Purpose
The purpose of the event was to enhance the understanding of food-based approaches to improve nutrient composition and bioavailability in foods in the context of climate change and how stable isotope techniques can help evaluate their effectiveness.
Participants
Ms Isabel Mank (Germany), Ms Fatiha Terki (Italy), Mr Patrick Teixeira (Ivory Coast), Ms Ilaria Schibba (Italy), Mr Anura Kurpad (India), Mr Abdou Badiane (Senegal), Ms Nanna Roos (Denmark), Mr Warren Lee (Thailand), Mr Erick Boy (USA), Ms Wantanee Kriengsinyos (Thailand), Mr Patrice Dion (Canada), Ms Shibani Ghosh (USA), Ms Lynnette Neufeld (Switzerland), Mr Mamane Zeilani (France), Ms Stineke Oenema (Italy), Ms Maria Xipsiti (Italy), Mr Michael Zimmermann (Switzerland), Mr Martin Mwangi (Malawi), Ms Beatrice Ekesa-Onyango (Uganda), Ms Gina Kennedy (USA), Mr Daniel Nyagawa (Tanzania), Mr Chiza Kumwenda (Zambia), Mr Omar Dary (USA), Mr Tawanda Muzhingi (Zimbabwe), Mr Daniel Tome (France), Ms Alida Melse-Boonstra (The Netherlands), Ms Lindiwe Majele Sibanda (South Africa), Ms Thalia Sparling (UK), Mr Mourad Moursi (USA), Ms Megan Parker (USA), and Ms Charlotte Dufour (France)

Scientific Secretary: Mr Victor Owino, IAEA

IAEA: Ms Cornelia Loechl, Ms Alexia Alford, Ms Pernille Kaestel, Mr Isaac Kofi Bimpong, Ms Janna van Dijke
Table of contents

Glossary ................................................................................................................. 4
Executive Summary ............................................................................................... 6
Key messages from the meeting ........................................................................... 6
  Introduction ........................................................................................................ 7
  Objectives .......................................................................................................... 7
  Participants ........................................................................................................ 7
  Methodology of the meeting .............................................................................. 7
  Way forward ....................................................................................................... 9
Report Summary .................................................................................................... 11
Official opening and welcome ........................................................................... 11
Presentations, discussions and way forward ...................................................... 11
  Session 1: Setting the Scene .......................................................................... 12
  Session 2: Improving diets in the context of climate change ....................... 18
  Session 3: Assessing linkages between food systems, diets and nutrition – the context for stable isotope research .................................................................................. 33
  Session 4: Reflecting together on the role of stable isotopes in climate change, food systems and nutrition ......................................................................................... 47
  Session 5: Bringing it all together and moving forward .................................. 50
List of Participants ................................................................................................. 52
Glossary

AME: Adult Male Equivalence
ANH: Agriculture, Nutrition and Health
ASF: Animal Source Food
CGIAR: Consultative Group on International Agricultural Research
COP: Conference of Parties
COVID: Coronavirus Disease
CRP: Coordinated Research Project
DIAAS: Digestible Indispensable Amino Acid Score
DXA: Dual X ray Absorptiometry
EED: Environmental Enteric Dysfunction
EGM: Evidence and Gap Map
FANRPAN: Food, Agriculture and Natural Resources Policy Analysis Network
FAO: Food and Agricultural Organization
FFQ: Food Frequency Questionnaire
FNG: Fill the Nutrient Gap
FZA: Fractional Zinc Absorption
HBS: Household Budget Survey
HCES: Household Consumption and Expenditure Surveys
INSP: Instituto Nacional de Salud Publica
GACSA: Global Alliance for Climate Smart Agriculture
GAIN: Global Alliance for Improved Nutrition
GDD: Global Dietary Database
GDQS: Global Diet Quality Score
GIFT: Global Individual Food consumption data Tool
GOS: Galacto-Oligosaccharides
IAEA: International Atomic Energy Agency
ICN2: International Congress on Nutrition
IMMANA: Innovative Metrics, Tools and Methods in Agriculture-Nutrition Research
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>INDDEX</td>
<td>International Dietary Data Expansion Project</td>
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<td>INFOODS</td>
<td>International Network of Food Data System</td>
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<tr>
<td>LAZ</td>
<td>Length-for-Age z Score</td>
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<tr>
<td>LMIC</td>
<td>Low-and-Middle-Income Country</td>
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<tr>
<td>MDD-W</td>
<td>Minimum Dietary Diversity Indicator for Women</td>
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<tr>
<td>MPA</td>
<td>Mean Probability of Adequacy</td>
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<tr>
<td>NAHRES</td>
<td>Nutritional and Health-Related Environmental Studies Section</td>
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<td>NCDs</td>
<td>Non-Communicable Diseases</td>
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<td>N4G</td>
<td>Nutrition for Growth</td>
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<td>NUE</td>
<td>Nitrogen Use Efficiency</td>
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<td>PDCAAS</td>
<td>Protein Digestibility Corrected Amino Acid Score</td>
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<td>SDGs</td>
<td>Sustainable Development Goals</td>
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<td>TM</td>
<td>Technical Meeting</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<td>UNSCN</td>
<td>United Nations System Standing Committee on Nutrition</td>
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<tr>
<td>WHA</td>
<td>World Health Assembly</td>
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<td>WISH</td>
<td>World Health Index of Sustainability and Health</td>
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<td>WFP</td>
<td>World Food Programme</td>
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<td>WHO</td>
<td>World Health Organization</td>
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<td>WRA</td>
<td>Women of Reproductive Age</td>
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<td>WUE</td>
<td>Water Use Efficiency</td>
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Executive Summary

Key messages from the meeting

- Food systems are influenced by climate change which has direct impact on nutrition and health. On the one hand there are changes in temperature and rainfall precipitation that can lead to increased (ca 3-84%) global food prices, reduced nutrient value and increased food insecurity. Food insecurity then triggers consumption of nutrient-poor and calorie-rich foods and ultimately, hunger and malnutrition (undernourishment, micronutrient deficiencies, overweight and obesity). From a systematic view there is a complex feedback loop in between dietary patterns and environmental impacts throughout the food system. There is reduced nutrient content leading to malnutrition on the one hand; climate change impacting biomass which in turn impacts agriculture and biodiversity ultimately leading to yield loss. This in turn leads to intensification of agriculture and trade which again leads to climate change.

- The world is relying on a smaller number of foodstuffs to feed a growing population that is expected to rise to around 10 billion people by 2050. Of the 6,000 plant species cultivated for food, just nine account for 66% of total crop production. The world’s livestock production is based on around 40 species with only a handful providing the vast majority of meat, milk and eggs.

- Consideration needs to be given to multiple trade-offs including, environmental footprint, crop yield versus grain content, grain protein versus starch content and grain protein versus anti-nutritional content associated with innovative interventions.

- Assessment of the impact of livestock on the environment and livelihood should not focus on single criteria such as greenhouse gas emissions, but should balance ecological, social, and nutritional costs and benefits.

- Forgotten and underutilized foods and other emerging foods with low carbon footprint including cereals, legumes, prebiotics, algal foods and cultured proteins will become increasingly important.

- Edible insects are climate friendly; they can be produced on less space, using less water and feed with less greenhouse gas emission than traditional livestock; more research is required on insect protein quality and the general impact on gut health and bioavailability of nutrients and bioactive compounds and the role of chitin.

- There is an urgent need to understand the impact of climate change on crop nutrient density and bioavailability; are there particularly sensitive nutrients and how does anti-nutrient content vary; this information can be used to build databases and food composition tables.

- Which methods can be used to generate a minimum set of indicators to assess the food systems value chain continuum in an integrated manner; stable isotope techniques can contribute to understanding nutrient bioavailability and generation of functional outcomes more so if applied in combination with other approaches including metabolomics, geospatial mapping.

- There is a need to shift from agriculture to a food systems approach and consider agriculture to nutrition pathways that encompass, food production for household consumption; income-oriented production for food, health and other non-food items; empowerment of women as agents of change; reduction in real food prices associated with increased agricultural production and; promoting nutrition-sensitive agriculture.

- Stable isotope techniques may aid our understanding of multiple domains of the food systems value chain including: 1) soil nutrients and water management; 2) plant breeding to select trait that enhance crop nutrient composition while limiting anti-nutrient content; 3) food safety, 4) breast milk composition and intake; 5) nutrient bioavailability/absorption, especially of amino acids, zinc, iron and provitamin A; 6) impact on vitamin A status; 7) linkage between gut function and nutrient absorption and: 8) assessment of nutritional status including growth and body composition.
Introduction

The Virtual Technical Meeting organized by the IAEA from 19-21 October 2020 focused on how stable isotopes and related nuclear techniques can be used to evaluate food-based approaches to improve diet quality in the face of rapidly changing food systems driven by adverse events such as climate change and the COVID-19 pandemic.

Objectives

The specific objectives of the TM were:

1. To critically synthesize scientific evidence on food-based approaches to improve food nutrient composition and bioavailability in the context of climate change.
2. To identify the most promising climate-smart food-based approaches that can improve food nutrient content and bioavailability.
3. To evaluate the potential role of stable isotope techniques in evaluating the impact of identified food-based approaches.
4. To propose a framework for potential IAEA contribution towards evidence.

Participants

About 39 participants, including IAEA staff, were drawn from 21 countries and over 30 organizations were represented, including UN agencies, CGIAR centers, technical assistance providers, research institutions and donors (full list available in Annex).

