initiatives should be implemented to greatly increase the quantum of education and training of the next generations of scientists, technologists, extension officers and leaders in agriculture, nutrition and food. Training should have a trans-disciplinary basis.

29 The implications of the use of land for non-food crop production (including for clothing and biofuels), urbanisation and industrial expansion for FNS and the preservation of biodiversity need to be better understood and reflected in policies and planning.

30 The rapid change in the world's climate introduces considerable uncertainty and risk for future world food production. The recommendations of the main international climate agreements, including Paris 215, the Sendai Framework for Disaster Risk Reduction 2015–2030 and the United Nations Sustainable Development Goals 2015, need to be addressed. Means to mitigate these risks in the Asia/Pacific region should be a priority.

31 Water and soil use management (and the contamination of water, soil and food with fertilisers, herbicides and pesticides) needs to be an integral part of any strategy to increase food production. Sustainability of production must be to the fore.

AASSA, the Association of Academies and Societies of Sciences in Asia, consists of the following national academies and academic bodies in Asia and Australasia.

Academy of Sciences of Afghanistan
National Academy of Sciences of Armenia
Australian Academy of Science
Azerbaijan National Academy of Sciences
Bangladesh Academy of Sciences
Chinese Academy of Sciences
Georgian National Academy of Sciences
Indian National Science Academy
Indonesian Academy of Sciences
The Academy of Sciences of Islamic Republic of Iran
Israel Academy of Sciences and Humanities
Science Council of Japan
Royal Scientific Society, Jordan
National Academy of Sciences of the Republic of Kazakhstan
The Korean Academy of Science and Technology
The National Academy of Science, Republic of Korea
National Academy of Sciences of the Kyrgyz Republic
Academy of Sciences Malaysia
Mongolian Academy of Sciences
Nepal Academy of Science and Technology
Royal Society of New Zealand
Pakistan Academy of Science
National Academy of Science and Technology, Philippines
Far Eastern Branch of the Russian Academy of Sciences
Siberian Branch of the Russian Academy of Sciences
Singapore National Academy of Science
National Academy of Sciences of Sri Lanka
The Academy of Sciences of the Republic of Tajikistan
The Science Society of Thailand under the Patronage of His Majesty the King
Thai Academy of Science and Technology
Turkish Academy of Sciences
Academy of Sciences of the Republic of Uzbekistan
Vietnam Academy of Science and Technology
ASEAN Academy of Engineering and Technology

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