Methodology of the meeting

The meeting was held in a virtual format. After an introduction on the relationships between food systems, climate change, diets and health outcomes, as well as the role of stable isotope techniques, participants took stock of existing knowledge about interventions to improve diet quality and tools to assess it. The way forward in terms of priority research gaps to be addressed with stable isotope techniques was defined through group and plenary discussions.

Main outcomes

Food systems, climate change and diet quality interactions and food-based interventions

Climate change is having significant impact on food systems and access to healthy diet. Further, the impact of infectious diseases such as the Covid-19 pandemic on food systems and the environment is often significant and disruptive. One of the immediate adverse effects of climate change is modification of soil and crop nutrient composition. Furthermore, nutrient bioavailability may be impacted in ways that are not yet fully clear but include increased anti-nutritional factors, elevated starch content and reduced micronutrient bioavailability. Climate change is further associated with poor sanitation and hygiene which is likely to lead to diarrhea, environmental enteric dysfunction and food contamination with microbial toxins (e.g. aflatoxins). COVID-19 on the other hand has had negative impact on food distribution, choice and access while limiting physical activity.

The meeting underscored the need for multi-disciplinary and multi-sectoral collaboration to address diet quality from a food systems and value chain approach in order to fully understand the pathways that underpin the link between food systems, diet quality and human health.
outcomes. Bio- and agro-diversity can be of dual benefit, providing resilience against climate change while supporting healthier diets and nutrition.

Although results from interventions such as biofortification, food fortification and consumption of a diverse diet show benefits on nutritional and health outcomes in controlled efficacy studies, more remains to be done to fully understand their effectiveness in real life situations and to replicate and scale up the interventions in different contexts. Additionally, there is a need to simultaneously utilize hitherto unknown or underutilized foods such as edible insects with low carbon footprint. The key role that animal source foods play in child growth and development was underscored, especially in contexts where plant-based diets are the norm. However, consideration needs to be given to multiple trade-offs including, environmental footprint, crop yield versus grain content, grain protein versus starch content and grain protein versus anti-nutritional content associated with these innovations. Nutrition sensitive programming such as cash transfers, school meals, social protection, general food assistance, smallholder farming initiatives and ensuring good hygiene and sanitation will continue to gain significance.

**Measuring diet quality and the role of stable isotope techniques**

The difficulties in measuring diet quality which is often defined based on adequate intake, specific dietary recommendations or perceived health benefits of context-specific dietary patterns were also discussed. Current diet quality measurement tools include the Minimum Dietary Diversity Indicator for Women (MDD-W) developed by the FAO that comprises 10 food groups, the consumption of which is correlated with the probability of meeting the intake requirements of 11 micronutrients. Additionally, the WFP supported ‘Fill the Nutrient Gap’ (FNG) analysis can assess the magnitude and nature of the nutrient gap by age groups and identify the main drivers including accessibility, physical access, affordability and demand. The Evidence and Gap Map (EGM) developed by the Innovative Metrics, Tools and Methods in Agriculture-Nutrition Research (IMMANA) consists of twelve elements spanning the entire foods systems continuum from seed to nutrition and health.

Non-invasive, accurate stable isotope techniques have been applied to assess various dimensions of diet quality including body composition, breastfeeding practices, micronutrient status and bioavailability, protein quality and how sanitary conditions influence gut function and nutrient absorption. In the food systems value chain nuclear techniques can be used in plant breeding, soil and water management, food safety and assessment of crop or food nutrient composition, nutrient absorption and related nutritional and health outcomes such as body composition. For example, the IAEA is supporting seven countries to use a dual isotope (deuterium and $^{13}$C) technique to assess true amino acid digestion from commonly consumed legume crops in the framework of a coordinated research project (CRP). Results from this CRP can enrich the FAO database on true protein digestion and aid future discussions on generating evidence to inform protein requirements. Regarding the link between sanitation and health outcomes, it was noted that the IAEA is already supporting Member States through a CRP to develop a stable isotope ($^{13}$C-Sucrose) based diagnostic tool for EED. Other IAEA-driven efforts include understanding vitamin A status in the context of multiple interventions to combat vitamin A deficiency and development of biomarkers of sugar intake and linking to risk of non-communicable diseases (NCDs).
The meeting recognized the imperative to take advantage of the renewed global interest on food systems and diet quality. Global initiatives and events such as the newly formed UN Nutrition, the Committee on World Food Security, the UN Environmental Assembly focusing on water, energy and food nexus, the biodiversity conference of parties (COP), the UN Food Systems Summit 2021, the climate COP and the Nutrition for Growth event planned for 2021 provide an opportunity to place the diet quality agenda at the very top. Partnerships and collaborations will be needed especially in generating nutrient composition and absorption databases. Lastly, a research agenda for a potential coordinated research project (CRP) on the use of stable isotope techniques to assess multiple dimensions of the foods’ systems value chain was defined; this would be guided by the research gaps and questions outlined below.

**Key knowledge gaps and research questions from the meeting**

1. **What is the impact of climate change on crop nutrient density and bioavailability; are there particularly sensitive nutrients and how does anti-nutrient content vary?**
2. **How does dietary intake vary in specific population groups?**
3. **What is the role of edible insects in the food systems value chain and what is the implication on environmental footprint and food waste?**
4. **What is the linkage between climate change, sanitary conditions and diet quality and health; what is the role of environmental enteric dysfunction, diarrhea and mycotoxins?**
5. **What is the minimum set of indicators that can be used to measure the entire food systems continuum (from food production to health including functional outcomes)?**
6. **How can we make nutrition and health-related research useful to policy makers?**
7. **How can we better mobilise resources to fund the unprecedented interest in diet quality?**
8. **What is the effect of climate change on the women’s nutrition and health outcomes and their ability to care for children?**
9. **What are the implications of climate change on diet quality in the context of population displacement, urbanization, and shifting consumer behaviour?**
10. **What partnerships and collaborations are needed; how can other sectors and disciplines be roped in to comprehensively understand the food systems continuum?**
11. **What role can stable isotope techniques play and is there benefit in using combined stable isotope technique to assess various dimensions of food systems simultaneously?**

**Way forward**

The linkages of the adverse changes climate change is having on food systems (and vice versa) and of the interventions to mitigate them on nutritional and health outcomes remain to be fully understood.

A shift to a food systems value chain approach is needed to ensure a sustainable diet that is adequately diverse and nutritious (Figure 1).

Within this value chain, stable isotope techniques may aid our understanding of multiple domains of the food systems value chain including: 1) soil nutrients and water management; 2) plant breeding to select trait that enhance crop nutrient composition while limiting anti-nutrient content; 3) food safety; 4) breast milk composition and intake; 5) nutrient bioavailability/absorption, especially of amino acids, zinc, iron and provitamin A; 6) impact
on vitamin A status; 7) linkage between gut function and nutrient absorption and; 8) assessment of nutritional status including growth and body composition. Adoption and deployment of different stable isotope techniques simultaneously that can measure various domains of the food systems value chain should be considered. The role of social behaviour change, and the interplay between disease, sanitary conditions and diet quality will need to be understood further.

FIG. 1. A food systems continuum and value chain schema to addressing the link between climate change and diet quality including entry opportunities for stable isotope techniques.
**Report Summary**

**Official opening and welcome**

The meeting was officially opened by Ms Najat Mokhtar, Deputy Director General and Head of the Department of Nuclear Sciences and Applications, IAEA. Ms Mokhtar reiterated the increasing concern among the nutrition community that some of the nutrition-related targets set by the World Health Assembly for 2025 may not be met. This situation has been further exacerbated by the current COVID-19 pandemic which has impacted food supply and access.

Ms Mokhtar welcomed the timeliness of the meeting and its alignment with IAEA’s core mandate of making nuclear science and technology available for peace, health, prosperity, and sustainable development. Nuclear techniques are applied in various sectors including food and agriculture, health and nutrition and environment.

In acknowledging a multidisciplinary group of experts and organizations from the United Nations, the CGIAR system, government agencies, academic and research institutions and non-governmental organizations, Ms Mokhtar expressed confidence the discussions will result in concrete proposals on new and innovative ways to ensure adequate diet quality during these difficult and complex times and thereby also contribute towards evidence-based solutions to the multiple burdens of malnutrition.

**Word of welcome by the Scientific Secretary**

Mr Victor Owino, a Nutrition Specialist at IAEA’s Nutritional and Health-Related Environmental Studies Section (NAHRES) highlighted recent research activities utilising stable isotope techniques including the completion of a coordinated research project (CRP) on protein digestion from plant-based diets, and its relevance to building a FAO recommended database on true ileal protein digestion toward development of recommendations for protein requirements for children aged 1-3 years in low- and middle-income countries. Secondly, he mentioned on-going CRP activities including the development of a diagnostic tool for environmental enteric dysfunction (EED). Other CRP activities focus on optimizing techniques to assess vitamin A status and discussions on developing stable isotope tools for long-term iron labelling to evaluate iron metabolism and monitor interventions. Finally, he made the participants aware of a call for proposals on a new CRP on efficacy of amino acid supplementation in treating EED among children at risk of malnutrition.

**Presentations, discussions and way forward**

The scientific discourse was organized into two main objectives:

1. To review the scientific evidence on food-based approaches to improve food nutrient composition and bioavailability in the context of climate change.

2. To identify the potential role of stable isotope techniques in evaluating food-based approaches to improve diet quality in the context of climate change.
As shown in Figure 2, a total of 5 sessions focused on: 1) setting the scene on food systems, climate change, diet quality and nutrition and health outcomes and the role of stable isotope techniques, 2) interventions to improve diet quality, 3) tools for assessment of diet quality, 4) group discussions and, 5) discussions on the way forward and thoughts of a research agenda involving stable isotope techniques.

**FIG. 2. Roadmap.**

**Session 1: Setting the Scene**

**Sustainable diets for healthy people and a healthy planet: making food systems work for a healthy diet**

Ms Stineke Oenema, Coordinator, United Nations System Standing Committee on Nutrition (UNSCN), Italy

Ms Oenema reflected on both the macro and micro levels of the complex interactions between food systems, climate change, diet quality and nutrition and health outcomes.

She noted that we are not on track to achieve nutrition objectives of the World Health Assembly (WHA) nor Sustainable Development Goals (SDGs) by 2030. In 2016, the UN Decade of Action on Nutrition was announced by the UN General Assembly to accelerate implementation of ICN2 commitments, achieve the Global Nutrition and diet-related targets by 2025 and contribute to the realisation of the SDGs by 2030.

Food systems constitute the first action track of the Decade of Action on Nutrition.
The definition of food systems is that it gathers all the elements (environment, people, inputs, processes, infrastructures, institutions etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes (Figure 3).

Food supply chains, food environments and consumer behaviour are central entry point elements to influence food systems. Diets, nutrition and health are the outcomes of food systems.

Food systems are also influenced by climate change which has direct impact on nutrition and health. On the one hand, there are changes in temperature and rainfall precipitation that can lead to increased (ca 3-84%) global food prices, reduced nutrient value and increased food insecurity. Food insecurity then triggers consumption of nutrient-poor and calorie-rich foods and leads ultimately to hunger and malnutrition (undernourishment, micronutrient deficiencies, overweight and obesity).

**FIG. 3.** How the three elements of food supply chain, food environment and consumer behaviour influence nutrition and health outcomes and the feedback loop to the system itself and where to trigger and pull the levers to influence the system through political, programme and institutional actions.
From a systematic view there is a complex feedback loop between dietary patterns and environmental impacts throughout the food system (Figure 4). Reduced nutrient content leads to malnutrition on the one hand; climate change impacts biomass which in turn impacts agriculture and biodiversity ultimately leading to yield loss. This in turn leads to intensification of agriculture and trade which again leads to climate change. We need to look at this complexity in order to grasp the system and identify entry points for positive impact.

Food environments are one of the central elements of food systems and represent the place where people meet the food system. Food environments encompass key elements namely, production, storage, transformation and transportation; these elements influence the external domain (consisting of food availability, vendor and product properties, prices, marketing and regulation) and the personal domain (consisting of accessibility, affordability, convenience and desirability). Both domains in turn influence food acquisition, consumption and ultimately health and nutrition outcomes.

As we thought about the food system and its complexity, COVID-19 pandemic hit hard; the food environment reacted and changed quickly and there were changes in the wider environment. Food supply disruption resulted in modified consumer behaviour with an impact on diet quality. Reduced income and earning opportunities impacted affordability. Closure of food outlets disrupted convenience with more people cooking at home. People resorted to eating less desirable foods such as ultra-processed foods with long shelf life. All this mean that COVID-19 portends reduced diet quality with a threat for increased malnutrition and a challenge on how to guarantee healthy diets for all.

Sustainable healthy diets should be the outcome of the food environment. Sustainable healthy diets can be defined as dietary patterns that promote all elements of individual’s health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable. These diets should be based on dietary guidelines that are sustainable; context specific, and sensitive to local culture, preferences and concerns.
Examples for food based dietary guidelines include reduced salt and sugar, eliminating trans fats, reduced food waste, moderate animal source food consumption, increased fruits and vegetable consumption, shift to more plant-based diets and choosing seafood from non-threatened stocks. The result of these guidelines should increase dietary diversity.

There are a number of global processes relevant for nutrition including ICN2 which for the first time proposed a food-systems thinking and proposed that nutrition is beyond the health system and recommended multi-sectoral synergies. Other initiatives in 2021 include the UN Environmental Assembly focusing on water, energy, and the food nexus; Biodiversity Conference of the Parties (COP), Food Systems Summit, Climate COP and Nutrition for Growth (N4G) which will include food systems. Another development is the newly formed UN Nutrition. We hope that after all these initiatives combining food, energy, water, biodiversity and nutrition, we can have a big ripple effect to reverse adverse impact of climate change and other shocks such as COVID-19 pandemic on nutrition and environment.

As a way forward we need:

1. Knowledge on what we eat with reference to specific groups such as adolescent girls in order to address generational circles of malnutrition
2. Nutrient composition of a diverse range of crops including indigenous and ‘forgotten’ ones.
3. Macro-level transdisciplinary research.
4. Micro-level research that includes an understanding of better ways to assess the impact of interventions on nutrition and health outcomes
5. Design of solid indicators and development of databases. Examples of indicators include the MDD-W and INFoods, both initiated by FAO.

In conclusion, we need to close the loops: global, country, food systems, food environments, diets, individual health and planetary health.

The role of stable isotopes in diet quality assessment: an IAEA perspective

Ms Cornelia Loechl, Nutritional and Health-Related Environmental Studies Section, IAEA

Ms Loechl presented an overview of IAEA’s support of nuclear applications in nutrition and examples of how stable isotope techniques have been applied in diet quality assessment. She also discussed limitations and opportunities associated with stable isotope techniques.

Isotopes are variations of the same element with different atomic mass due to a difference in the number of neutrons in the nucleus. This mass differential enables the use of isotopes as tracers as the different isotopes can be separated in biological systems. Stable isotopes are non-radioactive. The most applied stable isotopes in nutrition include those of hydrogen, carbon and oxygen.
Stable isotopes are also available for elements such as nitrogen, calcium, iron and zinc (Figure 5). Compounds such as vitamin A can be labelled with the stable isotopes of hydrogen or carbon.

<table>
<thead>
<tr>
<th>Major stable isotope</th>
<th>Minor stable isotope</th>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
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<tr>
<td>Oxygen</td>
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FIG. 5. Stable isotopes commonly applied in nutrition assessments.

Stable isotopes have been applied to assess various dimensions of diet quality including breastfeeding practices (amount of breast milk consumed and whether the infant is exclusively breastfed), vitamin A status, micronutrient bioavailability and protein quality (Figure 6). A stable isotope-based breath test to diagnose and classify environmental enteric dysfunction (EED) and to understand the interlinkage with nutrient absorption is being optimised and validated in 9 countries across the world. A coordinated research project to develop a stable isotope-based biomarker of added sugar intake and link to NCDs is also underway. Stable isotope techniques to assess functional outcomes such as body composition and total energy expenditure in addition to nuclear techniques such as dual energy X ray absorptiometry (DXA) that allow visualisation of body fat distribution and bone mineral density are also well established.

FIG. 6. IAEA’s support of nuclear applications in nutrition.
Ms Loechl gave examples of how the IAEA has supported the use of isotope techniques in Member States. Data collected using the deuterium oxide dose-to-mother technique across all regions show the importance of breast milk in early life (Figure 7). The data confirm that breast milk should be considered as part of food systems.

**FIG. 7. Breast milk intake over time in g/day and g/kg body weight per day.**

Another example how the IAEA has supported its Member States to address nutrition policy and programming is the use of iron stable isotopes in Morocco to help confirm the most bioavailable iron compound to add to wheat flour in the context of Morocco’s national fortification programme to tackle iron-deficiency anaemia.

Ms Loechl also informed the participants of a new isotope method that was developed to assess protein digestion and amino acid bioavailability. This new technique can help generate more data on protein digestion to ultimately enable the revision of recommendations for protein requirements across age groups. The related research project was conducted in partnership with FAO as the results will potentially contribute to building a database on true amino acid digestion based on the digestible indispensable amino acid score (DIAAS).

Ms Loechl concluded by outlining the strengths and limitations of stable isotope techniques.

**Opportunities**

- Stable isotope techniques are accurate;
- Enable assessment of the effectiveness/efficacy/impact of
  - Bioavailability/absorption of iron and zinc from biofortified food varieties;
  - Vitamin A bioefficacy of crops;
– Protein quality from diets;
– Impact of food-based interventions on vitamin A status, body composition.

• Contribution to international databases, e.g. FAO database on true ileal protein digestibility;
• Contribution to future efforts on protein intake and revisiting protein requirements, especially for children 1-3 years of age;
• Leveraging IAEA’s Technical Cooperation Programme and Coordinated Research projects to enable scale up and further research;
• Development of hand-held instruments and breath assays are much easier;
• Further simplification of isotope techniques.

Challenges/limitations

• Small sample sizes due to cost;
• Expensive and complex instrumentation not always compatible with LMIC settings;
• Diet-quality related stable isotopes are expensive;
• Need for highly skilled laboratory personnel;
• All the above limit scalability and coverage;
• Acceptability and ethical issues since most techniques involve blood draw.

Session 2: Improving diets in the context of climate change

This session discussed existing and emerging interventions to improved diet quality including dietary diversity, biodiversity, animal source foods, biofortification, food fortification, and edible insects.

Food systems approach, an opportunity for achieving dietary diversity

Ms Lindiwe Sibanda, Co-Chair Global Alliance for Climate Smart Agriculture (GACSA)

According to Ms Sibanda, dietary diversity, defined as a quantitative number of food groups is used extensively as a method for ascertaining variety and nutrient adequacy of diets. A diverse diet, with foods from all food groups, is necessary for population groups to meet their requirements for essential nutrients. In addition, dietary diversity has been linked to the pillars of food security: accessibility, availability and utilization.

Currently, the population-based indicator of micronutrient adequacy in diets is based on the consumption of ten food groups: grains, white roots and tubers, and plantains; pulses (beans, peas and lentils); nuts and seeds; dairy; meat, poultry and fish; eggs; dark green leafy vegetables; other vitamin A-rich fruits and vegetables; other vegetables and; other fruits.
Addressing malnutrition requires a multi-sectoral approach as conceptualized below (Figure 8) by the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN).

![Multi-sectoral linkages to tackle malnutrition.](Image)

It is also important and urgent to bust the myths related to diet including, the ambiguity between food quality and food quantity, gender preferences in food allocation, relating overweight and excess fat to being wealthy and the notion that stunting is hereditary.

Further, there is a need to shift from agriculture to a food systems approach and consider agriculture to nutrition pathways that encompass, food production for household consumption; income-oriented production for food, health and other non-food items; empowerment of women as agents of change; reduction in real food prices associated with increased agricultural production and; promoting nutrition-sensitive agriculture.
Vulnerable households eat only 5 food types or less (Figure 9). Further, most farmers grow less than 5 crops, with a focus on staple foods and sometimes cash crops; fruits and vegetable production remains low and seed supply chain is a challenge. This in turn means that most rural households spend most of their income on food. For example, according to the results of a World Bank Living Standards Measurement Survey, the proportion of purchased food in low- and middle-income countries ranges from 55% in Ethiopia to 86% in India. Low-income consumers are often underserved by the market in two fundamental ways: 1) diverse and healthy diets are not affordable for low-income consumers and 2) health quality of products on the market is low overall.

**FIG. 9. Dietary diversity by level of vulnerability.**

As a way forward, the following strategies should be considered for a working food systems approach:

- Healthy diets by definition address both ends of the spectrum of undernutrition and overnutrition,
- Key focus should be increased availability and affordability of nutrient-dense foods—dairy, eggs, legumes by increasing productivity, women’s empowerment, and consumption simultaneously,
- Agricultural and food sector should not only focus on the production side but should also include nutrition and health considerations,
- Looking at food systems more broadly, beyond farm-level interventions—increased focus on food safety, processing, market access, policy and multi-stakeholder roles.
Ms Sibanda closed by emphasizing that healthy food connects to all the SDGs (Figure 10).

![FIG. 10. Healthy food connects with all SDGs.]

**Nexus of Biodiversity, Climate Change, Food and Nutrition Security: Understanding the gaps and exploring opportunities**

Ms Beatrice Ekesa, Alliance of Bioversity International and CIAT, Uganda

Ms Ekesa discussed the role of biodiversity in the quest for sustainable and healthy diets. She defined biodiversity as the variety of different forms of life found on earth and the variations within species. It is a measure of the variety of organisms present in different ecosystems. Biodiversity can be manifested at different levels: genetic, species and ecosystem (terrestrial, freshwater, marine) as shown in Figure 11.

![FIG. 11. Components of biodiversity.]

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*Figure 10: Healthy food connects with all SDGs.*

*Figure 11: Components of biodiversity.*
Agrobiodiversity comprises all the components of biological diversity associated with food and agriculture (Figure 12), and all the components of biological diversity that are related to agricultural ecosystems: The variety and variability of animals, plants and microorganisms at the genetic, species and ecosystem levels, which are essential to sustain key functions of the agroecosystem as well as its structure and process.

**FIG. 12. Components of agrobiodiversity.**
There is a complex nexus between biodiversity, climate change, dietary diversity, diet quality and nutrition and health outcomes (Figure 13). Biodiversity is driven directly by land use, over-harvest, climate change, pollution and invasive species. Indirect drivers of biodiversity include demographic and socio-cultural factors, economic and technological factors such as monocultural mass agricultural production, institutions and governance, and conflict and epidemics. These driving factors influence the biodiversity, ecosystem, and climate change resilience interactions and how all these influence food and nutrition security.

Ms Ekesa painted a grim picture related to the loss of global biodiversity. The world is experiencing rapid loss in biodiversity with some areas already seeing 100% loss. The loss of species diversity has reached unsafe levels across 58% of the world’s land surface. Of 9600 edible wild species included in the International Union for Conservation of Nature’s Red List, 20 percent are under threat of extinction. A quarter of livestock breeds are at risk. Between 1990 and 2015, global forest area—a vital reservoir of biodiversity—decreased from 31.6 percent of world’s land area to 30.6 percent. Sub-Saharan Africa is the area where forests are disappearing the fastest. Over 3m hectares of natural habitat are converted for other uses each year in Africa.

The world is relying on a smaller number of foodstuffs to feed a growing population that is expected to rise to around 10 billion people by 2050. Of the 6,000 plant species cultivated for food, just nine account for 66% of total crop production. The world’s livestock production is based on around 40 species with only a handful providing the vast majority of meat, milk and eggs.
In order to safeguard biodiversity, the following considerations need to be in place within six core domains: 1) knowledge and co-production, 2) enabling environment, 3) integration, 4) conservation, 5) education and awareness raising and, 6) monitoring and evaluation.

Looking forward the following can be done:

- Enabling environment (policies, multidisciplinary approaches, stakeholder engagement);
- Documentation (Inherited knowledge and biodiversity documentation);
- Using multiple species, integrating the use of crop, livestock, forest and aquatic resources, and conserving; and
- Enhanced investment in research for development to support building of more evidence around the nexus;
- Enhanced use of BIG DATA;
- Scaling of participatory and inclusive approaches that support the nexus: citizen farmers.

**Biofortification: the path to increasing staple crops mineral density and beyond**

Mr Erick Boy, HarvestPlus, United States of America

Mr Boy argued that a nourishing, diverse diet is the ideal goal as part of the strategies for addressing hidden hunger. Biofortification alongside fortification and supplementation present a suite of complementary and overlapping nutrition strategies that can be used in context-specific combinations. The principles and conditions underlying the success of a biofortification programme include:

- Plant breeders must increase nutrient levels (and/or increase bioavailability) without penalties on driving agronomic traits (yield);
- Regular consumption of staple foods should generate measurable improvements in nutritional status;
- Farmers adopt the varieties (grow and consume/use them); and
- Mainstreaming to ensure implementing partners along the value chain integrate biofortification as central/core activities.

He noted that so far biofortification has worked in maize, millet, sweet potatoes and cassava and impact has been demonstrated when the crops are consumed as the main staple. One challenge is that there is a physiological limit to how much nutrients a plant can store in edible parts.
Delivery and adoption of the biofortified crops have been successful among about 8.5 million households representing about 42 million people (Figures 14 and 15). Over 340 varieties of biofortified crops have been released in 40 countries (Figure 16) with many more in the pipeline.

**FIG. 14. Successfully biofortified staple crops.**

**FIG. 15. Trends in biofortified crop adoption.**

**FIG. 16. Global distribution of new biofortified varieties (a total of >340 varieties have been released).**
With the wide adoption and release of varieties, the question is whether these biofortified crops have measurable nutrition impact. Based on the history of zinc biofortified crops as an example, there is evidence since 2003 that biofortified crops have some nutritional impact; consumption of crops biofortified with zinc resulted in significantly increased total absorbed zinc without changing fractional zinc absorption (FZA) and enabled vulnerable groups to meet their dietary zinc requirements without changing food sources.

Mr Boy proposed that going forward, more research is needed on nutrient retention, bioavailability, efficacy and effectiveness. Plasma zinc which is recommended by the World Health Organization (WHO) lacks specific and sensitive biomarkers which respond to food interventions, signifying the need to move beyond growth and immunity-based assessments.

**Food fortification: an intervention to increase micronutrient bioavailability, while addressing some of the climate change adversities**

Mr Daniel Nyagawa, Nutrition International, United Republic of Tanzania

Mr Nyagawa discussed the role of food fortification in improving diet quality. Food fortification is defined as the addition of one or more essential nutrients (micronutrients) to a food, whether or not the nutrients are normally contained in the food, for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population or specific population groups. Food fortification is one of the low-cost and high-impact interventions (very cost-effective public health intervention). It involves the addition of micronutrients to food at production site or directly to prepared food (home fortification). Nutrients commonly used to fortify food include iron, iodine, folate, Vit A, and Vit B_{12} – which reflect common micronutrient deficiencies (a sample of a fortified food package is shown in Figure 17).

*FIG. 17. Sample package of a fortified supplementary food.*
The success of food fortification programmes depends on a number of conditions:

– Evidence of the problem e.g. iron deficiency, iodine deficiency, and Vit A deficiency,
– Food vehicle – edible oil, wheat/maize flour, salt,
– Consumption pattern and acceptability in the population,
– Effects of fortificants on the food vehicle – colour, taste,
– Bioavailability of the fortificants.

Food fortification has numerous advantages and some limitations. The advantages include:

➢ Ability to address multiple deficiencies,
➢ Potential to improve the nutritional status of a large proportion of the population,
➢ Delivery system for fortified foods is already in place, especially for industry-processed foods,
➢ Often more cost-effective than other strategies.

The main limitations are:

➢ Poorest segments of the general population often at the greatest risk of micronutrient deficiencies are missed out,
➢ Unresolved technological issues relating to fortificants – levels, stability, nutrient interactions etc.,
➢ Colour and flavour change of food vehicle (dependent on the nature of the food).

In order to understand the impact of food fortification programmes on nutrition and health outcomes, robust evaluation and assessment strategies need to be put in place.

A number of knowledge and research gaps exist in order to make food fortification programmes effective:

• Data gaps in micronutrient deficiencies:
  o a significant number of people around the world are affected by micronutrient deficiencies; better understanding of the micronutrient status will help in better targeting the programming of interventions.
• Evidence gaps in assessing the potential for impact on public health outcomes:
  o effectiveness of the food fortification interventions in relation to functional outcomes such as growth, cognitive development, morbidity, and mortality.
• Technological gaps: fortificants/prefix - nutrient interactions, levels, stability, etc.
• Accessibility gaps: industrially-processed vs locally produced, urban vs rural.

Stable isotopes could be used to address some of the research gaps with specific focus on:

• Bioaccessibility - nutrient that is available for absorption after digestion;
• Bioavailability - proportion of a given nutrient that is absorbed and available for physiologic function;
• Bioefficacy - proportion of a nutrient that is ultimately converted to the active form.
Animal Source Foods and diet quality

Ms Shibani Ghosh, Tufts University, United States of America

Ms Ghosh analysed the role of animal source foods in improving diet quality. The quality of protein consumed is negatively associated with stunting in children under 5 years of age. Animal Source Foods (ASF) intake is negatively associated with disability-adjusted life years linked to stunting in children aged 6-59 months. Infants and young children who do not consume any ASF have a higher probability of being stunted. Consuming more than one type of ASF is associated with a 2.3% point reduction in stunting. The type of animal source foods seems to matter as far as the impact is concerned. A study by Neumman and colleagues among Kenyan children showed that meat consumption improved cognitive performance, led to higher levels of physical activity, increased initiative and leadership behaviors, and increased the mid upper arm muscle area (lean mass) with benefits on vitamin B12, iron and zinc status. On the other hand, milk consumption improved linear growth in younger and already stunted children.

In a study from Ecuador, children aged 6-9 months were randomly assigned to treatment (1 egg per day for 6 months, n=83) or control (no intervention, n=80). Children consuming eggs had a greater length-for-age z score (LAZ) compared to those in the control group. However, the egg intervention effect on linear growth was no longer present after two years. The same intervention with eggs was replicated in Malawi by Stewart and colleagues among 660 infants but there was no effect on LAZ. However, there was significant improvement in head circumference for age, potentially indicating better brain development. A 48-month longitudinal study from Nepal (Miller and colleagues) showed that head circumference is associated with the number of ASF consumed (Figure 18).

**FIG. 18.** Association of head circumference with the number of ASFs consumed.
However, the effect of ASF on length for age (LAZ) varies by context; while past ASF consumption is linked to greater LAZ among Nepalese and Bangladeshi children, the same has not been observed for Ugandan children (Figure 19).

- Nepal (N=1564 children)
  - 4 annual nationally representative surveys (2013-2016)
- Bangladesh (N=2413 children)
  - 3 biannual surveys (2016-2017) from south-western Bangladesh
- Uganda (N=2370 children)
  - 3 biennial surveys (2012-2016) from northern and south-western Uganda
- 24h diet recall

<table>
<thead>
<tr>
<th>Length-for-age z-score</th>
<th>Nepal (N=787)</th>
<th>Bangladesh (N=1381)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed any ASF in the daily diet last year (Nepal) or 6 months ago</td>
<td>0.257**</td>
<td>0.140**</td>
</tr>
<tr>
<td>(Bangladesh)</td>
<td>(0.093)</td>
<td>(0.049)</td>
</tr>
<tr>
<td>Consumed 1 type of ASF in the daily diet last year (Nepal) or 6 months ago</td>
<td>0.254**</td>
<td>0.095</td>
</tr>
<tr>
<td>(Bangladesh)</td>
<td>(0.102)</td>
<td>(0.061)</td>
</tr>
<tr>
<td>Consumed ≥2 types of ASF in the daily diet last year (Nepal) or 6 months ago</td>
<td>0.283</td>
<td>0.231***</td>
</tr>
<tr>
<td>(Bangladesh)</td>
<td>(0.162)</td>
<td>(0.048)</td>
</tr>
</tbody>
</table>

Reported estimates are from fixed effects panel regressions. * p<0.1; ** p<0.05; *** p<0.01. Regressions include district x survey round fixed effects.

Control variables (not shown): Consumed starchy staples, consumed any fruit and vegetables, consumed legumes nuts and seeds, age, age^2, gender, child had diarrhea in the past 3 weeks, caregiver’s education (years), caregiver’s height, whether household has an improved latrine.

Zaharia, Ghosh et al 2020- Nature Food, under review

**FIG. 19.** The impact of ASF on LAZ varies by context.

According to the EAT Lancet Commission publication of 2019, ‘healthy diets have an appropriate caloric intake and consist of a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars. The cost of a healthy diet is much higher in low income settings (Figure 20).

**FIG. 20.** The cost of healthy diet.
A number of metrics exist to evaluate the quality of ASF, including the World Health Index of Sustainability and Health (WISH) and the Global Diet Quality Score (GDQS) as in Figure 21. Other metrics focus on protein quality, including the Protein Digestibility Corrected Amino Acid Score (PDCAAS) and the Digestible Indispensable Amino Acid Score (DIAAS). It is now clear that DIAAS, compared to PDCAAS, is a better indicator of protein quality, especially in some dairy and plant proteins.

<table>
<thead>
<tr>
<th>Healthy</th>
<th>WISH</th>
<th>GDQS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>Eggs, low-fat dairy</td>
<td></td>
</tr>
<tr>
<td>Unhealthy</td>
<td>Red meat</td>
<td>Processed meat</td>
</tr>
<tr>
<td>Neutral/non-linear</td>
<td>Eggs, chicken</td>
<td>High-fat dairy, red meat</td>
</tr>
</tbody>
</table>

*FIG. 21. Classification of ASF.*

The following areas warrant future research:

- To scale up the use of DIAAS as a protein quality metric there is need to generate ileal digestibility databases;
- Amino acid intakes are rarely assessed in diets. Amino acid composition data is largely unavailable in most food composition tables (except in developed country food composition tables);
- Sustainability and improving the environmental footprint of ASF production systems particularly in low resource environments where ASF in small quantities do matter;
- Better understanding of what is “healthy” versus “unhealthy” within the context of ASF consumption by different populations (geography) and population sub-groups (demographics, gender, age);
- Harmonization of diet metrics - MDDW, Minimum Acceptable Diet in infants and young children, WISH, DGQS.

The consumption of ASF is essential for the growth and development of young children. Key is to find the perfect balance of nutritional intake between the diversity of plant-based foods while consuming low amounts of ASF. Livestock contributes directly and indirectly to environmental and economic sustainability via various pathways. Some livestock systems are particularly effective at carbon sequestration and hence reducing greenhouse gas emissions that contribute to global warming. Assessment of the impact of livestock on the environment and livelihood should not focus on single criteria such as greenhouse gas emissions, but should balance ecological, social, and nutritional costs and benefits. Sustainable livestock systems contribute to food security, economic and environmental stewardship, and sociocultural needs and are vital for achieving most of the UN SDGs. They are particularly important for improving
human nutrition, health, and economic productivity. Concerted efforts are needed to promote such systems in low- and middle-income countries.

**Edible insects in human nutrition and health: knowledge and knowledge gaps**

Ms Nanna Roos, University of Copenhagen, Denmark

Ms Roos discussed how emerging interest in edible insects as a source of sustainable food can be leveraged to attain healthy and nutritious diets. She reflected on the environmental footprint related to insect production, insect nutritional composition, safety and advances in assessment of edible insect protein quality.

In 2013, edible insects entered the global agenda for sustainable food production via the FAO report 171 (Figure 22). More than 2000 species of edible insects are identified in traditional diets around the world. Some insect species convert organic feed substrates very efficiently into animal tissue (protein, fat, other compounds). Edible insects can be produced on less space, using less water and feed and with less greenhouse gas emission than traditional livestock.

*FIG. 22. FAO report 171 on edible insects (2013).*
Figure 23 shows the reduced environmental footprint from cricket production compared to broiler production in Thailand. It is also possible to feed insects on recycled food waste.

Crude protein content in insects reported in many studies ranges from 40 to 80% on dry matter basis (assuming N conversion factor of 6.25). The variation is depending on fat and chitin contents. The digestibility of edible insect protein, based on the PDCAAS published range, is around 0.7. Ultraviolet light radiated insect species synthesize vitamin D$_3$ (cholecalciferol) and small amounts of vitamin D$_2$ (ergocalciferol) assumingly accumulated from fungi in the diets. Mealworm (*Tenebrio molitor*) accumulates vitamin D$_3$ corresponding to 0.38 µg/100 g fresh weight. Beef contains 0.6 µg/100 g and salmon 6.6 µg/100 g. Most edible insect species have high or very high total iron contents. A human isotope study found fractional iron absorption from crickets to be low (<4%) in refined and phytate rich meals (Melse-Boonstra et al.). The insect iron metabolism is different from mammals by using ferritin as iron transporters and having no haem-iron. Insect ferritin differs by being larger than mammalian ferritin.

Research questions:

❖ Fundamental understanding of absorption and bioavailability of iron from meals and diets with insects;
❖ Understanding potential inhibiting compounds (anti-nutrients) in insect species and different life stages;
❖ Understanding impact of processing on bioavailability.

In conclusion, Ms Roos noted that the production of edible insects is climate friendly; insects can be produced on less space, using less water and feed with less greenhouse gas emission than traditional livestock. However, more research is required to point out whether insects have similar protein digestibility in humans and understand the general impact on gut health (enteric...
environmental dysfunction). Other research gaps are the bioavailability of bioactive compounds in edible insects such as vitamin D and vitamin B12 and the bioavailability of iron.

Session 3: Assessing linkages between food systems, diets and nutrition – the context for stable isotope research

This session consisted of five presentations that dealt with the complexity in measuring diet quality and offered insights into existing tools for diet quality assessment including new tools such as the Global Diet Quality Score, Evidence Gap Map, the Minimum Dietary Diversity for Women (MDD-W), the Fill the Nutrient Gap (FNG) analysis tool and reflections on trade-offs involved in crop yield-nutrient density balance and the application of stable isotope techniques to assess diet quality with a specific focus on protein quality and iron bioavailability.

Part 1: Research on food systems and nutrition and dietary assessment methods

Advancing agriculture, food systems and nutrition linkages: where do stable isotope techniques fit in the landscape?

Ms Thalia Sparling, London School of Hygiene and Tropical Medicine, United Kingdom of Great Britain and Northern Ireland

Ms Sparling discussed how an innovative Evidence Gap Map (EGM) can be used to bring together multiple domains of the food systems continuum to enable the design of interventions to improve diet quality.
The EGM developed by Innovative Metrics and Methods for Agriculture and Nutrition Actions (IMMANA) covers 12 domains of the Agriculture, Nutrition and Health landscape: (1) primary food production (growing, cultivating, raising, catching, harvesting, storing), (2) value chains and food transformation, (3) food safety, (4) economy, (5) markets, (6) food environments, (7) water, sanitation and hygiene, (8) ecology, sustainability and environment, (9) food policy, governance, trade, (10) conflict of interest, (11) food security, (12) diet, nutrition and health (Figure 24).

**FIG. 24.** EGM focusing on three pillars: primary food production, value chains and food transformation, and food safety and covers 12 domains.
Stable isotope techniques would be suitable for the assessment of bio-accessibility, bioavailability and bio-efficacy (Figure 25). Within the EGM, stable isotopes could fit within dietary tools, metrics and methods; food production; ecology and climate change thematic areas. Figure 26 shows links to ANH and EGM resources.

**FIG. 25.** Potential entry points for stable isotopes in the EGM framework.

**FIG. 26.** ANH and EGM resource links.

**Links to ANH and EGM resources**

ANH Academy: [https://www.anh-academy.org/evidence-gap-map](https://www.anh-academy.org/evidence-gap-map)
- Evidence and Gap Map
- Tutorials and presentations
- RFPs for grants and fellowships


- Username: IMMANA
- Password: nutrition
Opportunities, challenges and gaps in diet quality assessment

Ms Lynnette Neufeld, Global Alliance for Improved Nutrition (GAIN), Switzerland

Ms Neufeld analysed the complexity and challenges involved in defining diet quality and its measurement and presented some criteria used to interpret diet quality results based on sources of data. She also presented emerging initiatives to assess diet quality with a food systems lens.

Nutrient-poor diets are a direct cause of persistent undernutrition. Unhealthy diets are a well-established risk factor for NCD’s. There is recognition of and growing focus on the role of the food system and food environments in fostering healthy diets.

There are many definitions of a healthy diet and an abundance of proposed approaches to measure it. Several new and on-going initiatives to improve the quality, consistency, quantity, accessibility, transparency, and use of diet data include:

- **INDDEX**: Methods development, innovation, data utilization
- **GDD**: Dietary data consolidation, analysis and methods improvement
- **INTAKE**: Technical support for dietary assessment in LMIC
- **INFOODS**: Consolidation, quality improvement of food composition tables
- **GIFT**: Public repository of quantitative individual-level dietary data

Three considerations related to diet quality assessment are: 1) the source of the data, 2) how it is processed and 3) how it is interpreted and used. Sources of data vary depending on the level. At the national level, food balance sheets are used. At household level, consumption and expenditure surveys (HCES) become useful. HCES can be used as “proxy” estimate of individual intake, if assumptions made that all consume equally or according to needs (e.g., via Adult Male Equivalence Method, AME).

At the individual level, biomarkers of intake, food records, 24-h recall and food frequency questionnaires are relevant. The potential of 24-h and food frequency questionnaires (FFQ) to serve varying objectives related to assessment of diet quality will depend on how the data is collected.
Diet quality data can be processed in the form of metrics or benchmarks, food composition tables or statistically analysed. Metrics and benchmarks include nutrient adequacy; consumption of specific health or disease promoting dietary components (e.g., fat, sugar, salt, fruits and vegetables) and overall quality of diet. How data is interpreted and used depends on the source of data as shown in Figure 27 (Tabled sourced from Micha et al Food Nutr Bull. 2018).

Two new initiatives that reflect important advances to filling the gap in diet quality metrics, methods, and global data are the Global Diet Quality Score and the Global Diet Quality Project.

**Global Diet Quality Score:**
- Food group-based reflecting (positive) nutrient adequacy, and (negative) NCD risk (semi-quantitative);
- Under development to be low-burden including automated tool for coding;
- Collaboration of Harvard, INSP Mexico, and INTAKE.

**Global Diet Quality Project:**
- Food group-based reflecting positive and negative dietary patterns;
- Validated against WHO and World Cancer Research Fund guidance;
- Low-burden surveys for use in Gallup World Poll, DHS;
- Data collection in 40+ countries 2020-2022;
- Collaboration of Harvard, Gallup World Poll, GAIN.

There is an opportunity to ride on the unprecedent interest in diet quality which is likely to bring additional resources to the chronically underfunded field of diet quality assessment. No single method is perfect, and all methods have their strengths and weaknesses. Reconciling human health with sustainability in assessing diet quality may bring even a new level of complexity not yet considered in diet metrics. Several new initiatives are making progress in
overcoming well-documented gaps in assessing diet quality, including the focus on malnutrition in all its forms.

Minimum Dietary Diversity Indicator for Women (MDD-W) - An Overview for Rapid Assessment of Diet Quality

Mr Warren Lee, FAO, Regional Office for Asia and the Pacific, Thailand

Mr Lee, while using the example of the minimum dietary diversity indicator for women (MDD-W), discussed how simple, cost-effective and field deployable tools that are easy to adapt to various contexts can be used to measure diet quality among vulnerable groups.

Healthy & diverse diets for women of reproductive age (WRA) are important due to numerous reasons, mainly:

- Healthy and diverse diets are a key to improve nutrition and health of women and their children;
- Women of reproductive age (WRA) (15-49-y) have higher nutritional requirements;
- Poor maternal diets affect birth weight and child health during the 1st 1,000 days.

An ideal indicator for use in the field should be simple and low cost and enable collection of timely dietary information in resource poor settings with inadequate technological capacity. Conventional dietary assessment methods, e.g. 24-hr recall or food records are costly, labor intensive and time-consuming to collect timely dietary data. On the other hand, anthropometrical methods assess nutrition outcomes only but not immediate dietary intake and its quality.

The MDD-W is constructed by correlating its 10 Food-Group Indicator (FGI-10) with the “Mean Probability of Adequacy” (MPA) of 11 micronutrients (vitamin A, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc) for WRA.

The MDD-W is a dichotomous indicator constructed of 14 food groups (Figure 28), with a cut-off of 5 to indicate diet adequacy, i.e. women consuming 5 or more food groups are more likely to meet the minimum dietary diversity than women consuming less than 5 food groups (i.e., diet is more likely to be micronutrient adequate).

The MDD-W can be used for a rapid assessment of diet quality, which makes it an optimal tool to assess and monitor a diet in a resource poor setting with inadequate technical capacity. It can be useful for target setting, programme evaluation and policy process. The assessment of the MDD-W is done by using either open-based recall or list-based recall of foods. The indicator may not be used to associate with functional outcomes.
There is need for a dietary matrix which should be used to link dietary diversity to functional outcomes. Stable isotopes can become handy in this respect.

MDD-W – with 14 food groups in a standard food grouping List

**FIG. 28.** The MDD-W consists of 14 food groups.

The MDD-W enables food group consumption analysis; for example, it was integrated into the National Household Budget Survey (HBS) in Tajikistan (Figure 29).

**FIG. 29.** Food group consumption analysis in Tajikistan.
In conclusion, Mr Lee noted that the MDD-W indicator *satisfactorily* reports what people eat and their dietary diversity, based on the validation study. However, the MDD-W hasn’t been validated against health & nutrition outcomes due to its simplicity and lack of quantitative data as well as reliance on a one-day dietary recall.

- The challenge is whether we can devise a robust dietary metric(s) to link up food group diversity with functional nutrition outcomes of key nutrients of public health concerns and identifying where using stable isotope techniques can help.

**Analytical tools for healthy diets: WFP’s perspective**

Ms Fatiha Terki, Nutrition Division, World Food Programme, Italy

Ms Terki discussed WFP’s overall mission and the innovative Fill the Nutrient Gap (FNG) tool for analysis of the enablers and barriers to achieving healthy and nutritious foods for all. The FNG is a systems focused situation analysis and nutrition sensitive programming tool.

FNG analyses what prevents people from eating a nutritious diet and aids the design of the most appropriate interventions for nutritious foods. It helps build sustainable food systems in countries (Figure 30).

![FIG. 30. FNG analysis components.](image)

The FNG analysis is a process that engages stakeholders from health, education, social protection, nutrition, agriculture and the private sector at all stages. It uses the cost of the diet software to estimate how much it costs a family to buy the nutritious foods they need from the local market and whether it is affordable based on their income (Figure 31).

![FIG. 31. Cost of diet analysis.](image)
FNG results are combined with information on agricultural production, living conditions, consumer behaviour and food culture to build an understanding of the complex and diverse issues that influence what people could and do choose to eat. It also identifies opportunities for action to make a healthy diet a reality for all (Figure 32). FNG was developed in 2016 and has since been rolled out in over 36 countries and results have been used to inform national programming and advocacy.

For example, the FNG analysis in Mali showed that availability and affordability of nutritious foods varies across the country; 20-75% of households cannot access nutritious diets. The results are being used to address the context-specific structural and systemic causes of malnutrition and to enact multi-sectoral approaches to improve healthy diets. It also helped to show that adolescent girls and lactating women have the highest cost of meeting their nutritional requirements. Together they comprise nearly 60% of the total household cost (Figure 33).

FIG. 32. The FNG analysis identifies multi-sectoral intervention and policy options to ensure a healthy and nutritious diet.

FIG. 33. Cost of diet among Malian households.
To address the identified gaps, WFP supports nutrition sensitive programming such as cash transfers, school meals, social protection, general food assistance and smallholder farming initiatives. A programme impact pathway is used to map causal pathways to impact nutrition. For example, a resilience programme in Sri Lanka is helping small holder farmers to diversify their livestock with a nutrition lens. Women headed households, widows and women without employment are helped to engage in market oriented, income generating activities with nutrition sensitive components embedded in all interventions.

Ms Terki concluded with an assurance that although malnutrition continues to be a worldwide problem, it is solvable. With the right tools and programming, we can overcome malnutrition.

**Part 2: Current stable isotope research on protein and micronutrients**

**Climate change, protein nutrition and plant trade-offs**

Mr Anura Kurpad, St. John’s Research Institute, India

Mr Kurpad discussed the complex relationship between climate change and nutrient density and the intricate trade-offs and balance pitting crop yield versus nutrient content in the light of climate-smart food production. He also provided an example of how stable isotopes can be used to assess protein quality.

There is a concern that rising CO₂ levels could affect cereal grain protein (and mineral) content. Further, rising temperatures could affect yield and nutrient content, while decreased availability of ground water could affect yield; all these then could contribute to undernutrition, particularly in those who depend on cereals for a large part of their nutrient intake. Some have shown that ambient CO₂ levels lead to a reduction of 20% in protein levels in cereal grains. Reduction in iron, zinc and vitamin B has also been found, although less profound (Figure 34).

**Nutrition security and CO₂**

![Image](FIG. 34. Climate change and crop nutrient composition.)
A number of trade-offs exist between yield and grain protein contents; between grain protein and starch content, and between grain protein and anti-nutritional factor content. For instance, data shows that yield increases when protein content is reduced. Experiments in India with different rice varieties showed that a reduction of 0.6% in grain protein content was associated with a 1 ton/hectare increase in yield (Figure 35).

However, how all this influences consumer and farmer behaviour is unknown. Increased intake of rice to meet protein requirements, for example, could increase the risk of overweight and further compounds the risk of protein and micronutrient undernutrition.

![FIG. 35. Yield versus grain protein content (courtesy: MS Sheshashayee, University of Agricultural Sciences, Bangalore).](image)

Important aspects to consider in light of climate change are: yield (water use efficiency), grain protein content (nitrogen use efficiency) and grain protein quality (amino acid score and digestibility).
Stable isotopes could be used to decipher all these trade-offs. For instance, the dual stable isotope method (Figure 36) can be of help in determining protein quality by establishing the amino acid score and digestibility. The method helps avoid invasive insertion of tubes into the stomach. The dual stable isotope method involves intrinsic labelling of the plant with deuterium and feeding a test meal alongside a $^{13}$C-labeled reference protein (such as $^{13}$C-spirulina which is commercially available) or amino acid. The individual digests the two proteins (i.e., $^2$H-labeled and $^{13}$C-labeled) with different efficiencies and the transfer to the blood stream is a reflection of what happens in the intestines. The ratio of isotope species in the blood is an index of digestibility.

**Dual isotope method and intrinsic labeling of dietary protein**

![Diagram](image)


Stable isotopes can also help with the assessment of water use efficiency (WUE) and nitrogen use efficiency (NUE).

The other problem is that high temperatures cause up to 30-40% increase in grain anti-nutrients including phytate and polyphenols. This affects digestion. For example, a study in India showed that one cup of tea taken with eggs resulted in up to 75% reduction in egg protein digestibility.

In closing, Mr Kurpad emphasized:

- Need for the use of stable isotopes to get a full picture of all trade-offs, but yield must also be a consideration;
- Assessment of sensory qualities is also very important as well as the implementation of field trials to determine the relationship between yield/protein content and acceptability;
- Recognition of the fact that if the theory of food intake to satisfy specific nutrient needs is correct, then overweight and obesity, with an additional burden of micronutrient undernutrition, are possible consequences of climate change.
Defining the potential impact of fortified and biofortified foods using stable isotopes of iron and zinc

Mr Michael Zimmermann, ETH Zurich, Switzerland

Mr Zimmermann discussed the usefulness of stable isotope techniques to understand the role of iron and to decipher how related factors including malaria, hepcidin and prebiotics can influence iron bioavailability from diets. The use of stable isotopes in measuring iron and zinc bioavailability is a highly precise method and can be safely used in all age groups. They can come in as a first step to assess the potential of foods/fortificants, to be then confirmed in long-term interventions before implementation. Various iron isotopes can be used, but the most common ones are iron 57 and iron 58. Figure 37 shows procedures for test meal labeling with iron 57, iron isotope dose IV administration and schedule for blood sample collection after two weeks.

![Stable iron isotopes in human nutrition](image)

**FIG. 37.** Procedure for iron bioavailability assessment in human studies.

Because of global warming, staple foods such as sorghum and millets become more important, while they are more drought resistant and can be biofortified with iron (Figure 38).

![Per capita consumption of sorghum and millet in Africa](image)

**FIG. 38.** Per capita consumption of sorghum and millet in Africa.
Evidence shows that biofortification of these staple foods with iron seems to have a positive effect on total iron absorption. Another potential area of interest is the use of prebiotics. Iron-containing micronutrient powders for infants are poorly absorbed (< 10%) and produce large increases in colonic iron, which can cause inflammation and diarrhea. One solution is to reduce the iron dose. Additionally, prebiotics such as galacto-oligosaccharides (GOS) can be added to increase iron absorption from an iron-containing micronutrient powder. A study in Kenyan infants showed that GOS increased iron absorption from a new micronutrient powder containing 2.5 mg iron as ferrous fumarate and 2.5 mg iron as NaFeEDTA by 62%. The effect of lactoferrin on iron absorption also needs to be considered. Lactoferrin is an iron-binding glycoprotein that exists in two forms: iron-free state (apo-lactoferrin) and with 2 ferric ions bound (holo-lactoferrin). Lactoferrin has both antimicrobial activity and immunomodulatory effects. However, there is recent focus on whether lactoferrin binds iron to facilitate its absorption and/or to sequester it away from potential enteropathogens.

In the tropics the question remains if iron absorption is reduced by common infections like malaria. A study from Benin involving young women (n=23) with afebrile *Plasmodium falciparum* malaria demonstrated that malaria leads to increased hepcidin that in turn blocks iron absorption (Figure 39). According to data shown by Mr Zimmermann, iron absorption is improved upon treatment of afebrile malaria.

**FIG. 39. Malaria, hepcidin and iron absorption nexus.**

Mr Zimmermann presented an example of how stable isotopes are being used to understand iron absorption from edible insects.
There is on-going work on measuring dietary iron absorption from *Tenebrio molitor* (Figure 40), which is consumed in many countries, and assessing the effect of chitin content on iron bioavailability. Its nutrient content is as follows: protein (20%), fat (13%), fibre (2%) and moisture (62%) and it is a potential source of iron, zinc, B-vitamins and PUFAs. Pilot studies on iron bioavailability in humans from crickets show that when insect biomass is added to wheat flour, then iron absorption is significantly reduced due to the presence of chitin that forms insoluble complexes with iron and other metal ions.

![Yellow mealworm (Tenebrio molitor).](image)

**FIG. 40.** Yellow mealworm (*Tenebrio molitor*).

In conclusion:

1. Iron stable isotopes are a high precision tool to measure iron bioavailability from a range of foods/fortificants;
2. Iron stable isotopes are safe in all age groups;
3. They can be used as a first step to assess the potential of foods/fortificants, which is then confirmed in long-term interventions before implementation.

**Session 4: Reflecting together on the role of stable isotopes in climate change, food systems and nutrition**

This session involved four parallel group discussions based on two broad questions. Two pairs of groups discussed the respective questions.

1. **What is the impact of climate change on diet quality and the link to nutrition and health - what is known and where are the gaps?**
2. **What are the climate smart-interventions that work and can be scaled up?**

**Impact of climate change on diet quality**

Climate change may lead nutrient density in plants to decrease and anti-nutritional factors to increase, while the quantity of starch in these plants increases and therefore the bioavailability of micronutrients reduces. The consumer (humans and animals alike) will face a reduction of micronutrient intake from plant-based diets, but also from animal source diets due to climate
change impacts. We asked the questions of “how does climate change impact crop nutrient composition and bioavailability” and “in what specific ways are climate-resilient crops affected?”. Subsequently, we identified a need to better understand the impact of the climate (1) on nutrient bioavailability, but also (2) on ongoing adaptation strategies such as the introduction of climate-resilient crops. It is also good to consider how climate change affects animal source foods. In this case it is imperative to understand the impact of climate change on the overall quality of the diet rather than focusing on changes in individual foods.

- Micronutrient content will be decreasing in crops with climate change (so we may need fortification e.g. rice fortification);

- Climate change, i.e. high CO₂ levels lead to crops with lower nutritional value. Climate change results in decreasing total protein content. Do we know if this affects amino acid content including some limiting amino acids? We need to study if CO₂ impacts certain amino acids more than others. Lysine and Methionine are often limiting amino acids in plant foods.

**Climate-smart interventions that work and can be scaled up**

The definition of climate-smart interventions connotes those interventions which do not increase or contribute to climate change as well as help us to adapt to climate change. However, the definition of healthy diets is often one-dimensional. Complex food systems have double benefit: bio- and agro-diversity provide resilience against climate change while supporting healthier diets and nutrition. How to assess this dual benefit remains a challenge.

To compensate for the effects of climate change on diets, it is imperative to develop adapted crops using biodiversity or biofortification, to fortify processed foods as well as to adopt novel food sources which are becoming more common (e.g. edible insects). For instance, sweet potato is a climate smart crop with only a 3-month growing cycle, no fertilizer is required, and little moisture is needed. Sweet potato roots are eaten as a source of starch while the leaves are eaten as vegetable in addition to being used as feed for livestock. How such crops can be scaled remains to be defined. Agronomic biofortification (the role of fertilizers) can also be considered. Utilization of climate-smart neglected or under-utilized crops and assessment of nutrient bioavailability thereof should be encouraged. Such crops include millet, sorghum, fonio, bambara groundnut and jackfruit. Further, more research is needed on the nutritional contribution of algae-based foods and cultured proteins as these could potentially contribute to significant reduction in greenhouse gas emissions. Cultured proteins are manufactured by fermentation (like beer) in the USA and Europe and have very low content of CO₂/kg protein produced. The effect of climate change on crop polyphenol or phytate levels and their effect on nutrient bioavailability is yet to be fully understood. Plant based proteins such as chickpea, soybean, quinoa, spirulina, duckweed, and potato protein isolates have adequate quantities of lysine and methionine which are often limiting in plants. Insects may be a sustainable source of protein, iron and zinc. Insects provide essential fatty acids for growth and maybe for a healthy microbiota too.

- Food composition tables for edible insects by region are needed.
- There is need to improve consumer acceptance by making insects an aspirational food.
Cross-cutting issues are related to urbanization, population growth and gender. How climate change affects women’s ability to care of children is unknown. With climate change, there is displacement of people and movement to already growing cities. What are the food sources (safe and nutritious and affordable) for the urban poor? Stable isotope research to study body composition (evidence for double burden of malnutrition) is needed.

The role of stable isotope techniques and other approaches

Stable isotope techniques can be applied to address the effect of climate change on various diet quality dimensions:

- Nutrient requirements of different population groups in the context of climate change;
- Nutrient bioavailability (protein quality, iron, zinc, provitamin A, Se and other minerals), quality and quantity of new climate smart diets, crops, and livestock;
- Contribution to food composition and nutrient databases.

Stable isotopes have strengths in being precise, specific and in some cases non-invasive. However, the techniques can sometimes be invasive, they are not easy to use and they are expensive. Therefore, often only small sample sizes are possible. In some cases, methods need to be improved or optimized. Stable isotope techniques can be applied alongside metabolomics and functional outcome indicators including cognitive function.

Other approaches could include geospatial modeling. In the framework of “from the farm to the fork” and so to the individual human, there is still a need to collect more knowledge and provide in-depth analyses on individual diets. This includes specifically a lack of knowledge on the consumption of complementary foods as well as on the nutrient content of breast milk. We observe a move towards plant-based diets (vegetarian diets) but are unfamiliar with adaptation mechanisms by different age groups and cultures in response to shocks including climate change. Hence, we asked the question of “how may social-behavior mitigate the impact of climate change on diets?”. Two aspects were suggested on how to address this question: (1) through the application of geospatial modeling that would support assessing dietary patterns at the household level, and (2) further research on the interplay between diseases and nutrient absorption. Studies have shown a link between iron intake and malaria prevalence, but little is known about linkages with other vitamins and minerals such as the effect of malaria on provitamin A intake from bananas.

Moving from evidence-based guidelines to policies and practice

Lastly, we noted that our research efforts largely contribute to evidence creation to enable the development of guidelines. However, there is a major gap in translating the evidence into policies and practice. In order to move from evidence to practice interdisciplinary exchange and research should be encouraged.

Several research questions and gaps in knowledge were raised.

Key knowledge gaps and research questions from the meeting

1. What is the impact of climate change on crop nutrient density and bioavailability; are there particularly sensitive nutrients and how does anti-nutrient content vary?
2. **How does dietary intake vary in specific population groups?**

3. **What is the role of edible insects in the food systems value chain and what is the implication on environmental footprint and food waste?**

4. **What is the linkage between climate change, sanitary conditions and diet quality and health; what is the role of environmental enteric dysfunction, diarrhea and mycotoxins?**

5. **What is the minimum set of indicators that can be used to measure the entire food systems continuum (from food production to health including functional outcomes)?**

6. **How can we make nutrition and health-related research useful to policy makers?**

7. **How can we better mobilise resources to fund the unprecedented interest in diet quality?**

8. **What is the effect of climate change on the women’s nutrition and health outcomes and their ability to care for children?**

9. **What are the implications of climate change on diet quality in the context of population displacement, urbanization, and shifting consumer behaviour?**

10. **What partnerships and collaborations are needed; how can other sectors and disciplines be roped in to comprehensively understand the food systems continuum?**

### Session 5: Bringing it all together and moving forward

The meeting concluded by recognising that given the complexity of food systems and the food environment, a shift from a monoculture agricultural approach to a food systems value chain approach is needed to ensure sustainable diets that are adequately diverse and nutritious.

Climate change impacts the food system through agriculture by directly causing reduced soil nutrient concentration (hence decreased crop yield) and bioavailability; protein, iron, zinc, and vitamin B concentrations decline while starch accumulates. In response to reduced crop yield, more intensive monocultural agricultural production systems are adopted; this in turn leads to further environmental degradation and climate change. Further, the risk of infectious diseases rises; COVID-19 has forced consumers to resort to poor quality diets and physical inactivity.

More research is needed to fully understand the climate change–diet quality nexus and the nutritional impact of climate-smart interventions such as biofortification, mutation breeding, food fortification and dietary diversification, including animal source foods. Accurate methods to assess diet quality including nuclear techniques are needed. The role of social behaviour change, and the interplay between disease, sanitary conditions and diet quality will need to be understood further. How trade-offs (such as crop yield versus protein content, protein versus starch content and nutrient-antinutrient interactions and palatability) associated with climate smart interventions impact consumer behaviour and nutrition and health needs to be further explored. More so, the definition of diet quality needs to take cognizance of context-specific issues. For example, while animal source foods are classified as bad for the environment, they are also known to have greater positive impact on child growth and development. In contexts where the diet is predominantly plant-based like in Africa, consumption of animal source foods needs to be recommended. The important role of climate resilient ‘unknown’ and underutilised foods, including sorghum, millet and edible insects was underscored.

Multi-disciplinary and multi-sectoral collaborations are needed to address diet quality from a food systems value chain approach. The discussions laid ground for a new coordinated research project in this area; potentially involving cross-divisional collaboration in the IAEA and
external partnerships with major actors such as the FAO in the generation of nutrient databases and with FAO and WHO towards recommendations on protein requirements.

A framework (Figure 1) that would enable adoption of a ‘from seed to fork to human health’ food systems value chain continuum drawing from multiple expertise including agronomy, plant breeding, food science and technology, sociology and nutrition in order to fully understand the pathways that underpin the link between food systems, diet quality and human health outcomes was developed. This framework includes critical entry points for nuclear techniques such as plant breeding, soil and water management, food safety, crop nutrient composition, nutrient absorption, and related nutritional and health outcomes such as individual nutritional status (including body composition) in addition to the assessment of breast milk output and breast milk nutrient composition. Adoption and deployment of different stable isotope techniques simultaneously that can measure various domains of the food systems value chain should be considered. Further, nuclear techniques could also help with understanding the impact of climate change on gut function taking advantage of an on-going IAEA-supported CRP to validate a $^{13}$C-sucrose breath test to diagnose environmental enteric dysfunction that is linked to child growth failure in low- and middle-income countries. The dual isotope tracer method will be important in generating data on true protein digestion. Exploring other methods such as metabolomics that can be used in combination with stable isotope techniques is necessary if we want to understand the impact of climate change and climate-smart interventions on functional outcomes, including cognitive capacity. Geospatial mapping could potentially help with exploring how specific population sub-groups respond to diet quality changes related to shifts in the food system.

FIG. 1. A food systems continuum and value chain schema to addressing the link between climate change and diet quality including entry opportunities for stable isotope techniques.
Technical Meeting
on
Leveraging of Stable Isotope Techniques in Evaluating Food-based Approaches
to Improve Diet Quality
EVT1904254

19-21 October 2020
Virtual via WebEx

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